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Human Ecology

Contemporary Research and Practice

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ISBN 978-1-4419-5700-9 e-ISBN 978-1-4419-5701-6
DOI 10.1007/978-1-4419-5701-6
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2010923236

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

This book arose from the need to develop accessible research-based case study material which addresses contemporary issues and problems in the rapidly evolving field of human ecology. Academic, political, and, indeed, public interest in the environmental sciences is on the rise. This is no doubt spurred by media coverage of climate change and global warming and attendant natural disasters such as unusual drought and flood conditions, toxic dust storms, pollution of air and water, and the like. But there is also a growing intellectual awareness of the social causes of anthropogenic environmental impacts, political vectors in determining conservation outcomes, and the role of local representations of ecological knowledge in resource management and sustainable yield production. This is reflected in the rapid increase of ecology courses being taught at leading universities in the fast-growing developing countries much as was the case a decade or two ago in Europe and North America.

The research presented here is all taken from recent issues of *Human Ecology: An Interdisciplinary Journal*. Since the journal itself is a leading forum for contemporary research, the articles we have selected represent a cross-section of work which brings the perspectives of human ecology to bear on current problems being faced around the world. The chapters are organized in such a way to facilitate the use of this volume either to teach a course or to introduce an informed reader to the field. Basic issues and key concepts are introduced in the general Introduction and in Overviews to each of the four subsequent sections.

Section I deals with theoretical and methodological issues, notably what constitutes causal explanation, the risky use of metaphors in ecological discourse, and the importance of biocultural diversity and local knowledge. Section II addresses the dynamics of change in food procurement strategies, Section III takes on the causes and consequences of agricultural intensification, and Section IV concerns common property management, conservation, and public policy. If used in a classroom, this modular arrangement is easily adaptable to the purposes and nature of the course.

Foremost, we thank all the contributors, whose enthusiasm and cooperation have made this collection possible. All actively participated in the final editing, which has resulted in each chapter being a more concise but still an intellectually valid representation of the original article. Pete Vayda occupies an unrivaled place in the development of human ecology within the social sciences and as the founding edi-

tor of *Human Ecology* some 38 years ago. We owe him a great debt of gratitude. We are also very grateful to Bill Tucker, Teresa Krauss, and Katie Chalbako, our New York editors at Springer, and Ms P. Arthi Prianka, our Project Manager. Many thanks go to Ludomir Lozny, Managing Editor of *Human Ecology*, for his generous intellectual, technical and practical support. In addition, we thank Bill Baughman, Gary Clevidence, Nancy Flowers, David Gilmore, Greg Johnson, and Flora Lu for their assistance with the project.

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Introduction

This volume utilizes contributions of some 21 recent articles published in the journal Human Ecology together with other relevant research to present an overview of current environmental thought, research, and practices in this highly eclectic field. Each chapter has implications for the evaluation of current environmental policies and development efforts as each of the contributors addresses significant problems in how people manage their resources and cope with threats to their food security or well-being. Indeed, human ecology is a theoretical orientation that emphasizes the problem-solving significance of human culture and behavior, from food procurement to social support systems as well as political and religious life. In particular, it emphasizes the complex ways in which humans shape and are shaped by their environment. The perspective generally embraced in this book is that human ecology is part and parcel of the larger scientific field of ecology and not simply analogous to it. Although very much aware of the distinctive nature of human environmental interactions, we nevertheless must recognize that humans ultimately succeed, flourish, or fail in the same manner as other species.

The term "ecology" (from the Greek "oikos" – house or habitation) to denote a scientific field was coined in 1870 by the biologist Haeckel and was understood by him to mean: "… the study of the economy, of the household, of animal organisms. This includes the relationships of animals with both the inorganic and organic environments, above all the beneficial and inimical relations that Darwin referred to as the conditions of the struggle for existence" (quoted in Netting 1977, p. 1). While ecology in general and human ecology in particular are rapidly growing foci among a wide panoply of scientific endeavors, they are not so much academic disciplines as they are perspectives or approaches to the interconnectedness and reciprocal behaviors of organisms in a given environmental setting. Thus, all ecological study is at once multidisciplinary. We will later be more specific about the basic building blocks of this very useful perspective, but it is sometimes helpful to note some fundamentals that are in fact so obvious they can be lost amid the intellectual trees. Foremost among these is that ecology in its most basic sense is rooted in two seemingly disparate but in reality integrated bodies of theory: physics and evolution.

In 1944, one of the founders of quantum mechanics, Erwin Schrodinger wrote an influential book entitled *What is Life*. As science writer, Jim Holt (2008, p. 17) puts it:

D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_1, © Springer Science+Business Media, LLC 2010

> Living things are made of matter, Schrodinger observed, yet they seem to violate the laws of physics. One of the most basic of these laws is the second law of thermodynamics, a universal tendency towards disorder. Entropy – a mathematical measure of the disorder present in a system – is always on the rise. Left on their own, things fall apart, run down, and become inert; they tend towards an equilibrial state of chaos and dissolution. This is a matter of cruel probability: as we all know from our own domestic lives, there are vastly more ways for things to be disordered than to be ordered, so it is far more likely that things will slip from orderly to disorderly rather than the reverse.

One clear implication of this observation is that all life on our planet is continually in a state of flux or transition. Secondly, stability, organization, and even continuity are simply artifacts of the time frame of the observer. The third implication is that all life is bound up in arrangements that depend on the sun or as Holt (2008, pp. 18–19), somewhat over lyrically, describes it:

> Terrestrial nature drinks up the sky's orderliness in a beautifully simple way. During the day, the earth gets energy from the sun in the form of photons of visible light. At night, the same amount of energy is dumped back out into space in the form of infrared photons, otherwise known as radiant heat.

Entropy always increases in any system that is cut off from outside influence; every living organism is exchanging with its environment. Energy absorbed returns as radiant heat; we take in ordered organic compounds and return them as less ordered or disordered waste. Plants on which directly or indirectly most terrestrial life depends are able to assemble organic compounds from solar energy through photosynthesis. All life forms exist in an "open system" dependent on external sources of energy. Most descriptions of life forms are simplifications treating these open systems as analytically closed – a convenience that sometimes unintentionally obscures the long-term dynamics of the phenomena studied.

For a century and a half virtually every serious naturalist and research biologist has embraced the second body of theory underlying ecology – evolution. All species of plants and animals tend to produce more offspring than the environment can support and this results in intense competition for living space, resources, and mates. Only a favored few survive long enough to reproduce. Darwin noted also that individual members of a species differ from one another physically. In contemporary iterations of evolutionary theory, it is understood that in a given population, some individuals may have genetically derived variant traits. These variations are said to be adaptive if they improve the animal or plant's chances of survival and thereby its reproductive fitness – the process of natural selection.

Today, evolutionary theory is at the very heart of all research in the biological and natural sciences. With the recent breakthroughs in modern genetics, population biology, and biochemistry, the utility of the "evolutionary synthesis," as it is now called, is established beyond doubt. However, while acknowledging the importance of evolution for the emergence of new species and biodiversity, general evolutionary processes were largely out of the picture in ecological or environmental research until fairly recently. This is because much ecological research is framed in what in evolutionary terms are very short-lasting interactions in which issues of genetic modifications within populations can be ignored. Today there is a significant line of inquiry variously called evolutionary ecology or behavioral ecology, which investigates the implications of natural selection models for human activities as diverse as territorial defense, common property management, foraging patterns, and mating choices are measured against the expectation that "individuals behave in such a way that their personal reproductive success and/or inclusive fitness is maximized" (Schutkowski 2007, pp. 13–14; for an expanded discussion, see also Bates 2005, p. 31ff., and Sutton and Anderson 2004).

While a discussion of contemporary evolutionary theory is beyond the scope of this book, it is worth emphasizing some basic ideas. First, any process or force that changes gene frequencies in a population results in what might be called an "evolutionary event," be it ever so trivial, and most would agree that over the long term it is natural selection that has shaped all life forms on earth, including the neural systems we employ to study them. Natural selection is a cumulative process in that it "builds" on what is already present in the form of genetic information. Thus, complex, highly intricate structures may emerge from very simple foundations. As selection acts on existing material and in response to specific environmental pressures, it is always "opportunistic" – that is, adapting whatever is available to the exigencies of the day.

As noted, it is easy to overlook the fact that evolution is an ongoing process. All species are continually being shaped by evolutionary forces as individuals are added to the population by birth or removed by death or migration. Usually, the consequences of these changes are imperceptible by human measures based on life experience. But over periods geologists consider very short, perhaps as little as a few millennia, major changes can occur. For example, a recently discovered new species of perch-like fish, the arrow cichlid, was found to have evolved within the last 2,000–28,000 years in a lake formed in an extinct volcano's crater on Lord Howe Island in the south Pacific when its ancestral population of Midas cichlids became isolated in the newly formed body of water (Zimmer 2008). The new species came to feed on a different diet, changed its body shape, and ultimately lost its ability to interbreed with members of the parent population. Scientists have long seen indisputable evidence for evolution in the fossil record, but only occasionally can they pinpoint the time of the emergence of a new living species. Of course, medical science continually deals with the consequences of rapid change due to natural selection in disease organisms such as flu viruses and HIV (see below).

The significance of this for ecology is that populations and their constituent members are always dynamic even if the changes are hidden by the time frame within which researchers necessarily work. Examples of such changes that appear to have occurred within recent times among modern humans, based on rapidly advancing DNA studies, include those affecting skin pigmentation, the ability to process certain sugars and alcohol, fatty acid metabolism, as well as genetic resistance to specific diseases such as malaria. These changes are occurring in different populations and clearly indicate that humans' technological breakthroughs have not put them beyond the reach of evolutionary forces.

Another example of evolutionary adaptation, albeit a negative one from a human vantage point, is the HIV-AIDS pandemic. Researchers now are confident that the

HIV-AIDS-causing virus arose in a central African population some 150 years ago through human–chimpanzee contact (bush meat is a significant dietary element among forest-dwelling peoples of the region). But the disease only reached epidemic proportions in the late twentieth century when urban centers attracted sufficient human carriers who lived long enough to transmit the deadly virus through multiple human–human contacts. Organisms, even viruses and bacteria, continually adapt opportunistically to their environments and thereby effect change over the long term.

Human Ecology Today

As natural scientists, ecologists are interested in three very broad questions. One, how does the environment affect the organism? Two, how does the organism affect its environment? Three, how does an organism affect other organisms in the environments in which it lives? The quest for answers to these questions encompasses almost everything ecologists do. Human ecology links the subject matters of anthropology, biology, geography, demography, economics, and other disciplines in an attempt to understand relationships between people and their environments in terms of these three areas of inquiry.

In contemporary ecology there is never an assumption of timelessness or total isolation. While historical change and external influence might once have been regarded as annoying distractions from or distortions of indigenous systems, they have now become the focus of attention. Earlier ecologists tended to ask how traditional behaviors enabled a population to maintain itself in a specific environment, but today we are more likely to ask: What are the problems confronted by the population of this place? How do individual actors deal with them? And we are more likely today to be aware of the fact that not all members of the group may share the same problems to the same degree (see Eder, this volume). Ecologists draw on demographic and evolutionary theory as well as upon biological models derived from field ecology. Contemporary human ecology in addition emphasizes the role of decision-making at the individual level as people strategize and optimize risk, costs, and benefits.

The Nature of Ecological Systems

The ecosystem concept is a model for the cycles of matter and energy that include organic entities and their linkages to the inorganic. All organisms depend on energy and on matter. Such relationships, taken together, constitute a vast network of individuals exchanging the energy, nutrients, and chemicals necessary to life; humans and bacteria alike are involved in the same process.

The Components of the Ecosystem

As we have noted, all the energy that flows through an ecosystem comes ultimately from the sun. Depending on their role in the transfer of that energy, the organisms in an ecosystem fall into three categories: producers, consumers, and decomposers. The *producers* are the green plants that convert solar energy (negative entropy) and nutrients in the soil into food. The organisms that rely on plants, directly or indirectly, for food are the *consumers*. Some of these consumers (herbivores) live on the plants; others (carnivores) live on other animals; and yet others (omnivores) on a combination of both. A given ecosystem may support several levels of consumers. The *decomposers* are bacteria and fungi that break down dead organic matter, converting it to nutrients, which are deposited in the soil to be used by the plants. Thus, each of these three groups is dependent on the others. The decomposers provide nutrients for the producers, the producers for the consumers, and the dead producers and consumers for the decomposers.

Both matter and energy are constantly flowing among these elements. The transfer of matter – the nutrients – is cyclical. Producers, consumers, and decomposers process the same nutrients over and over. Energy flow is noncyclical. Energy is constantly being supplied at one end, by the sun, and constantly expended at the other end in nonreusable forms (primarily heat but also in gaseous emissions).

The usefulness of the ecosystem concept is, first, that it can be applied to any environment. Second, and more important, the ecosystem concept allows us to describe humans in dynamic interaction with one another, with other species, and with the physical environment. We can chart and quantify the flow of energy and nutrients and specify the interactions critical for the maintenance of any local population. Thus, the ecosystem concept gives us a way of describing how human populations influence and are influenced by their surroundings.

There is usually considerable apparent order and continuity in natural ecosystems. This is not surprising because, over time, the myriad component species of any ecosystem have come to mutually limit one another as they feed, reproduce, and die. The fact that ecosystems appear to persist through time does not mean, however, that they are static. Importantly, one must keep in mind that ecosystems are heuristic tools and not fixed entities in nature. Their scope or scale, components, and relationships are set by the observer depending on the object of interest at hand. Although most ecosystems are viewed as being in equilibrium or near equilibrium, in fact relations among the component populations are continually changing. It is a common methodology and analytical fallacy to attribute the raison d'être of any component of an ecosystem to its role in "maintaining" the system (see Jelinski, this volume).

Two concepts are used to describe continuity and change in ecosystems: resilience and stability. *Resilience* is a measure of the degree of change a system can undergo while still maintaining its basic elements or relationships. *Stability* is a measure of the speed with which a system returns to equilibrium after absorbing disturbances. Systems with high resilience but low stability may undergo continual and profound changes but still continue to exist as a system; that is, their constituent parts persist together even though they take a very long time to return to their initial states. Systems with high stability but low resilience, on the other hand, may show little change when suffering some disturbances but then collapse suddenly.

The Distinctiveness of Human Ecology

The ecosystem approach has contributed to understanding systemic change as well as the seeming persistence in equilibrium of some populations over long periods in their habitats. Archeologists and others concerned with landscape history on a large scale may not have ready access to data at the individual level but can make useful inferences using this model, as Stiner and Kuhn (in this volume) do in their insightful analysis of the Mediterranean Basin during the Paleolithic period. But there are limitations to this approach. Some have to do with theory; the ecosystem model is less useful for studies where the focus is on the outcome of individual actions. An equally important set of limitations concerns the treatment of populations within ecosystems in terms of the functional roles they purport to play in system processes such as "food chains" or "regulatory" agents. While the local population of a particular species can be described in a functional model, that is, as a food source, prey, predator, or population-limiting disease vector, this does not speak to causation. Malaria-bearing mosquitoes may, to use a Mediterranean example again, keep farmers out of coastal marsh lands in summer, thus creating pastures for transhumant herders in the winter, but as we have noted before that does not explain so much as describe a transient situation. The special attributes of the human species in particular pose problems for modeling local interactions as discrete or bounded systems.

Human distinctiveness becomes strikingly evident when we look at the habitats and niches that our species occupies. The *habitat* of a species is the area where it lives, its surroundings. Its *niche* is its "way of making a living," as defined by what it eats, what eats it, how it defends itself, and how it reproduces and rears its young. Most species are limited to a few habitats and a relatively narrow niche. By contrast, humans occupy an exceptionally broad culturally constructed niche and consequently live in an extremely wide range of habitats. Human niches can be rapidly transformed, thereby changing myriad other interspecific relationships. Indeed, there are very few habitats where human beings have not found a way to thrive, and judging from the archeological record, all bear witness to change in human habits and behavior.

Once humans enter a habitat, they tend to strongly affect the life chances and reproductive rates of the other populations through the use of technology. Although other species use tools, no other species has developed them to the extent humans have, nor depends on them to such a great extent for survival. If one were to look only at human morphology (large body size) and place in the food chain (analogous to top predator) one might conclude that human population densities would be quite low.

At six and a half billion worldwide, this is obviously not the case. Human technologies have enabled us to create environments such as farms and cities which maintain very high population densities by greatly increasing the inflow and outflow of energy, materials, and information.

Much, if not most, technology has been developed explicitly to facilitate energy transfer, capture, and storage in ways unique to humans. A persistent focus in human ecology has been upon energy flows. Economists deal with energy indirectly, defining human labor productivity as the monetary value of what is produced (dollar value added per hour of work) by a unit of human labor. Ultimately, of course, all human societies are energy dependent and are power limited in some way. However, the nature of energy limits in the ecological system or economy varies greatly according to how the flow of energy is organized as well as to the technology employed. Leslie White (1949) was an early proponent of the idea that the nature of human society is structured by its ability to utilize extrasomatic sources of energy, and Howard Odum (1971) later developed a more ecologically directed model of societal energy flows.

As economies worldwide developed, they moved from being limited by power shortages in the form of human labor to being constrained by limits or costs of extrasomatic energy sources, mainly the availability of wood in the eighteenth century, coal in the nineteenth century, and oil today. Mechanized use of extrasomatic energy sources, fossil fuel or hydroelectric power, for example, distinguishes the technologically advanced societies. In the United States, about 230,000 kc of energy are expended per capita per year; in Burundi, central Africa, 24,000 are expended. Moreover, in the United States, only 10% of the country's "total time" (the population × 24 × 365) is allocated to work; in Burundi, 25% of the nation's "total time" is needed; in short, a Burundian worker must expend twice as much energy to extract a fraction of the usable energy that an American worker does. Where human labor constitutes the main "power supply," and energy to support it comes largely from standing biomass (crops, trees, etc.), as it does in at least 18 countries, there is little "spare" energy to devote to anything other than maintaining current infrastructure, reproduction, and food procurement (see Giampietro et al. 1993, pp. 229–260).

The implications for societal development and ecological relations in general can be measured in many ways at levels ranging from the individual worker to the individual and his or her dependents, groups of co-workers, up to the societal. Every society has energy *sources* and energy *converters* that generate power or useful work. In preindustrial or partially industrialized societies, energy sources are largely in standing biomass – the trees, plants, and animals available to support humans – which is converted into useful work via human labor, possibly supplemented by animal traction, to support the population and its material culture, but the power available for converting the biomass is limited. In the United States in the 1850s, 91% of energy expended came from standing biomass; today only 4% does, with the balance coming from extrasomatic sources, notably fossil fuels, converted into useful work by machinery. (See Pimentel et al., this volume, for why we cannot return to biofuels soon.) While industrial societies are limited by energy sources, nonindustrial societies are limited by the low rate at which energy can be converted with human labor only partially amplified by animals and machinery.

Another continuing concern in human ecology is how humans perceive themselves, other people, and their environments. We rely upon and are dramatically affected by our symbolic interpretations and representations of ourselves and those around us. Symbols guide the ways we interact with the organic and nonorganic elements of our environments by making them intelligible in ways specific to our cultures. In this volume, Jelinski, Lu, Palmer and Wadley, Cocks, and Peloquin and Berkes devote considerable attention to the complex and often slippery ways in which people deploy linguistic models of their environments. Of major importance to humans is the way we distinguish and act upon group differences symbolically and thus cultural diversity is an important element of our social environment. As a result of uniquely human communicative abilities, humans respond to environmental and other problems with greater behavioral rapidity and elasticity than other species. This is because language greatly enhances learning and the transmission of ideas. Language, even without writing, allows learning to be a cumulative process. As Daniel Dennett puts it, language allows humans to design adaptive arrangements that for other species would require vast periods of evolutionary time and space, if they were possible at all (1995).

Intraspecific exchange is another hallmark of the human species. Our propensity to engage in the exchange of goods, services, and information among widely separated individuals and groups has the effect of vastly extending the range of our resources and of our impacts upon them. It is rare today for a local population to rely entirely on local resources. With reference to what was often regarded as a self-sufficient foraging society, Edwin Wilmsen (1989), using archeological evidence associated with the San-speaking regions of Southwestern Africa, found that, far from being isolated, trade goods indicate that the foragers were integrated to a considerable degree into distant markets long before the present century (but see Yasuoka, this volume).

Human populations are socially differentiated in ways that are significant for ecological research. Political ecology is a subfield concerned with such issues (see Peet and Watts 1994 for a good introduction). In the following chapters, Loker, Crate, Cliggett et al., Eder, Pedersen and Benjaminsen, and Wutich all deal with how humans not only engage in a division of labor beyond that associated with age and gender roles, but also create systems of perpetuated subordination and inequality, such as caste, class, and other forms of social, economic, and political ranking. Such inequality has major environmental ramifications. Consider Chinese agrarian society where for millennia farmers, laborers, and artisans were linked in a large-scale hierarchy of exchange via subordination, taxation or tribute, and entitlements according to rank. In any such system, the potential for widespread and amplifying famine, conflict, and disorder is great. A flood or the collapse of a large agricultural region due to weather or civil war can set in motion a cascade of forced migration, conflict, and civil collapse. The fact that there are no physical limits on the accumulation of wealth in a market economy, for example, has important consequences for the way that natural resources are exploited. And the fact that the nominal owners of resources control the means of exploiting them, but do not necessarily live and work near them, has important consequences for the people who do (see, for example, Loker, Cliggett et al., and Acheson and McCloskey, this volume). Thus, local people may be limited in their power to prevent their central government from granting rights to foreign companies to exploit local resources with little regard for indigenous peoples or long-term impacts (see Lu, this volume).

There are other ramifications of group differentiation. A population might deliberately destroy the resource base of a group they perceive as enemies and wish to dislodge – a classic stratagem of warfare. Or a local population might knowingly overexploit its own resources in the expectation of moving on to new ones, often at the expense of neighboring groups. While there are analogous examples from non-human populations, humans are clearly distinctive in the extent to which intergroup competition and subjugation take place.

The impact of cultural diversity, exchange, and perpetuated inequality on the ways that humans interact with environments has grown with time and with changes in human social organization since the earliest hominids developed tool technology. Throughout time, the pace of change has accelerated as well. Most human ecologists require conceptual tools beyond those of general ecology in order to address the factors that affect changing human relationships with their environments because of the influence of the complex relationships humans have with one another.

Section I
Theory, Method, and Explanation in Human Ecology

Section Overview

While all the articles collected in this volume offer useful insights relating to theory and method, those in this Section are particularly helpful in this regard as they offer a cross-section of major concerns. All research is directed to explanation at some level. Often, it may be portrayed as description but the act of defining relations implies some directionality or causal linkage, even if imprecise. Human ecology is no exception. It is generally agreed that the most satisfactory form of explanation is in identifying causation; and it is also generally agreed that for purposes of doing so, the more specific or detailed the causal chain or links, the easier it is to falsify and thereby test the claim. In his article on the causes of forest fires in Indonesia, Vayda offers both practical measures and high-level programmatic statements pertaining to causation. Jeliniski also presents a much-needed reminder that all explanation is affected by the linguistic tools employed by researchers. Brown and colleagues offer an alternative to narrative-based models: the mathematical description of foraging and other behavior involving movement over the landscape, here using a variant of "rational choice" or "optimal foraging theory."

While formal models are of indisputable value, many areas of practical and theoretical concern in human ecology are recalcitrant subjects; for example, the relationship between cultural beliefs and practices and biological diversity in a given habitat. These linkages are often subsumed under the rubric of "biocultural diversity," but in her cautionary essay, Cocks points out the difficulty in differentiating indigenous from nonindigenous and the dangers of assuming a simple relationship between cultural and biological diversity. In a related essay, Flora Lu introduces the uses and pitfalls of local environmental knowledge (LEK). Palmer and Wadley likewise address a contentious issue regarding what is usually called "local environmental knowledge." How can we separate local knowledge from general knowledge, from gossip, misstatement, or even verbal game playing? We will take these up in more detail shortly.

It is impossible to outline all of the pathways of ecological research, but we can focus on a number of useful ideas and examples. All of the research reports presented in this book have implications for method and theory, and taken together they represent some of the most fruitful techniques of posing questions and gathering data on a wide range of issues. We have already outlined some approaches in the Introduction: the ecosystem approach (see Moran 1990, Sutton and Anderson 2004 for a good discussion), evolutionary ecology (see Smith and Winterhalter 1992), and political ecology (see Peet and Watts 1994). One thread that runs through many of the studies presented here is the idea of taking an "event" and tracing its origins and consequences through time and space; for example, a forest fire (Vayda, this Section), a shift in commodity production (Loker, Sect. III), the building of a large dam (Cligget et al., Sect. III), the collapse of a national socio-political system (Crate, Sect. III), or the dramatic decline in an important prey population (see Peloquin and Berkes, Sect. IV).

In ecological theory as in formal economics, it is usually assumed that complex social or economic patterns rest on individual decisions, choices, and behaviors. After all, social and political groupings such as households, lineages or clans, villages, or hunting parties coalesce as a result of individual choices and behaviors but often experience membership change in short order if circumstances change. Economic strategies such as crop mixes, animals herded or foraging patterns also boil down to individual choices. These assumptions, in turn, rest on the idea that the decision-maker desires to obtain the largest sum of satisfaction or utility, and that each additional unit of whatever is desired is of less value than the preceding unit. At some point the cost of acquiring additional units will increase faster than the added value each unit or activity yields. This is true for social prestige as well. This leads to demand curves or points of "diminishing" or declining marginal return, which is why people will shift production strategies under some circumstances but not others; or why they may or may not be interested in certain investments of labor, or even in conservation of resources, and can help to explain food choices, migration decisions, innovation in food production, etc. Of course, realistically no one believes that *only* maximizing assumptions are at work in any society. Behavioral economics is a growing field that studies the exceptions to rational choice. But generations of social scientists have erred in the other direction and assumed that people in weakly monetarized or "traditional" economies lack a sense of informed self-interest and instead make decisions affecting their social and economic environments largely based on custom or tradition. Boyd's fascinating analysis (Sect. II) of New Guinea pig raising shows how wrong that notion usually is.

In everyday scientific practice, high-level models of phenomena and their explanation are built upon and tested by case study material or data collected and organized around very specific questions. If a researcher is interested in the general issue of why people, often at considerable expenditure of time and effort, choose to increase food production, the first step is to rephrase the question, as Hunt does so elegantly (Sect. III), to deal with specific instances, events, times, and circumstances. The data needed determine the methods employed, within the obvious constraints of time, costs, and codes relating to human subjects. But any questions posed and conclusions drawn require clarity in language, assumptions, and measures. When dealing with human populations, informant views, opinions, and general knowledge inevitably become germane. This is why discussions of "local knowledge" occupy such an important place in contemporary studies. Given the obvious difficulties the researcher faces in gaining local knowledge, as discussed in several of the chapters here, it is often a time-consuming process not infrequently involving repeat field trips, building long-term relationships, and getting to know a relatively small patch of territory exceptionally well. Human ecologists, from whatever discipline, tend to become exceptionally knowledgeable about quite narrowly bounded research areas, but on the basis of this often gain unique insights that have much broader applicability.

Returning again to the four chapters in this section, Pete Vayda, over a five-decade career, has contributed to and then moved on to build new models through critiques of previous scholarship, not sparing his own and that of his students. In the 1960s, when "cultural ecology" was in vogue, he argued for a "human ecology" and was a leader in the development of systems approaches to human–environment relations. However, in the early 1970s he joined Bonnie McCay and others in criticizing the teleology and other excesses of systems-based human ecology, arguing instead for an agent-based approach which, in fact, most of the authors in this collection adhere to. In recent years, he has advanced a pragmatic analytical methodology which is directed to the causal explanation of events (Walters et al. 2008, pp 1–2).

In his examination here of the causes of Indonesian forest fires, he is critical of approaches which he feels offer little in substantive causal explanations or at best a confounding of the causes of fire ignitions with the underlying reasons why large fires occur when and where they do – which has little directly to do with ignition per se. Vayda lays out a pragmatic course of analysis and practice that can be a guide to seeking causal explanations of any number of events. In particular, the laser-like manner in which one has to follow the data trail, keeping in mind a very clear distinction between what is being explained and the tools which one is using to describe causation. His admonitions are: (a) be clear as to what you intend to explicate; (b) do not be sidetracked by ancillary issues (for example, with fires, the least important issue may be the actual ignition event); (c) let the problem lead you to the data, do not simply go to where it is easiest to collect information (in Indonesia, much fire related research was carried out far from the areas most afflicted); (d) do not a priori privilege any particular source of causal explanation. Vayda also has a special note for social scientists that might be difficult for some to implement: one needs to combine investigation from the viewpoint of both people who use fire and the uses to which "fire puts people," that is, how human actions set up opportunities for fires to occur and spread. In some ways this seems to parallel the methodology used to study epidemics. One can easily substitute any number of events for fire and employ the same perspective.

While not drawing explicitly on Vayda, Jelinski is similarly concerned with precision in formulating research problems. While postmodern philosophy is anathema to most empiricists and nearly universally scorned among ecologists, Jelinski addresses an overlooked truth voiced often in postmodernist thought: namely, that all forms of explanation are "situated" in a body of knowledge and that many commonly employed idioms of explanation are "socially constituted metaphors."

His point in raising this is not to lament the threat to objectivity this poses but to draw attention to how scholars of ecosystems and environmental problems can inadvertently be drawn into very basic but unfounded assumptions which are grounded in particular cultures. For example, "nature" as an existential force or the notions of a "balance of nature" are dangerous misconceptions. In short, he points out why we should be wary of seeing the world through metaphors. He offers a valuable lesson on the perils of reification or sloppy holistic thinking.

Descriptions of environmental relations and the behavior of elements in an ecosystem rely on heuristic models, as previously noted. They can be simply verbal depictions or they may be more abstract. In ecology, as in economics, a common approach to modeling is among "rational choice" alternatives: actors deploy their time and energy to best achieve ends – success in mating, healthy offspring, acquisition of food, or in the case of modern humans, the acquisition of wealth. It is hard to explain, let alone predict any behavior without such optimizing assumptions. The chapter here by Clifford T. Brown, Larry S. Liebovitch, and Rachel Glendon looks at the foraging patterns of the Dobe Ju/'hoansi of the Kalahari and finds that they conform to what mathematicians would consider to be the most efficient use of time and movement in an area of scarce and randomly located targets – in this case food sources. One important implication of this study using data from the Kalahari is that it provides a new approach for understanding possible foraging strategies, settlement patterns, and migrations of the past. It is an important correction to earlier optimal foraging models and offers an alternative to simple narrative in describing or at least inferring causation.

A concept that is often central to biotic studies at a macro level and to conservation is biodiversity, a contraction of "biological diversity," and defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems." Unfortunately, the gross number of species in a given habitat or ecosystem is deceptively hard to measure since many species may be difficult to count (Sutton and Anderson 2004, p 39ff) thus making it hard to account for the relative number of different species. Highly diverse ecosystems can be called "generalized," for example, tropical forests, while ones with low diversity are termed "specialized," for example deserts and arctic ecosystems. Agricultural intensification seems to inevitably modify ecosystems by focusing on a few species and thereby reducing diversity. For this reason, many researchers and conservation experts postulate a relationship between long-established indigenous or "local" farming techniques and biodiversity. The term "biocultural diversity" draws attention to the linkages between biological and cultural diversity and has implications for programs designed to maintain or conserve biodiversity. Unfortunately, as Cocks shows with respect to a South African community, this is fraught with distinctions difficult to operationalize in practice.

Flora Lu's essay introduces a number of concerns basic to contemporary human ecology: sustainability, common pool property rights, conservation, and the importance of local environmental knowledge (LEK). Common property theory informs us that when pressure on a resource is low due to few users, limited procurement technologies, and subsistence-level production, there is little incentive for the development of the coordinated resource use behaviors which characterize conservation. At the same time, experience, as well as formal economic theory, tells us (in the words of primatologist John Oates) "…there is little robust evidence that … 'traditional' societies anywhere in the world…have been natural conservationists. On the contrary, wherever people have had the tools, techniques, and opportunities to exploit natural systems they have done so" (1999, p 55). As a consequence, many ecologists and conservation biologists have, according to Lu, turned away from "people-oriented" approaches to conservation to advocate a return to protectionism – restrictions on access, enforcement, and authoritarian controls imposed externally. Conservation practices comprise a set of social understandings and behavioral patterns that can emerge when there is agreement by a group of people to temper their resource use in the expectation that others will do the same. Using her fieldwork among the Huaorani people of the Ecuadoran Amazon, Lu finds that their land management institutions and practices, although aimed at conflict mitigation rather than conservation per se, nevertheless provide an infrastructure that could be used to limit over-exploitation. Instead of trying to establish whether or not people are natural conservationists, she advocates efforts to identify the conditions which foster conservation practices.

Humans through their cognitive sophistication and language capability can communicate their perceptions of their environments, rationalize their behavior, and act upon ideas transmitted over long distances. Craig Palmer and the late Reed Wadley analyze the ramifications of this for evaluating what is often called LEK using data from Newfoundland. In short, they conclude that a great deal of what purports to be LEK is really LET – local environmental talk. Furthermore, Newfoundlanders have a playful way of "sending up" the unwary listener. This is likely to be a widely shared trait worldwide and presents a significant challenge for researchers seeking to establish what people actually think and thus the motivations for their behavioral strategies.

Explaining Indonesian Forest Fires: Both Ends of the Firestick[1]

Andrew P. Vayda

Introduction

My object in this article is to discuss some things that have been wrong with causal explanations of Indonesian forest fires in the past and some ways in which they might be made better as explanations and, concomitantly, more useful for fire management. I will give examples not only of problematic explanations but also of fire-research and fire-management recommendations and programs made problematic by faulty or unsubstantiated causal assumptions or explanations. My focus is on causes of fires in either primary or selectively logged but still presumably biodiversity-rich tropical moist Indonesian forests for which there remains some hope of conservation. I will draw on both my literature searches on the fires and their explanations and, to a more limited extent, the fieldwork I conducted on these subjects in the province of East Kalimantan in collaboration with Ahmad Sahur of South Sulawesi's Hasanuddin University in 1998, 2000, and 2001.

Ignition Studies: Problems, Needs, and Applications

Arguably, the most consequential distortions of research priorities in attempts to explain Indonesian forest fires have been the undue attention and the wrong kind of attention accorded to the study of ignition events and their causes. Many studies

[1] This essay is an abridged and re-titled version of an article published first in *Human Ecology* 3: 615–635 (October 2006) and, in slightly revised form, as Chap. 2 of A. P. Vayda, *Explaining Human Actions and Environmental Changes*. Lanham, MD: AltaMira Press (2009), a book with more discussion of the methodological and explanatory issues addressed here.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_2,

of the extensive 1997–1998 El Niño-related fires simply did not make the crucial distinction between explanations of the start of fires and explanations of their spread and, accordingly, made no attempt to identify and prioritize research needed for the latter in particular. These failures are reflected in the jumble of factors listed together as causes of fires in reports resulting from some of these studies, including, I am somewhat embarrassed to admit, my own WWF report (Vayda 1999), as well as articles and reports (e.g., Applegate et al. 2001; Colfer 2002; Dennis et al. 2005; Suyanto 2000; Tomich et al. 1998, 2004) resulting from a project whose progress I followed during several stays at Center for International Forestry Research (CIFOR) headquarters in Bogor. Such listed causes as arson, the facilitation of access to resources, and the clearing of land for swiddens and plantations clearly pertain to what fires are started for. They are causes of ignition events. On the other hand, other listed causes such as changes in forest microclimates and the build-up of fuel loads and both intensive logging and specific forestry policies as causes of the microclimate and fuel-load changes clearly pertain to the spread of fires.

These reports do at least take note of causes of fire spread, even if they indiscriminately lump them with causes of ignitions. There have also been a few studies (e.g., Steenis and Fogarty 2001) explicitly concerned with the problem of explaining fire spread in Indonesian forests as a *different* problem than explaining ignitions. However, other reports and analyses (e.g., Abberger et al. 2002; Varma 2003) consider only causes of ignitions and evidently assume that the understanding or explanations achieved by so doing suffice for making recommendations for controlling forest fires. Far from being peculiar to Indonesian forest-fire studies and policy-making, such assumptions underlie fire-management strategies set forth as general recommendations by leading conservation organizations (e.g., IUCN and WWF 2001).

If what we want to explain and manage are indeed forest fires and not simply ignition events, certain points need to be kept in mind:

1. Not all ignitions lead to forest wildfires, defined here as uncontrolled burning in forest areas.
2. It follows that if our objective is to prevent or limit forest damage or destruction from wildfires, our focus needs to be on forest fires and not ignitions per se as our primary objects of explanation and control.
3. In order to make ignition studies more relevant to explaining and controlling forest fires, we need (a) studies reconstructing the ignition events that have led to particular forest wildfires and (b) analyses of findings from such studies in order to ascertain whether forest wildfires are more likely to result from ignitions either for some particular purposes or by some particular types of actors.
4. If the possible ignition sources are seen to be many and/or difficult to monitor and control, causal explanation and control of wildfires in tropical moist forests may require priority attention not to ignitions but to changes in fuel loads, decreases in moisture, and similar factors affecting forest flammability, notwithstanding that a convention followed by many fire scientists (e.g., Stolle et al. 2003,

pp. 278–279; Stolle and Lambin 2003, p. 376) is to designate these not as causes of forest fires but as "predisposing" factors or conditions.[2]

Relevant methodological injunctions here are those generally applicable in research guided by the goal of causal explanation. Fundamental is the injunction to be clear and focused about one's explananda, i.e., about what one is trying to explain (see Roberts 1996, p. 105 ff; Vayda 2009: esp. Chaps. 9 and 10). A corollary is not to be sidetracked from explaining the designated explanandum events, like forest fires, to explaining other events, like particular ignitions or types of ignitions, before their causal significance with respect to the designated explananda has been seriously or sufficiently probed (see Vayda 2009, pp. 26–28). As mentioned, I myself lost sight of this corollary at times in the course of my 1998–1999 research and writing on causes of forest fires.

I discuss the four points seriatim. The first may seem so obvious as to require little further consideration or documentation. Still it is notable that an analysis of data on East Kalimantan hotspots (Steenis and Fogarty 2001)[3] suggested that only a small proportion of the presumably very large number of small and isolated fires lit before and during the "major outbreaks of 1998" led to large and damaging wildfires (Fogarty et al. 2001, p. 2). This would seem to argue that, if ignition events are to be studied, priority should be given to those from which wildfires are known to have or are at least likely to have eventuated. However, despite the fact that the impetus for the CIFOR/ICRAF project and its funding were clearly the disastrous 1997–1998 fires and the disabling and financially costly smoke haze associated with them (Dennis et al. 2005, p. 466ff.), project participants are explicit in stating that their eight research sites in Kalimantan and Sumatra "were not selected to document causes of the most extensive fires of the late 1990s, or the fires that generated the most smoke." Instead, the rationale for site selection was as follows:

> Due to the importance to this study of information drawn from interviews and narratives concerning sensitive topics related to fire, and on land use mapping by members of local communities, our selection of sites prioritized locales where we believed credible information would be available from research partners (Dennis et al. 2005, p. 472).

[2] This convention, which I do not regard as analytically useful, may reflect an everyday view of explanation whereby particular triggering events are favored over particular conditions, or changes in conditions, as causes and explanatory factors even if, as discussed later, counterfactual analysis indicates that occurrence of the explanandum events in question (e.g., forest fires) depends more on the particular conditions than on particular triggers. The methodological and semantic issues raised here are discussed in a general but pragmatic way by Hart and Honore (1985, pp. 71–73) and Miller (1987, pp. 60–61). In both works, the example of fires as explanandum events is cited and counterfactual reasoning is used to support arguments in favor of sometimes including conditions as causes in our explanations.

[3] Hotspots are "High Temperature Events" (HTE) detected by NOAA satellites and indicating fire activity. Although fire detection by such means is far from foolproof (Flasse and Ceccato 1996), hotspot data can still be used to identify significant spatial patterns in fire occurrence and spread. For a fuller description of the East Kalimantan hotspot data used in their analysis, see Steenis and Fogarty (2001, p. 5).

In other words, availability of information counted for site selection, while the likely explanatory import of the information for the 1997–1998 wildfires or its pertinence to ascertaining significant causes of those fires did not count. This violates point two above, and it should be no surprise that for explanatory purposes the information obtained at some of the sites suffered from limitations to be discussed below. It's all very well to decry the analysis of fire hotspots in isolation and without "a textured understanding of social landscapes and the role they play in creating fire hazards" (Dennis et al. 2005, p. 468, citing Harwell 2000). Such understanding should certainly be sought. But it's no advance to seek it without first trying to establish, through hotspot analyses or other means, whether there is some correspondence between the social landscapes selected for study and zones of both ignition and spread for the extensive wildfires that we want to explain – and prevent in the future.

Perhaps fortuitously, the CIFOR/ICRAF project included a Sumatran site where a wildfire in October 1997 had burned between 100 and 500 ha according to the disparate estimates of officials and locals. However, simply asking about ignition sources for the wildfire proved inconclusive. As often happens in such cases, officials blamed local farmers' slash-and-burn land-clearing methods, while the farmers themselves mostly blamed illegal loggers' unextinguished campfires and cigarette butts (Suyanto 2000).

The question of what are better means for identifying ignition sources and ignition zones takes us to my third point. Important means are such forensic fire-scene investigations as are routinely undertaken in some countries, like Australia, after forest fires. Such investigations were, in fact, strongly recommended for Indonesia in an unfortunately little publicized 1998 Working Paper of the Bappenas Planning for Fire Prevention and Drought Management Project (Bappenas [National Development Planning Agency of Indonesia] 1998, p. 36):

> To build a data base of fire causes [i.e., causes of ignition events leading to forest fires] requires some form of investigation into the circumstances surrounding individual fires, including on site investigation if practicable and assignation of causes. Investigation needs to commence as soon as possible after ignition to ensure that clues and pointers to ignition sources and the reasons behind those sources are preserved.
>
> Clearly, such a course of action is impractical for the 1997/1998 Indonesian fire event. There was no formal fire investigation process or structure evident, apart from the observation of fire on particular lands either by direct observation or by use of remotely sensed images. The fire path and pattern of fire on a particular parcel of land may give some clue as to the precise point of origin of the fire and even to the base cause. Unless those clues are supported by detailed evidence arising from investigation, admission of deliberate lighting by the perpetrator of the fire, or by eyewitness accounts, it is very difficult to accurately ascribe cause...
>
> Because individuals or organisations who have a vested interest in lighting fire are almost always unwilling to admit causing them, the only way to establish cause accurately is to investigate as many fires as possible while the fire activity is current. That is the only way to obtain proof.

April 1998, when this paper was produced, was the last month of the 1997–1998 fires. However, the fires of subsequent years, although not as severe and widespread, still provided opportunities for putting into effect the recommended fire-scene investigations, but, by and large, the opportunities were not taken. Cost and personnel considerations no doubt precluded carrying out investigations for a large number of forest fires. However, in 2006, only two individuals in all of Indonesia carried them out at all (Chew 2006). In my discussions at CIFOR and WWF, forest-fire researchers expressed little or no interest in either pursuing fire-scene investigations themselves or otherwise finding or providing support for them, despite the availability of a substantial professional literature on the subject. This overlooked literature includes detailed discussions pertaining to forest fires in particular and addresses such matters as how the directions from which fires have spread can be determined from the greater depth of charring of tree trunks and the greater heat discoloration of rocks on one side than the other as well as what to look for as evidence of arson once ignition sites are ascertained (DeHaan 2002, Chap. 8; Ford 1987, 1995).[4]

Once it had been decided in projects like the CIFOR/ICRAF one to study causes of extensive forest fires without prioritizing research sites where they had occurred, it was still possible to seek data on whether uncontrolled fires, extensive or not, resulted from identified ignition events at the chosen sites. The CIFOR/ICRAF project did, in fact, obtain local reports and some other evidence of escaped fires in study sites other than the Sumatran one noted above. However, the more reliable reports referring to arson as a weapon in conflicts over land use or resource access were concerned with the spread of fires to areas either already set aside or already actually used for oil-palm or timber plantations. This severely limits their explanatory import for the extensive 1997–1998 fires in tropical moist forests for which there is still some hope of conserving, *inter alia*, their biodiversity value. Using such reports, as the CIFOR/ICRAF project has done, to make broad claims about land-use or resource-access conflicts as underlying causes of the extensive fires is not warranted. The most that can justifiably be said is that such conflicts were underlying causes of some ignitions. Whether those ignitions contributed to the extensive forest fires of explanatory interest to us has simply not been shown yet. A methodological argument supported by the failure in this regard is that, for causal explanation of wildfires and not just of ignitions, it would have been more efficient and productive to begin research where extensive forest fires had recently occurred and to work backwards in time to seek data on where, how, and why the fires had started.[5]

As far as controlling, and not simply explaining forest fires, is concerned, research such as the CIFOR/ICRAF project might still be useful in pointing to the

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[4] Forest rangers in one East Kalimantan nature reserve did conduct motorcycle patrols no more than 6–7 km from their guard post, but they simply noted where fires had occurred and, on the basis of quick visual inspection, assigned them to a preconceived category of causes, like unextinguished cigarette butts (Vayda 1999, p. 30). Such cursory exercises do not constitute *bona fide* forensic fire-scene investigations.

[5] For comparison of "forward" and "backward" causal inquiry, see Einhorn and Hogarth 1987.

number and variety of ignition sources that may need to be dealt with. However, such research seems generally to have been accorded low priority in decisions about recommending and instituting fire-management programs. Thus, for example, Varma (2003, criticized by Tacconi and Vayda 2006) and Guyon and Simorangkir (2002) recommended solving Indonesia's forest-fire problem by curtailing or even eliminating land-clearing fires as if it had been well established that ignitions for other purposes are inconsequential. It may be true that research on other possible ignition sources has not firmly demonstrated their role, but that's true also of research on the land-clearing fires as a source. Clearly what need to be prioritized in ignition studies for fire management are the kinds of studies and analyses recommended in point 3 above.

Of course, in Indonesia as elsewhere, there often is pressure to put management programs into operation without waiting for research to produce results or even to be undertaken. No doubt this happened when fire was high on both political and donor agendas during and right after the 1997–1998 Indonesian fires, when what in other contexts have been called privileged solutions (Adams and Hulme 2001, pp. 18–21; Moris 1987, p. 99f.) were proposed. Because of the gravity of the problem at hand, such solutions are thought to require only the resources and will to act. Examples in the case of the Indonesian forest fires are curtailing land-clearing fires and promoting community fire management. The latter merits some discussion in order to show that a privileged solution may be substantially wide of the mark and that decisions on the amount of resources expended on it might have been quite different if higher priority had been accorded to getting answers to certain research questions.

Community fire management was already prominent in plans formulated in the wake of extended fire and smoke episodes in Indonesia in the 1980s and 1991 (Goldammer *et al*. 2004, pp. 383–384). By 2002, more than 60 villages in East Kalimantan had received "basic fire management training" under a project designed by the German Agency for Technical Cooperation (GTZ) (Abberger et al. 2002, p. 57).[6] For some villages, training was carried further and, with a focus on institutionalization of fire management at the village level, included the development of volunteer village fire brigades or fire-management crews charged with preventing and suppressing wildfires in the village and promoting "safe burning practices in slash-and-burn agriculture" (*idem*). All this appears to have been undertaken and achieved without any empirical justification for pushing fire-management efforts much more in villages than elsewhere.

In fact, certain conclusions from Steenis and Fogarty's (2001) analysis of data on East Kalimantan hotspots should have pushed efforts *away* from the villages. Part of the analysis pertained to a main 5.3 million-ha study area, for which 48,300 hotspots were recorded in the 129 days from January 6 through May 15, 1998.[7]

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[6] This "Integrated Forest Fire Management Project" (IFFM) was implemented jointly by GTZ and various Indonesian government agencies and services.

[7] The hotspot database was built by Anja Hoffmann and Lenny Christy of the GTZ–IFFM project. January 6 was the day on which the 1998 fires started in East Kalimantan.

According to Steenis and Fogarty (2001, p. 7), this area was "systematically and manually scanned through visual interpretation" to find clusters of equal-dated hotspots constituting zones with spatial and temporal connectivity. Some of these could be identified on the basis of temporal considerations as "fire ignition zones" (FIZ) within which the fires started, while others could be identified as zones to which the fires spread during the 129 days analyzed. The following are some of the conclusions reached about FIZ (Steenis and Fogarty 2001, p. 19, 27):

1. The greatest number of FIZ was in heavily logged over forest, which also comprised the largest area within the FIZ.
2. Logging roads were present in 76% of the 258 FIZ identified in the main study area.
3. More than 50% (possibly as high as 75%) of settlements or villages were more than 5 km away from FIZ.
4. Since hotspot analysis could identify only the zones where fires started and not who started them, it remains possible that some of the fires in FIZ more than 5 km from villages were started by village-based forest users; however, the distances involved make it unlikely that starting many of the fires in these FIZ was directly connected to routine village agricultural activities.

Some caveats are in order. The first is that I am arguing not against community fire management per se but only against privileging it as a solution without having evidence from fire-path and fire-source investigations and without paying attention to such ignition-zone studies as Steenis and Fogarty's. Another caveat, which Steenis and Fogarty themselves sound in their report (pp. 2–3), is a warning against extrapolating the results of hotspot analyses from one region to another, e.g., assuming, as many did during the 1997–1998 fires, that what was found in parts of Sumatra with respect to the concentration of hotspots in areas allocated for oil-palm plantations (see Bowen et al. 2001) must be true also in East Kalimantan, notwithstanding substantial differences in land-use patterns. Similarly, even with respect to specific regions or areas, we must beware of extrapolating findings from one time to another without considering the possibility of change. For example, with the spread of oil-palm plantations in East Kalimantan, future hotspot analyses there might indicate clusters more like those in parts of Sumatra during the 1997–1998 fires than like those found by Steenis and Fogarty. As contexts or conditions change, so do FIZ and causes of wildfires. Such caveats are consistent with my calls for research guided by the goal of causal explanation and should, in fact, serve to reinforce them.

Steenis and Fogarty's concluding recommendation (p. 19) is that those involved in various ignition-producing activities in identified FIZ should be especially targeted in fire-management programs, but they say nothing about how that should be done. While I certainly agree with a main implication of their report that targeting decisions should be on the basis of more and better research, I would add that assessments of the costs and feasibility of reaching particular categories of people (those whom officials regard as illegal loggers, for example) involved in ignition-producing activities need to be made before deciding to target them or not.

In fact, despite large gaps in research, there has been no lack of information indicating that such FIZ as identified by Steenis and Fogarty could have been the sites of a variety of ignition-producing activities other than agricultural land-clearing by community-based small farmers. An admittedly partial list of other possible causes of ignition includes arson; the facilitation of access to resources; loggers' and other forest-users' need for fire for cooking, insect repulsion, and nighttime warmth; long-burning underground coal seams extending to or near ground surface; and loggers' use of equipment subject to accidental ignitions, e.g., engine exhaust or friction heating fires in bulldozers, trucks, chainsaws, and other logging machinery and also ignitions of gasoline spillage or overflow when chain-saws are refueled. Cigarette smoking is another possible cause that cannot be completely ruled out, even though claims for its efficacy in causing forest wildfires have little empirical support.[8]

Not only could all of these ignition sources have been present in Steenis and Fogarty's FIZ, but there were reasons for the presence of some of them in areas of logged forest rather than elsewhere. Examples are ignitions involving logging equipment and those for loggers' cooking fires and campfires and for burning slashed vegetation to facilitate illegal access to relatively fire-resistant and commercially valuable Borneo ironwood trees. There have also been plausible if unproved reports that arson has been committed in logged forest areas by agents of timber concessions or plantation companies seeking government approval either for converting the areas to plantations or for moving on to new areas for timber harvesting. In addition, there are reports of arson by illegal loggers for the purpose of either destroying evidence of their activities or diverting attention from them.

And even if land-clearing for relatively small-scale agricultural operations was among the possible causes of ignitions in Steenis and Fogarty's FIZ, it would not necessarily have been done by community-based small farmers who would have been reached by projects like GTZ's. Instead, land speculators intending to claim the land by virtue of having had it cleared could have recruited hired hands or would-be sharecroppers new to the area for the job. In what is now East Kalimantan's East Kutai district, Sahur and I interviewed a number of such entrepreneurs in 1998 in an area where land speculation was rife because of rumors that a large coal-mining company was planning to expand to new locations and would pay compensation to those with claims to the land there. When we returned in 2000, we found also that some of the entrepreneurs were establishing official "Farmer Groups"

[8] Neither I nor any of the numerous fire specialists I have consulted have succeeded in finding any reliable studies or good data showing cigarette butts as ignition sources for actual forest fires in Indonesia or anywhere else. According to one authority (DeHaan 2002, p. 139, 527), cigarettes have "been blamed in many more instances than they should" as sources of ignition even for fires in buildings. However, an experiment conducted in 1964 (Ford 1995, pp. 105–106, 166) and another conducted in response to my inquiries in 2004 (Gönner, pers. commun. [2004]) indicated that unextinguished cigarettes may ignite wildland fires if certain conditions are met, e.g., if relative humidity is below 18–22% and if at least 1/3 of the smoldering cigarette's surface is in direct contact with fine fuels.

(*Kelompok Tani*), made up mostly but not entirely of fictitious members, to gain access to parcels of forest land ranging in size from 20 to 100 ha. The entrepreneurs were intent mostly on making speculative gains from the parcels and obtaining credit and subsidies from the government, although one of them also professed a desire to enhance his status as a traditional patron by allocating a part of an 80 ha farmer-group parcel to those who had paid some small membership fees to join the group on the promise of profit from land speculation. In any event, neither the entrepreneurs living in villages or small towns at least 20 km from the forest land being converted to farmland, nor the non-community based hired hands or would-be sharecroppers using fire to clear the forest land, would have been reached by community fire-management projects.[9]

Whether practices like these occurred widely in Steenis and Fogarty's FIZ is not known. However, that they occurred, or could have occurred, in some of them emphasizes the need for more research on ignition sources in FIZ before community management aimed at controlling fires in village farms and settlements is privileged as a solution to Indonesia's forest-fire problems.[10] Ideally there would be forensic fire-scene investigations to provide guidance on who should, and could, be targeted in fire-management programs. If such investigations were too costly or otherwise too difficult to implement, priority research could consist of hotspot analyses to identify FIZ, followed by systematic consideration of possible ignition causes.

Studying Fire Susceptibility and Fire Behavior: Problems, Needs, and Applications

Available data on fire damage to East Kalimantan's forests in 1997–1998 support the generalization that recently logged forests are likely to be hit harder by fire than are "undisturbed or partially recovered forests" (Siegert et al. 2001, p. 440; see Cochrane et al. 2004 for a review of Amazon data supporting this generalization and Stolle and Lambin 2003, p. 384 for Sumatran exceptions to it). However, while findings about the association between logging and forest fires in East Kalimantan may be important for causal explanation (perhaps in the way that the early findings of an association between smoking and lung cancer or between bacterial infection and duodenal ulcers were important), they can be regarded as only a starting point for research to ascertain how specific characteristics or components of the land use

[9] See Vayda 2000, for a more detailed account of speculative forest-clearing and the *Kelompok Tani*.

[10] For a historical parallel, consider the aftermath of the Great Fire of 1871 in Michigan: Ill-conceived remedies focused on fire prevention in villages and towns rather than in the surrounding timberlands where the fire had actually originated, having been caused by "unsafe lumbering practices" (Kreger 1998).

in question affect fire behavior and flammability under specific conditions.[11] If, as indicated by remote-sensing data, fire reached 59% of East Kalimantan's logged forest area and only 5.7% of its undisturbed forest area in 1997–1998 (Siegert et al. 2001, p. 439), then concluding from this that logging causes forest fires may suffice for some broad analytic and policy purposes but leaves us with unanswered questions about the fire causes or fire-inducing mechanisms present in 59% of the logged area and absent from the other 41%. Similarly, there may be some justification for the claim that Suharto-era forestry policies, having led to uncontrolled logging that made forests more fire-susceptible, were underlying causes of the 1997–1998 fires (see especially Barber and Schweithelm 2000 and Dauvergne 1998), but the claim still leaves open the questions of just how the flammability changes were caused by the uncontrolled logging and what, if any, kind of *controlled* logging would not have had similar effects. So there is again indicated the need for more research if mechanistic or finer-grained causal understanding is to be attained.

The further work to be done is challenging and likely to require better and more sustained funding than has been accorded to past forest-fire research projects in Indonesia. Many observations and measurements of a large number of fires occurring under, and moving through, different conditions, combined with bio-physical research to characterize those conditions, should make it possible to construct more useful, empirically supported models and explanations of fire behavior and flammability insofar as due consideration will have been given to how fire behavior and flammability may be affected by variations in not only ambient weather and type and structure of forest but also, for example, the ability of trees to tap into deep soil moisture, as well as by variations in forest fuels in structure, chemical composition, and response to changes in atmospheric humidity (on these variables, see Cochrane 2003, pp. 916–917 and the references cited therein; also Ray et al. 2005, p. 1,676).

At this point, a fairly clear and simple statement may be made about why higher priority should be accorded to research on fire behavior and forest flammability than to the kinds of ignition studies and training programs that have thus far been characteristic of Indonesian forest-fire research. If explaining and controlling forest fires are indeed the goals, there's simply little sense in expending resources on

[11] In the finer-grained research being recommended here, we would still be trying to explain extensive forest fires, albeit, in effect, regarding as our immediate explananda such forest-fire "sub-events" as certain changes in fire's direction, speed, or height and some re-ignitions (cf. Gruner 1969, pp. 148–150 on "events" and "sub-events" in historical analyses). Illuminating observations on the progression from correlation to causation by moving to finer-grained research to account for lung cancer, duodenal ulcers, and other diseases may be found in Thagard (2000, p. 256 ff). My arguments here are intended as an endorsement of finer-grained research only when it may be expected to yield theoretically or practically significant answers to questions about causes (cf. Vayda 1996, p. 17 and note 9 and Vayda 2009, pp. 14–15). My objection to detailed ignition studies in the absence of studies more or less systematically connecting the ignitions to forest fires is, in effect, arguing *against* according high priority to finer-grained research which is, by itself, of not much use for explaining forest fires.

studying and controlling those ignitions which, by and large, are precluded by bio-physical and spatial factors from leading to forest fires. So the priority needs to be on establishing the conditions under which fires can happen in tropical moist forests and on the factors that either create those conditions or keep them from occurring. Once these are known, programs to monitor, study, and control ignitions would be very much in order where and when the ignitions would, according to our prior research, have the potential to lead to forest fires.

Interdisciplinary Research and the Human Dimension

A failure of perspective that fire historian Stephen Pyne (2000) has attributed to anthropologists and some other social scientists is having their focus so much on seeing fire through people's eyes as to fail to "pick up the other end of the firestick" and see people "through fire's eyes." Whether or not Pyne is right in saying that this failure is "exceedingly common," social scientists in such projects as the CIFOR/ICRAF one have indeed made their objects of explanation not so much forest fires as people's use of fire. Moreover, they have applied themselves to studying such use without duly considering whether it was occurring under conditions that could lead to forest fires. Thus, in many cases, there has been no special attention paid to distinguishing people's use of fire under non-drought conditions and under drought conditions or away from flammable forests and in them or near them. It should be no surprise then if the findings produced by social scientists in such cases are more on how fire helps or hinders people in pursuing their ends than on how people, pursuing their ends, do things that either help or hinder fire spreading in forests.

The case for considering the human use of fire especially under drought conditions nicely illustrates the need to combine investigations from the people viewpoint and the fire viewpoint. Too much of the social science contribution to tropical forest-fire research has consisted of studies of the uses that people make of fire under non-drought conditions. Failures to obtain data on the extent to which any of the fire uses studied in such projects do actually lead to forest fires have already been discussed. In addition, a critical limitation of studies pertaining to non-drought uses of fire arises from the fact that there are people who use fire differently (and with a fair likelihood of adverse effects on forests) when drought presents them with special opportunities or needs. Thus, South Sumatran rice-growers take advantage of drought to practice deliberately uncontrolled burning of marshland vegetation in the hope that some of the burnt area, otherwise unusable for agriculture, will have soil properties making it good for cultivation (Ramon and Wall 1998; Bompard and Guizol 1999; Chokkalingam et al. 2007; State Ministry for Environment 1998: I, 73; cf. Vayda 1999, pp. 14–15, 26–28, on this and, along with Chokkalingam et al. 2005, also on drought-specific use of fire to facilitate access to commercially valuable turtles in East Kalimantan's Middle Mahakam peatlands). In an East Kalimantan area of lowland dipterocarp forest as well, Sahur and I found that some farmers whose cocoa and/or banana plantations were destroyed fairly early in the

1997–1998 drought tried, before the drought's end, to make up for their losses either by using fire to clear forest for emergency swiddens or by illegal logging, which, at a time of heightened wildfire danger, involved making cooking fires and campfires, using potentially fire-igniting chainsaws, and producing flammable logging residues in the forest.

If time and funds were unlimited, we could perhaps undertake tropical forest-fire projects that include investigation of *all* land-use practices involving fire (see Sorrensen 2000). However, real-world limitations on the resources available make it important to combine the people viewpoint and the fire viewpoint and to prioritize accordingly. For both explaining and managing tropical forest fires, the priority must then be higher for obtaining data on how people use fire in times of drought than for obtaining data on all the different ways that they use it at any time. As indicated above, it would be desirable to go further and to prioritize forensic fire-scene investigations and/or hotspot analyses identifying FIZ to produce findings to guide decisions about locations for surveys or other studies of people's use of fire. Still, even when the most logical sequential ordering of research may have to be ruled out for practical reasons, why has the study of how people use fire not been guided more by considered judgments about where and when forests are more fire-susceptible?

The fault may lie, at least partly, in the rationale, organization, and conduct of so-called interdisciplinary research, whether on forest fires or more generally. According to Sayer and Campbell (2004, p. 50, 158–159) writing in the context of programs of natural resource management, the goal of causal explanation cannot serve to guide interdisciplinary research because the study of causal relations, requiring attention to fine levels of detail, is necessarily a disciplinary or even subdisciplinary specialization. I have argued against this view both here and elsewhere (Vayda 1998, 2009, and Vayda et al. 2004). Bolstering my arguments is the fact that the crossing of old disciplinary boundaries in a quest for understanding of causes or causal mechanisms is often what brings into being productive and exciting new areas of research.[12] Nor can I accept the view that joining interdisciplinary or multidisciplinary projects entails an obligation to serve, first and foremost, as representatives of our disciplines and the perspectives or foci associated with them. According to this view, if one is, for example, an anthropologist, the obligation is "to place people ahead of plants, animals, and soil" (Kottak 1999, p. 33). In the same sectarian spirit, social scientists have opted for a *separate* section for themselves within the Society for Conservation Biology (Mascia et al. 2003; Mascia 2005) rather than advocating mechanisms for closer interaction with biological and physical scientists and for more effective integration of their respective research.

Moreover, ignition events, characterized earlier as receiving "undue attention" in forest-fire research, have received just about *all* of the attention of some social

[12] A current example is "social neuroscience" (Cacioppo and Berntson 2004; Harmon-Jones and Winkielman 2007), which has developed dramatically since elimination of the old boundary between studies and explanations of social behavior and studies and explanations of brain mechanisms (cf. Azar 2002; Ochsner and Lieberman 2001).

scientists claiming to deal, as in Simmons et al. 2004, with "*the* human dimensions" of forest fires. This has not necessarily been simply a choice on the part of the social scientists. In my own experience, biological and physical scientists have often regarded only household surveys and community studies of fire use as the jobs of their social science colleagues. Fine-grained research on possibly important anthropogenic influences on fire behavior and fire susceptibility has been almost completely neglected.

Consider hypothetically that fine-grained fire-ecology research showed the following to be important as factors affecting fire susceptibility and fire propagation in logged over forests: the amounts and spatial distribution of deadwood logging residues and the size and spatial distribution of canopy openings resulting from both timber-cutting and extraction pathways. Explaining and controlling fires would then call for data on the human actions – and the causes of the human actions – producing the outcomes of interest. Such data would probably be forthcoming if the organization and work of an interdisciplinary research team were guided by the common goal of causally explaining forest fires but would not be forthcoming if researchers were left to pursue discipline-based interests and priorities. Important work has indeed been done on the ethnography of logging in Kalimantan and Sumatra (e.g., Casson and Obidzinski 2002; McCarthy 2000; Obidzinski et al. 2001; Ravenel 2004; Wadley 2006; Wadley and Eilenberg 2005) showing, inter alia, the proliferation of small-scale, illegal logging in place of the large-scale concession logging of the first decades of the Suharto-era timber boom. As, however, this research has been guided by such goals as analyzing political and economic causes of the changes and not at all by the goal of causally explaining forest fires, it is no surprise that the research has not included fine-grained observations on how or to what extent the reported changes have affected the logging-residue and canopy-opening variables.

In fact, for straightforward illustration of the kinds of "human-dimension" observations that could be useful for explaining whatever causally significant variation is found in these variables, the report of a 1992 Amazon study is more useful than any reports from Kalimantan or Sumatra:

> Tree-felling decisions are made by chain sawyers (contract workers) as they walk the forest in search of potential timber trees. The chain sawyers have little formal training in tree felling and no training in forest management or silviculture and they are paid according to the volume of timber they fell per day. Thus, rapid sawing is better rewarded than careful sawing. Log skidding by bulldozer occurs several days after tree felling. Although chain sawyers and bulldozer drivers live in the same camp, there seems to be little communication among them regarding the locations of the felled trees. To find felled trees, bulldozer operators drive their tractors towards openings in the forest canopy. When a log is found, it is skidded back to the log landing, but not necessarily by retracing the path used to arrive at the log. The result of this unplanned searching and skidding is a criss-crossing network of skid trails, some of which lead to natural forest gaps in which no timber tree was felled. (Gerwing et al. 1996).

The report also describes poor felling techniques and poor skid-trail layout as causes of collateral forest damage. Two hundred trees per hectare with more than 10 cm dbh were reckoned to have been damaged, even though the number of commercial trees cut per hectare was only 5–6. In the context of forest-fire research, part of the significance of such damage is that the increased tree mortality resulting from it would contribute to fire susceptibility (see Sist and Nguyen-Thé 2002 for Kalimantan studies of this).

Concluding Remarks

Much of the discussion to which my distinctions and arguments have led here has been, explicitly or implicitly, about the inadequacy of evidence to support claims being made about the causes of forest fires. For example, I noted that whatever evidence there may be on causes of ignition events, there is very little evidence on the spread of fires from particular ignitions or types of ignitions; that whatever evidence there may be on human use of fire in general, there is, with a few exceptions, very little systematic evidence on its use specifically when and where forests are susceptible to wildfires; that however much fire-management programs emphasize control of ignitions, evidence is lacking to show that the programs are effective and deserve a higher priority than programs emphasizing the control of changes in forest flammability; and that however strong the evidence, mostly from remote-sensing, that uncontrolled logging increases forest flammability and hence fire propagation, there have not yet been on-the-ground fire-behavior studies to provide the necessary evidence for deciding what, if any, kind of controlled logging would not have similar effects. The kinds of questions I have raised are important in making us see more clearly that we don't know some things we need to know for advancing our causal explanations and for basing fire-management policies and programs on them, as well as for setting priorities for research when the time, money, and other resources available are limited.

Accordingly, for the purpose of explaining and controlling the spread of fires in tropical moist forests, it may fairly be said that lower priority should be assigned to studies of all the causes of ignition events or all the ways in which fire is used than to the more specific or sharply focused studies that could provide the kind of needed evidence I have discussed. Among examples I have given are studies reconstructing the paths and ignition sources of particular forest fires; studies of fire use in or near forests during times of drought specifically; fine-grained research on fire behavior and fire susceptibility under varying conditions of fuel availability and moisture; and systematic research on human actions affecting those conditions.

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On the Notions of Mother Nature and the Balance of Nature and Their Implications for Conservation[1]

Dennis E. Jelinski

Introduction

The evolutionary biologist Stephen Jay Gould (1996, p. 57) wrote, "The most erroneous stories are the ones we think we know best – and therefore never scrutinize or question." This essay addresses two intertwining narratives that demand close scrutiny – Mother Nature and the Balance of Nature. Both are common in environmental discourse and generally accepted without question. For example, consider how often western popular culture refers to the workings of "Mother Nature" in affecting the "balance of nature." Wood (1999) suggested in an article entitled "It's not nice to fool Mother Nature" that with respect to genetically modified foods, "Consumer concerns about tampering with the balance of nature are legitimate...." Similarly, an organic gardening newsletter instructs "By mimicking Mother Nature and taking cues from her natural cycle, organic gardeners ... enhance the balance of nature" (Anonymous, VillageOrganics.com). This essay has three objectives: first, to examine Mother Nature and the evolution of the metaphor from deity through the dualistic human-nature paradigm; second, to trace the development of Balance of Nature as a cultural and scientific concept, and third, to weave together the notions of Mother Nature and Balance of Nature insofar as they hold implications for environmental conservation.

Mother Nature

Using the internet search engine *Google*™, the phrase "Mother Nature" throws up some 9,230,000 listings! Pop culture makes frequent reference to Mother Nature (for example, Lennon and McCartney's *Mother Nature's Son*, Sting's ballad *Rock*

[1] The original article *There is No Mother Nature – There is No Balance of Nature: Culture, Ecology and Conservation* appeared in *Human Ecology* Vol. 33, No. 2, April 2005.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_3, © Springer Science+Business Media, LLC 2010

Steady, and The Guess Who's *No Sugar Tonight/New Mother Nature*). Webster's New World College Dictionary (2005) defines Mother Nature as "the power or force that seems to regulate the physical universe." This ostensible "force" is frequently cited in advertisements, for example, advocating the virtues of a brand of margarine over butter with the warning "It isn't nice to fool Mother Nature," or praising the ability of an SUV to protect its driver from Mother Nature's onslaughts of torrential rains, hot deserts, and howling winds. The news media too highlight the unpredictability of Mother Nature. An article in the February 17, 2009, online edition of the Vancouver Province newspaper headlined "Mother Nature has the upper hand" concluded "In the end, all the organizers [of the 2010 winter Olympics] can do is prepare as thoroughly as humanly possible, then wait to see what Mother Nature has planned." An article in the Buffalo News (Elliot 2002) stated that "Mother Nature also brought some big fishery surprises," describing the invasion of nonnative zebra mussels and fishes in the Great Lakes. The article encourages "Be nice when fooling with Mother Nature." Even the United States Department of Agriculture, commenting on sharply rising wheat prices, reported that "Mother Nature stir(red) up the wheat market" (USDA 1997).

Mother Nature is frequently characterized as capricious and blamed for poor weather. Following the deaths of seven Canadian high school students in an avalanche while back-country skiing in Alberta, a local resident described the accident as "[A]n act of Mother Nature" (Globe and Mail, February 4, 2002). An article in CNN Money about disaster insurance was subtitled "How to protect your home when Mother Nature kicks in the door" (Geary 2002). Yet others espouse the idea that Mother Nature is wounded and in need of healing. For example, Thomas Friedman of the New York Times discussing the 2008 economic crisis, wrote "the whole growth model we created over the last 50 years is simply unsustainable economically and ecologically and that 2008 was when we hit the wall – when Mother Nature and the market both said: 'No more'" (http://www.alternet.org, March 10, 2009).

Some scientists, too, are taken by the notion of Mother Nature. ScienceNow, an online daily news site of the prestigious journal *Science*, posted an article on human-caused soil erosion by Mason (2005, March 4) entitled "Outdoing Mother Nature" which opened "Move over Mother Nature, another force is outdoing you." Another article (Kerr 2008, May 2) was headlined "Mother Nature cools the greenhouse, but hotter times lie ahead." Herring (2000), in a NASA Earth Observatory online article entitled "Second guessing Mother Nature: forecasting the snow of January, 2000," asked "So why didn't meteorologists foresee the winter bomb Mother Nature was preparing to drop on most of the eastern United States?" Similarly, James Lovelock (1988, p. 212) wrote "Gaia [Mother Nature] ...always keep[s] the world warm and comfortable for those who obey the rules, but [is] ruthless in her destruction of those who transgress."

These headlines and articles reflect a wider western belief that variously characterizes Mother Nature as on one hand "good" for supplying us with bountiful natural resources, abundant harvests, forests teeming with wildlife, majestic mountains, fish-rich rivers, and inspiring sunsets, and on the other hand, as fickle or even "bad" when some natural calamity occurs, especially insofar as it affects human agency. And "she" is apparently arbitrary, even capricious, in terms of the exercise of "her" powers. Mother Nature as an idealized organism has individuality, and with individuality comes a personality, and thus, clearly, value-laden idiosyncrasies.

Mother Nature as Deity and Metaphor

So who is she, this Mother Nature? The word nature derives from the Latin *natura*, meaning "to be born from." Thus the term nature began as an adjective describing "the essential quality and character *of* something" and evolved into (1) a force that directs either the world and (or) humans, and (2) the material world, which may or may not include humans (Williams 1976). From early on, Nature became personified in the form of "nature gods" (this is still true, particularly in animistic religions, which continue to be dominant or are at least a strong undercurrent in many rural areas of developing countries where people's lives and livelihoods depend on the vagaries of natural forces).

Goddess worship is evident from the earliest human images of Venus figures, dating back to the Cro-Magnons of the Upper Paleolithic period between 35,000 and 10,000 BC (Ucko 1962). Depictions of a Great Goddess appear at Proto-Neolithic (ca. 9,000–7,000 BC) sites from Ireland to Siberia, and throughout the Mediterranean area, the Near East, and Northern Africa (Davis 1971). In ancient Egypt (ca. 7,000–6,000 BC), the principle goddess, Isis, was known as the giver of life and responsible for cycles such as breathing, the alteration of day and night, the flooding of the Nile, and the yearly passage of the stars across the heavens (Engelsman 1979). Later yet, Gaia, or Ge, the Greek goddess of the sacred Earth, was described by Homer (ca. 850 BC) as the mother of all, who feeds all creatures that are in the world (Rose 1957). In 50 BC, the Roman poet Lucretius wrote, "the Earth deserves her name of Mother," because "the Earth would furnish to the children food; warmth was their swaddling cloth, the grass their bed abounding in soft down." These "organic views" of Mother Nature as a typically loving mother who cares for environments, plants, and animals were further elaborated in early Christianity by the Gnostics, who held Sophia as the Godhead of Wisdom and Nature (Schafer 2002).

The Middle Ages produced relatively little discussion of nature beyond its conception as the handiwork of God, created and ordered according to the Holy Scriptures (Egerton 1973). By the time of the Enlightenment, however, biblical explanations of the cosmos and nature were being challenged (Byrne 1997). In the seventeenth century, René Descartes, the leading rationalist philosopher, advocated a mathematical description of nature and the use of analytic thought. Descartes' ambition was to give a precise and complete account of all natural phenomena with absolute mathematical certainty. The Cartesian view of nature as a machine constructed from separate parts, with the whole no more than the sum of its parts, contains a basic dichotomy between *nature* and *culture* that stems from Aristotelian logic that everything must be classifiable as one thing *or* another ("law of the excluded middle") and a thing cannot be both one thing *and* another ("law of contradiction"). Embedded in this dualism were *mind* (man) and *matter* (nature), or *self* and *other*. Humans, by virtue of being endowed with a soul, reason, culture, and self-awareness, rise above the primitive, irrational, instinct-driven animal world (Serpell 1996). The dichotomy of nature and culture gave license to mastery over the natural world (Merchant 1980; O'Brien 2002) (the etymological meaning of *culture* is the process of cultivating the natural: to subordinate it to human control). Descartes wrote that the separation of humans from nature was to "render ourselves as lords and possessors of nature" (1960 (1637, 1641), p. 45).

In summary, the concept of Mother Nature began as deification, typically benign and organic, and gradually evolved a more metaphorical meaning such that by the Victorian era, "she" was seen as being often capricious, vengeful, and ruthless. The Industrial Revolution brought structural changes to western society and the way people related to nature, which could now be modified on a large-scale. In fact, nature and the "wild" were often seen as obstacles to human survival, progress, and civilization itself. Nature was forced into the dualist model with contrasts of wild–domestic, human–animal, nature–culture, good–evil, wilderness–civilization (O'Rourke 2000). The separation of nature–culture and other dualisms associated with a patriarchal worldview, its concepts of power structures, and "otherness" have been used to justify widespread destruction and exploitation of natural environments, and vast numbers of species extinctions. How to conceive of nature's agency in ways that are not anthropomorphic (or sexist) seems to be a central problem for the dismantling of discourses that define nature.

Balance of Nature

You cannot step into the same river twice, for fresh waters are ever flowing in upon you.

Heraclitus, ca. 544–483 BC

The myth that there is balance in nature is part of most cosmologies and central to natural history (Egerton 1973). The Merriam-Webster Dictionary defines myth as "a usually traditional story of ostensibly historical events that serves to unfold part of the world view of a people or explain a practice, belief, or natural phenomenon." The Chinese philosophy of yin (Earth/Female) and yang (Heaven/Male) enclosed in a hermetically sealed circle reflects a harmonious universe resulting from the balance of forces. In western thought, a similar concept can be traced to the ancient Greeks, who had several deities with the power to order the universe including Tethys, Gaia, Themis, and Metis. The Greek historian Herodotus described balance in nature as natural laws that kept predators from driving prey populations to extinction (e.g., he suggested that the mechanism limiting lion reproduction was that the cub, having sharp claws, must rip out the mother's womb while being born, and also noted the symbiotic relationship between Nile crocodiles and a species of plover) (Egerton 1973). So while the ancient Greeks recognized that change took place in the world, they also believed these changes cycled around a stable endpoint of equilibrium.

The concept of a balance of nature has likewise deeply permeated modern western philosophy and science, especially ecology. As mentioned in the previous section, the seventeenth century Rationalists believed that laws governed nature and ensured natural order (i.e., balance). To be without balance would be contrary to the belief that an all-powerful God would not allow nature to be random and unpredictable, or allow a species he had created to go extinct. Thus divine order begets natural order. The work of the English philosopher and theologian William Paley, notably *Natural Theology* (1802), also had a profound influence on conceptions of a balance of nature. According to Paley, the adaptation of a watch's parts to the reporting of time indicates that it is the product of intelligence, and not simply the output of undirected natural processes. Paley extended this argument to living organisms: since the existence of something as complex as a watch implied the existence of a watchmaker, the infinitely greater complexity of nature had necessarily to imply the existence of a creator, for him the God of Christianity. Furthermore, Paley and his followers held that God displays his existence, benevolence, and omniscience in the optimal design of all biota and harmony of ecosystem functions, as manifested, for example, in the exquisite "balance" of the food chain, or water and nutrient cycles. Natural laws were held to be divinely ordained and did not allow the possibility of randomness and extinction (Glacken 1967; Egerton 1973). In the nineteenth century, many amateur naturalists were also theologians and readers of Paley's work, thus intertwining religion, culture, and science. The notion of balance in nature also permeated the early conservation movement. George Perkins Marsh, a geographer and leading conservationist, wrote in *Man and Nature* (1864): "But she [i.e., Mother Nature] has left it within the power of man irreparably to derange the combinations of inorganic matter and of organic life, which through the night of eons she had been proportioning and *balancing* [my italics] … Nature, left undisturbed, so fashions her territory to give it almost unchanging permanence of form, outline and proportion" (p. 29). Marsh's warnings against humans disrupting equilibrium in nature were revolutionary. Darwin also used the concept of balance in nature, but explicitly recognized this as a potentially transitory state in complex natural systems when he wrote:

> ... and so onwards in ever-increasing circles of complexity. Not that under nature the relations [among organisms] will ever be as simple as this. Battle within battle must be continually recurring with varying success; and yet in the long-run the forces are so nicely balanced, that the face of nature remains for long periods of time uniform, though assuredly the merest trifle would give the victory to one organic being over another. (1859, pp. 72–73)

For most of the twentieth century, biogeographers and ecologists believed in a balance of nature. The paradigm has at its core properties whereby ecosystems have a strategy of self-regulation replete with an integrated and homeostatic system, governed by their own organic laws and ability to respond to feedbacks in accordance with the mechanistic principles of cause and effect (Pimm 1991; Wu and Loucks 1995), all directed toward achieving internal equilibrium or balance. This view, which continues to prevail in much public discourse, maintains, for example, that predators and prey are odd allies in a symmetrical relationship that helps each to prosper, to ultimately help or serve humans (e.g., by controlling pest outbreaks), and to preserve a mystical, divinely ordained harmonious condition. The concept of balance in nature can be examined at three levels of ecological organization: communities, ecosystems, and landscapes.

Ecological Communities

Much of the argument for holism in ecological communities can be traced to the American plant ecologist Frederic Clements (1916, 1936). In his model, plant communities are characterized as super-organisms that come into existence and grow from a juvenile stage to a well-defined stable "mature" stage, which he called the "climax" equilibrium state – the phenomenon known in ecology as succession. That the climax state was, for Clements, entirely predictable meant that it was a state of equilibrium. The deterministic aspects of succession were a product of Newtonian thinking. In this balance of nature paradigm, disturbance (e.g., fire, wind, insects, and disease) was considered a rare and, importantly, an external event, and its effects would diminish over time as the community became increasingly more stable or balanced. Clements believed the process was so orderly that if ecologists could not predict the exact community that would develop following disturbance, they simply did not know enough about the situation.

The work of Gleason (1926, 1939) challenged this holistic, super-organism view. Gleason's individualistic concept predicted that each species is distributed independently of other species, and therefore a community has no natural boundaries, but rather is defined by the types of species that happen to co-occur in a particular area, and that the assemblages appear to be balanced only because of our snapshot "view." However, Gleason's views were largely ignored until the 1950s (McIntosh 1985), and Clements' approach was adopted by major textbooks on animal populations and animal ecology (e.g., Allee et al. 1949) because its holism, homeostasis, and orderly neatness made it pedagogically attractive (McIntosh 1985). For example, Shelford (1913) described animal communities as "systems of correlated working parts" where equilibrium was principally maintained by a balance between food supply and reciprocal fluctuations in predators and prey. Nevertheless, not all animal ecologists were of like mind. Charles Elton (1930) attacked the ubiquitous clockwork simile used by ecologists: "The balance of nature does not exist, and perhaps, never has existed. The numbers of wild animals are constantly varying to a greater or less extent, and the variations are usually irregular in period and always irregular in amplitude."

Ecosystems

In his landmark paper Arthur Tansley (1935) advanced the concept of *ecosystem* as an interacting complex of the biotic community and the environment, claiming that ecosystems were the basic unit of nature on earth, in contrast to Clements' idea that aggregations (formations) of plants had the properties of organisms. He suggested that succession involved complex interactions of vegetation with soils, landforms, human agency, and climate, which lead to a range of successional trajectories. However, like Clements, Tansley thought that ecosystems develop toward a state of equilibrium with negative feedback bringing the system back into balance following perturbations. Six years after the term "ecosystem" was employed, Raymond Lindeman (1941) presented the first explicit exploration and expansion of the concept in his treatise on the ecological functioning of lakes. He used aspects of both community and ecosystem ecology to understand food webs, energy transfer among organisms, and the implications for succession. He provided the first quantitative food web for understanding temporal change in aquatic ecosystems with the notion that there are organized patterns of energy expenditure within the system (i.e., a balance of sorts).

Following the Second World War, Lindeman's approach to ecosystem analysis was propelled into prominence by E. P. Odum, who ultimately became the doyen of American ecology for the mid-to-late twentieth century (McIntosh 1985). The basic premise of Odum's view (1959, 1973) of ecosystem functioning was that homeostasis, as a general trait of biological systems ranging from cells to ecosystems, maintains conditions of equilibrium, and significant changes in numbers of each species and the number of species only occur when something upsets the norm of the system "balance." "Homeostasis at the organism level is a well-known concept in physiology… We find that equilibrium between organisms and environment may also be maintained by factors which resist change in the system as a whole. Much has been written about this "balance of nature" but only with the recent development of good methods for measuring rates of function of whole systems has a beginning been made in the understanding of the mechanisms involved" (Odum 1959).

A characteristic of the holistic systems approach was that ecosystems have a "strategy" and in fact the balance is rarely upset as "stability" would be achieved and maintained through various feedback mechanisms and cybernetic-like information networks in the form of food webs and nutrient cycling, which integrate and coordinate the workings of their components (e.g., populations, species). This systems approach relied heavily on understanding energy flows as the principal structuring agent in ecosystems. The system thus had clearly defined boundaries and natural order preordained by the laws of thermodynamics. (This emphasis on interdependences and relationships, and the associated ideas of stability and self-regulation, later formed the core of radical or "deep" ecology.) A crucial point about thermodynamic systems is that any deflection from "normal, equilibrium behavior" is seen as random noise rather than an integral part of the system. Thus the prevailing belief was, for example, that aperiodic and idiosyncratic rainfall events in semiarid ecosystems are external to the system and not an integral part of that ecosystem's behavior (i.e., the system is considered "closed"). Accordingly, ecologists held that ecosystems were quite resilient and even when significantly perturbed (particularly nonanthropocentric disturbance), they would return to some equilibratory point or steady state, much like elastic after being stretched. Taken together, the ideas of stability and equilibrium supported a balance of nature paradigm. In other words, modern ecological science represents a social–cultural controlled search for natural order. As Wiens (1984) states, "belief in equilibrium theory amounts to verification of a paradigm" rather than being based on the weight of empirically tested evidence.

Scientists attempt to understand and explain the world through objective evaluation. However, philosophers and most scientists will quickly point out there can be no such thing as observer-free observation. Moreover, the practice of science is often affected by the larger sociological context (Wilson 1998), which can determine what counts as useful research and what sorts of answers are acceptable. Thus the cultural myth and metaphorical idea of "balance of nature" may have predisposed scientists to accept the equilibrium paradigm. They were seeking to explain the "web of life," the "laws of nature", and the "grand cycle of decay and rebirth." Students of ecology were likely influenced by the homeostasis witnessed in everyday life. Societies also have degrees of homeostasis in achieving stability despite competing political, economic, and cultural factors (change is generally acceptable where it is so slow and gradual as to be imperceptible). In fact, the idea of prey being controlled by predators has the same essential intuitive appeal as Adam Smith's "invisible hand" whereby the interaction of supply and demand keeps market prices reasonably stable – in balance. Ghiselin (1981) suggested that the super-organism concept of the balance of nature persisted in ecology because it has aspects of romanticism and indeed mysticism and that ecologists subscribing to this concept "share an unwillingness to see natural occurrences, and especially biotic communities, as they are rather than as the observer wishes."

Landscape Ecology: The Paradigm Shift and the Nonequilibrium View

Nature keeps things controlled, but rarely keeps anything constant

Paul Schullery

In the late twentieth century, it became increasingly obvious equilibrium conditions were rare, and disturbance events so common that most ecological systems never reach equilibrium, including vegetation even over large landscapes (White 1979; Pimm 1991). At the population and community level, elements of nonequilibrium ecology can be traced back to Andrewartha and Birch (1954) and Gleason (1926) among others (see Rhode (2005) for a thorough review).

Questions about the role of disturbance, disequilbrium, and large-scale spatial heterogeneity in ecosystem processes helped spawn the emerging science of landscape ecology. By this time, it was well established that the successional sequence of species replacement was not predictable. Rather, the pattern of recovery following disturbance depends on the features of the species themselves, the nature of interactions among species, the constitution of the vegetation in the surrounding landscape, plus many unpredictable factors. Equilibrium may be reached only as a mosaic steady state where the creation of new patches (via disturbance) is balanced (i.e., a dynamic equilibrium) by the maturation of old ones (via succession) such that the landscape maintains a constant proportion in each patch type. For example, Romme and Despain (1989) concluded that Yellowstone National Park is a landscape characterized by non-steady state dynamics wherein the landscape fluctuates markedly (though not predictably) in structure and function over periods of 300 years. Baker (1989) found a similar condition for the 400,000 ha Boundary Waters region of Minnesota. These landscapes do not have a single equilibrium of species (e.g., populations and distributions) and habitats but instead are characterized by multiple equilibria, stochastic as well as deterministic processes, destabilizing forces, and sometimes an absence of any equilibria (Holling and Meffe 1996 and references therein). O'Neill (2001) characterizes ecosystems as having metastability, constantly changing yet perfectly reproducing.

This is not to declare that equilibrium states are never achieved; rather equilibrium conditions exist only at certain spatio-temporal scales (Pickett et al. 1994). The new nonequilibrium paradigm asserts that landscapes and ecosystems often exhibit emergent phenomena with relatively sudden reconfigurations beyond prediction, as the component parts mix, meld, separate, or randomly combine, and are "open" to a range of outside influences including those from other ecosystems and human activities. Natural spatial and temporal variation is a cornerstone in the contemporary nonequilibrium paradigm of ecology and its metaphor, the "flux of nature" (Wu and Loucks 1995). As Odum (1992) came to realize, ecosystems are "thermodynamically open, far from equilibrium."

Although this paradigm shift in ecology largely took place in the 1980s, Hull et al. (2002) recently interviewed 44 people professionally involved in the science, policy, and management of forests in southwestern Virginia and reported that more than half of the respondents (23) employed, at some point during their interview, a "balance of nature" argument. They suggested that nature was "balanced" or in "harmony" or that there exists an "equilibrium" in nature due to "forces" that "heal," "improve," or otherwise guide nature towards some balanced or healthy state. An ecosystem, it was suggested, functions like an organism with "self-perpetuating," "self-maintaining" processes that allow it to "heal itself." High school students are still often taught that predators and prey need each other to keep their populations in balance. For example, the high school textbook *Biology: The Dynamics of Life* (Merrill Publishing Company) published in 1991 states: "Birds have many roles in the environments in which they are found. Birds help to maintain balance in the environment. Some birds eat insects that would otherwise increase in number so much that they would overwhelm natural habitats. Predatory birds feed on rats and mice and keep them in check."

Balance of Nature and Mother Nature in Conservation

The Mother Nature and Balance of Nature paradigms have considerable modern-day appeal in the conservation movement. Many conservationists with nonanthropocentric sympathies adopted Aldo Leopold's Land Ethic, which has at its core a holistic view towards ecosystem protection wherein humans are "plain members and citizens" of the "land community." Leopold (1949, p. 262) held that "[A] thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." In other words, the balance of nature and steady-state theories lend support to the view among some conservationists that the best way to conserve nature is to seek out discrete ecosystems, remove human influences, such as domestic livestock grazing and fire, and reestablish natural biodiversity by stabilizing ecological processes. Thus conservation efforts are often aimed at achieving the seductive states of natural balance and stability. Such an approach largely fails. As noted earlier, ecosystems are dynamic (change is the only constant) and spatially heterogeneous. So, while the general ethic remains valid, conservation efforts must acknowledge the primacy of disturbance in ecological systems, the asymptotic return afterwards, and hence the normalcy of change, much of which is unpredictable.

Even from a nonscientific viewpoint, the paradigms present problems for the conservation movement, especially so-called deep ecologists and New Age adherents who have embraced James Lovelock's (1988) Gaia hypothesis, which states:

> The entire range of living matter on Earth, from whales to viruses, from oaks to algae, could be regarded as constituting a single living entity, capable of manipulating the Earth's atmosphere to suit its overall needs and endowed with faculties and powers far beyond those of its constituent parts.

Lovelock describes global feedback in metaphysical terms, and by naming the phenomenon "Gaia," has led some to deify Gaia as an object of reverence and providence. Gaia comes close to fulfilling the desire of many New Age advocates for a conservation science that subsumes religious belief. Paradoxically, such New Age thinking and the reappropriation of the term "Gaia" to represent the Earth (Mother Nature) replicates the language of dominance and reinforces patriarchal dualisms and hierarchical traditions which continue to objectify women and nature (in Greek mythology, Gaia becomes subservient to her son–husband, Uranus). Furthermore, personalizing this relationship with Mother Nature at the helm is very dangerous. The Gaia ideology could work against conservation if the Earth is truly believed to be self-regulating even in the face of human-caused perturbations driving millions of species to extinction and leading to large-scale deforestation and global climate change. Moreover, denial of the ascendancy of nonequilibrium theory and clinging to the notion of steady-state ecosystems and harmony in nature will preclude from our narratives all but a limited fraction of the phenomena that constitute our daily world. Indeed, it would make it difficult to accept that the Earth's ecosystems are so remarkably complicated that we can never completely understand them.

Conclusion

The philosopher Max Black (1962) maintained that metaphors are necessarily open-ended and cannot be tested for falsity, and argues that they are purely ways of assisting understanding. I have attempted here to show that the Mother Nature and Balance of Nature metaphors have produced cultural, social, and scientific misconceptions about the structure and function of nature rather than fostering any useful or meaningful understanding. Overall, we tend to ignore the true forces of nature, which are firmly grounded in physics, Earth systems science, chemistry, and biology, none of which are capable of conspiring to ruin our weekends, create famine, and kill off wildlife, or, alternatively, produce bumper crops, great wines, and weather ideal for picnics. Instead, age-old myths, metaphors, and distorted science allow for misguided perceptions of the natural world notwithstanding that the general notions of order, permanence, harmony, symmetry, and regularity are desirable attributes more generally (i.e., beyond nature and ecology). Myths cannot be used to construct theory per se, but do often inspire its construction. On the other hand, myths cannot be destroyed by facts. They can only be abandoned when people realize that the explanations that they appear to offer can never be verified by critical testing.

Wilson (1998) believes people are innate romantics and desperately need myth and dogma. Sadly, however, the myth and dogma associated with Mother Nature represent a deification of Earth and gendered images of a capricious being. The metaphor reinforces many of the dualistic assumptions that underlie the Cartesian worldview, especially man-vs.-nature. In reality there is no larger power that is orchestrating ecological calamity and otherwise wreaking havoc, or being beneficent and nurturing. Similarly, the Balance of Nature paradigm is a misguided effort to match ecological science with theological and scientific visions of a perfect universe, a single parsimonious system such as Einstein sought. There is no harmony in nature; rather, as Botkin (1990) asserts, there are discordant harmonies of nature. He maintains that ecosystems cannot be analyzed "as if they were nineteenth century machines, full of gears and wheels, for which our managerial goal, like that of any traditional engineer, is a steady-state operation" (Botkin 1990, p. 12).

As ecology has undergone a profound shift from the notion that nature is a well-regulated, deterministic system, conservationists must no longer conceive of nature as balanced and integrated. Nature is dynamic and highly variable with open-ended trajectories contingent upon preceding events. There are no equilibratory forms of ecosystems or steady states that nature should be in, and there is no Mother Nature. Our understanding of social science, science, and environmental conservation needs to reflect this reality.

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Hunter–Gatherers Optimize Their Foraging Patterns Using Lévy Flights[1]

Clifford T. Brown, Larry S. Liebovitch, and Rachel Glendon

Introduction

We present evidence that human hunter–gatherers employ foraging movement patterns that are described by the statistics of Lévy flights rather than by conventional Gaussian statistics. Human movement across the landscape is not usually considered an anthropological problem as such. For example, Green (1987, p. 273) observed that the way foragers move between resource patches has been the subject of little quantitative work. Nevertheless, movement patterns influence not only foraging itself but also cultural diffusion, demic diffusion, gene flow, and perhaps migration into virgin territory. So the discovery of Lévy flights in foraging patterns carries implications for various theories in anthropology, including optimal foraging theory as applied to hunter–gatherers and by extension for archeological models of human subsistence settlement systems in prehistory. Moreover, it may help us understand the processes of diffusion and migration. Here, however, we focus our discussion on the implications for optimal foraging theory in cultural ecology and archeology.

Optimal foraging theory is not really a single theory, but rather a diverse suite of formal models that are used to understand foraging patterns of both animals and humans. The approach usually taken is to analyze a quantitative model of decisions made by foragers to see whether or how they maximize some kind of "currency" (often some quantity, such as the net amount of energy gained) under a set of specified constraints. Most models fall into one of two categories: (1) those that analyze diet choices, often called "prey models" and (2) those that examine when a forager should leave a patch of resources, the so-called "patch" models. The prey or diet models have generally examined the proportions of different foods in the diet or the likelihood of pursuing one prey vs. another. In contrast, the patch models generally

[1] The original article *Lévy Flights in Dobe Ju/'hoansi Foraging Patterns* appeared in *Human Ecology* Vol. 35, No. 1, February 2007.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*, DOI 10.1007/978-1-4419-5701-6_4, © Springer Science+Business Media, LLC 2010

evaluate the time spent in resource patches and the timing of the move to the next resource patch after the presence of the forager has depressed the availability of the resource in the patch. All these models include travel times between resource patches or prey search times as an important variable and therefore should take into account spatial patterns of foraging behavior. So as not to oversimplify our discussion, we note that many different specific foraging models that consider the outcomes of varying assumptions or constraints have been developed.

Lévy Flights

Lévy flights, named after the French mathematician Paul Lévy, are a class of random walks in which the step lengths are drawn from a probability distribution with a power law tail. These probability distributions are known as Lévy distributions or stable distributions. The lengths, l, of the steps or jumps of the walks are distributed as a power law, $P(l)=l^{-\mu}$ with $1<\mu\leq 3$ (Viswanathan et al. 1999).This gives Lévy flights a very distinctive appearance, one which can be described subjectively as "clumps" of small steps separated by dramatic jumps. The pattern contrasts visually with the more homogenous pattern of Brownian motion in which the step lengths are drawn from a normal distribution (Bartumeus et al. 2003, p. 12,772).

In recent years, biologists have discovered that Lévy flights describe foraging patterns in a number of species of animals and insects: ants, bumble bees, *Drosophila melanogaster* (Cole 1995), albatrosses (ben-Avraham and Havlin, 2000, pp. 48–49; Viswanathan et al. 1996, 1999), jackals (Atkinson et al. 2002) and reindeer (Mårell et al. 2002). Even zooplankton have been observed to forage in Lévy flight patterns (Bartumeus et al. 2003, p. 12,772). Recently, primate ethologists have observed nonhuman primates foraging in patterns that obey Lévy statistics (Boyer et al. 2004; Ramos-Fernández et al. 2003). This latter research, which recorded the behavior of *Ateles geoffroyi* (spider monkeys) in the Yucatán Peninsula, is important both because of its focus on primates and because *Ateles* forage in groups, which influences the model and the results. Earlier studies had all focused on lone foragers. Group foragers exhibit patterns of movement that may imply that groups are more efficient than individuals in locating food, an argument that has long been offered as one explanation for the existence of social groups of primates. The fission–fusion group dynamic found in spider monkeys is also characteristic of the primates most closely related to humans, the chimpanzees (*Pan* spp.). So, these findings may carry implications for the behavior of the common ancestor of *Pan* and the hominid clade.

Optimal foraging theory predicts, or sometimes assumes, that foragers (human or animal) will exhibit optimizing behavior, normally measured in terms of maximizing the net return in energy for their investment of effort in foraging. Our study of foraging movement allows us to evaluate one aspect of this idea, namely that foragers minimize the energy expended in searching for food by optimizing their search patterns, because Lévy flights with an exponent of two are optimal search patterns for foragers searching for scarce targets that are randomly placed and can be visited any number of times (Viswanathan et al. 1999, 2000, 2002).

The Ju/'Hoansi: Human Foragers

Here we present evidence that human foragers use Lévy flights as search patterns as part of their subsistence strategies, and furthermore that they indeed perform optimal searches. We have analyzed data published by Yellen (1977) describing the movements of the Dobe Ju/'hoansi during hunting and collecting trips made in 1968.

The Dobe Ju/'hoansi are – or were until their recent resettlement – hunters and foragers living in and around the Kalahari Desert in Botswana and Namibia. They speak a "click" language of the Khoisan family. They have been intensively studied with special attention to their subsistence system and economy (Lee 1979, 1993; Lee and DeVore 1976). In their traditional subsistence system, men hunted and women gathered plant foods. In the 1960s, when these observations were made, meat, procured by men hunting, provided 30% of the overall caloric intake and plants provided the remaining 70% (Lee 1993, p. 50). Men did perform some gathering, raising their total contribution to the diet to about 45%, but, interestingly, women never hunted (Lee 1993, p. 56; Marshall 1976, p. 96). A wide variety of game was pursued and over 100 species of plants were considered edible (Lee 1993, p. 45). The most important plant food by far was the mongongo or mangetti nut (*Ricinodendron rautanenii*), a highly nutritious food which is virtually a staple in the Ju/'hoansi diet.

Like other San groups, the Dobe band of the Ju/'hoansi spent the winter–spring dry season at a permanent water source – in their case, the Dobe waterhole (whence the name). During and after the rains, the social group broke up into smaller subgroups that moved out into the hinterland and built short-term camps near seasonal water sources. At each camp, the people exploited nearby food sources until they consumed most of the desirable food. They would then move on to another temporary camp. After some days or a few weeks, they would return to Dobe for a short time before setting out on another trip. The data analyzed here consist of the locations of those rainy season camps that were occupied by one small kin group from January 27 to July 11, 1968 (Yellen 1977). This kin group was composed of two married men and their families. They made a total of 37 moves and occupied 28 different camps in the course of their five trips from the Dobe waterhole (Yellen 1977, p. 59). In this article, we examine the statistical patterning of these moves.

To understand the meaning of these data, one must appreciate the considerations that enter into the choice of camp location. Generally speaking, in this hot and dry climate water is the most important determinant of settlement location, but the way in which it affects camp location is not simple and absolute. For example, Lorna Marshall (1976, pp. 75–76) recounts an occasion when a Ju/'hoansi band camped in a mongongo tree grove 6 miles from a temporary waterhole. Every day for as long as the water lasted, they sent their boys on the 12-mile round trip to bring water. In addition to water, many other factors enter into the decision of where to make camp, including the presence of plant food or game. The landscape and environment are complex. The patchy distributions of plants and animals are affected by geomorphology, soils, and rainfall patterns (Yellen and Lee 1976). It is therefore not surprising that the locations of camps form a complex spatial pattern. Mongongo nut groves, for example, are an important influence on camp location. In the Dobe area, the groves are found only on dune crests (Yellen 1977, p. 21). The dunes in turn are not randomly distributed; they form long, east-west trending ridges from 8 to 80 km in length between dry river courses (Yellen 1977, pp. 18–20). Elsewhere in the region, the mongongo groves form other kinds of patches that closely correlate with geomorphology and soil types (Lee 1979, pp. 182–185). The essential point is that camp location represents a decision about resource patch location that is identical to the decisions analyzed by optimal foraging theory patch models.

Ju/’hoansi foraging has been studied using diet breadth models (Belovsky 1987, 1988; Hawkes and O’Connell 1981, 1985). It can be argued, however, that the patch model is equally if not more relevant to understanding their foraging patterns because patch models generally consider the problem of when a forager should decide to move to a new patch after having depressed the resources available in his present patch. This is precisely the decision that the Ju/’hoansi make as they shift their camps, and therefore the patch model is clearly relevant to understanding the behavior that created our data set.

Materials and Methods

Our data come from Yellen’s 1977 book on the Dobe Ju/’hoansi settlement patterns and camp structure. That research was undertaken as part of the long-term Harvard University Kung Bushman ethnology and human ecology project. Yellen (1977, pp. 61–63) discusses the strengths and weaknesses of this data set, including the potential influences of his anthropological team and of nearby Bantu settlers. He concludes, nevertheless, that “[h]ad neither Bantu nor anthropologists been there, I believe that the basic pattern would have been the same but less time would have been spent at the permanent waterhole.” This statement leads us to believe that we can rely upon the camp location data but that the occupational times may be somewhat less accurate.

We measured the distances between camps on Yellen’s map in the order in which they were occupied, and we drew the lengths of the camps’ occupations from the published tables. We analyzed the geographic distances between camps in the order in which they were occupied to see if they conformed to a power-law distribution of step lengths predicted by a Lévy flight. We also analyzed the lengths of camp occupations to see if they conformed to a power-law distribution as they would if they were the wait times at the turning points of a Lévy flight.

Results

Our analyses of the data sets yielded the following results. Using Liebovitch's multihistogram method (Liebovitch et al. 1987, 1999, 2001) we found that the step lengths, that is distances between the Ju/'hoansi camps, are distributed as a power law with an exponent of −1.9675 (r^2=0.965) (Fig. 1). This is a clearly a power-law relation, indicating that these movements conform to a Lévy flight. Similarly, the wait times (i.e., lengths of occupations of the camps) are distributed as a power law with an exponent of −1.4503 (r^2=0.828) (Fig. 2). Note that, as mentioned earlier, the occupational times may have been influenced by external factors.

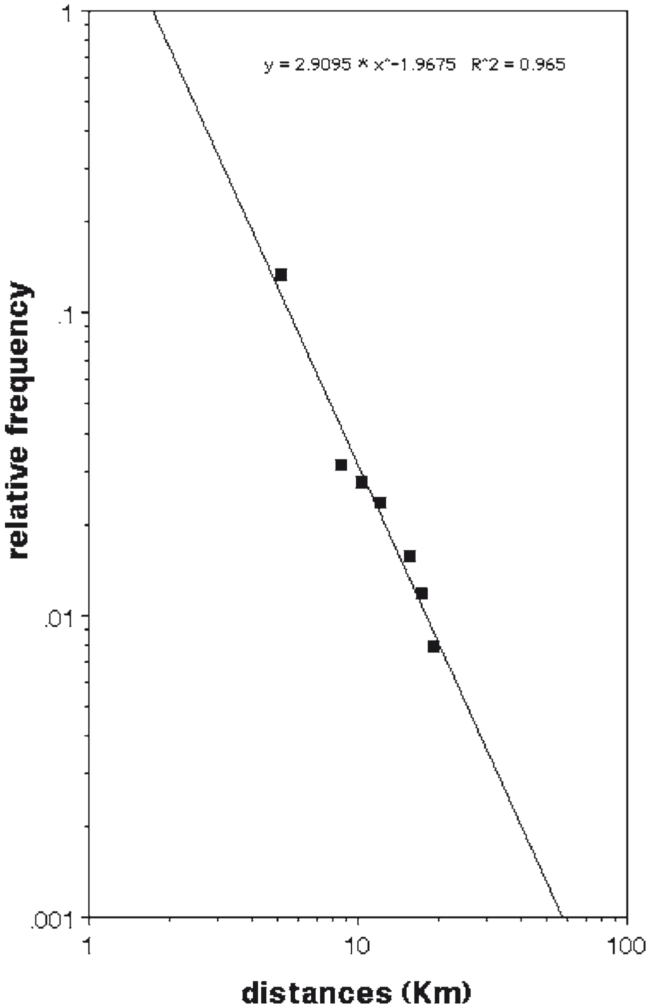

Fig. 1 Power-law distribution of distances between campsites, exhibiting an exponent of 1.9675

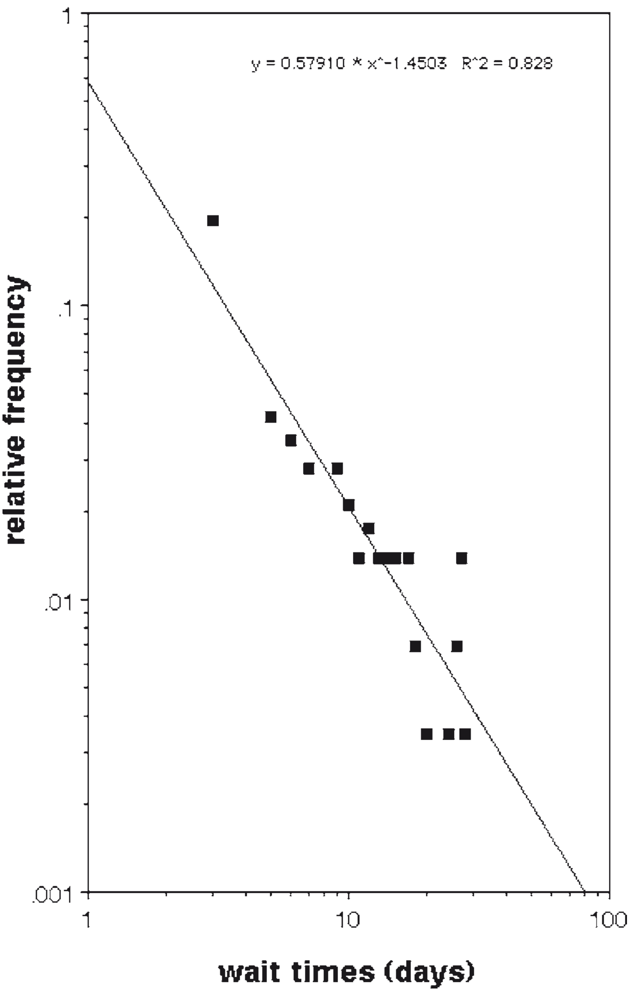

Fig. 2 Power-law distribution of camp residence times, exhibiting an exponent of 1.4503

To determine whether the Lévy flights model was the best description of our data, we also examined several other plausible models. We feel that evaluating alternate hypotheses is an appropriate means for identifying and supporting the best choice among competing explanations (Johnson and Omland 2004). The falsification of alternative possibilities reinforces and buttresses a scientific argument. The choice of model, however, is not simple because the possibilities are infinite. To choose from among these possibilities, we believe that one should start from concepts with clear social interpretations and implications, rather than beginning with the quantitative possibilities. In other words, model selection should not be an exercise in curve fitting, followed by an attempt to understand the social implications of the curve that fits best. One should first conceptualize the social model and then evaluate its quantitative implications.

Considering these ideas, we selected three alternatives to the Lévy flight model, which implies a power law distribution of step length. The alternative models were a normal distribution, a uniform distribution, and an exponential distribution. We tested these models in two ways. First, we tested the exponential distribution of step lengths (which seemed the most likely of the alternative possibilities) by using the multihistogram method (Liebovitch et al. 1987, 1999, 2001) so that it would be directly comparable to the Lévy flight test described above. Then, we examined all three alternatives (including the exponential distribution again) by examining the distributions of step lengths using one-sample Kolmogorov–Smirnov tests in SPSS Release 12.0.

Normal Distribution

A normal or Gaussian distribution of step lengths is probably the most common model of human movements across the landscape. For example, Ammerman and Cavalli-Sforza's famous "wave of advance" model for the spread of agriculture (1979) assumes a Gaussian distribution of steps. The approach originated in Fisher's (1937) model for the diffusion of advantageous alleles across the landscape. This model is effectively a stochastic one, which would arise in the event of a spatially random distribution of campsites. This kind of model is, of course, common for two reasons. First, the existence of random effects in natural (or cultural) processes such as these seems innately reasonable to some investigators. Second, Gaussian statistics have traditionally been used in modeling because they are mathematically tractable. The Gaussian model of step lengths can, however, be rejected as a model of the Ju/'hoansi data set because $p<0.05$ (Table 1).

Table 1 One-sample Kolmogorov–Smirnov test comparing the Ju/'hoansi step length data to a normal distribution

		Distance
N		37
Normal parameters[a,b]	Mean	6.1762
	Std. deviation	4.21463
Most extreme differences	Absolute	0.226
	Positive	0.226
	Negative	–0.145
Kolmogorov–Smirnov *Z*		1.376
Asymp. sig. (two-tailed)		0.045

[a] Test distribution is normal
[b] Calculated from data

Uniform Distribution

To our knowledge, no one has hypothesized that humans move about the landscape in a uniform spatial pattern, but it is not an unreasonable possibility. If resources were uniformly, or at least redundantly, distributed across the landscape, then groups of foragers might move relatively similar distances each time they shifted camp. In such a case, the step lengths might be driven by external forces, such as the locations of other social groups, rather than by the distribution of resources. Other scenarios might also be imagined that would lead to a relatively even pattern of movements. Regardless of the possible reason, the Ju/'hoansi step length data do not match well to a uniform distribution (Table 2). The test statistic yields $p = 0.000$, allowing us to reject the hypothesis.

Exponential Distribution

Exponential distributions arise for the length of a set of walks when, at each step in a walk, there is a constant probability that the walk will end. Sometimes the walk ends after only a few steps, sometimes after many steps. Longer walks are less likely because they must survive many more equally likely terminations. It can be shown that if the probability per unit length to terminate the walk remains constant, the distribution of lengths of many walks has an exponential form. (See, for example, Liebovitch et al. 1987 where this is derived in terms of durations of time, which are here analogous to the lengths of the walks.) This model could represent human behavior. The band continues a walk, at each moment deciding whether it has been worthwhile and whether, with the same chance, it should be continued or ended. We also wish to test an exponential function because Ju/'hoansi migration distances (in the sense of the distance between the birthplaces of spouses, see below) seem to resemble an exponential distribution. Interestingly, the step lengths of the Ju/'hoansi data do not appear to match an exponential distribution well, as shown by the

Table 2 One-sample Kolmogorov–Smirnov test comparing the Ju/'hoan step length data to a uniform distribution

		Distance
N		37
Uniform parameters[a,b]	Minimum	1.72
	Maximum	17.46
Most extreme differences	Absolute	0.418
	Positive	0.418
	Negative	–0.027
Kolmogorov–Smirnov *Z*		2.543
Asymp. sig. (two-tailed)		0.000

[a] Test distribution is uniform
[b] Calculated from data

Table 3 One-sample Kolmogorov–Smirnov test comparing the Ju/'hoansi step length data to an exponential distribution

		Distance
N		37
Exponential parameter[a,b]	Mean	6.1762
Most extreme differences	Absolute	0.252
	Positive	0.072
	Negative	–0.252
Kolmogorov–Smirnov Z		1.531
Asymp. sig. (two-tailed)		0.018

[a] Test distribution is exponential
[b] Calculated from data

Kolmogorov–Smirnov test statistic of $p = 0.018$ (Table 3). We also tried to fit an exponential curve to the step length data using the multihistogram method (Fig. 3). The coefficient of determination (R^2) for the exponential distribution is 0.910, markedly lower than the same coefficient for the power law ($R^2 = 0.965$). This, of course, suggests that the power law is a better fit to the data. We conclude that the power law distribution of step lengths, which implies a Lévy flight model of movement, is the best fit to the data of the alternatives tested.

Discussion

First, of primary importance is the fact that the pattern of camp movement comprises a Lévy flight. The movements are not distributed in a Gaussian or exponential mode, as might be expected, but as a power function. When migration and diffusion are modeled, researchers typically assume a Gaussian distribution of migration distances. Lévy flight movements may help explain rapid, long-distance migrations that advance through processes such as leapfrogging (Anthony 1990). Lévy flights can produce faster long-distance migration than Brownian motion because the latter will have few long jumps and many medium-length jumps, whereas the former will produce some surprisingly long leaps.

The assumption of a Gaussian distribution of migration distances is also undermined by some real migration data. For example, migration distances often seem to be modeled by an exponential relation (Wijsman and Cavalli-Sforza 1984). Interestingly, Ju/'hoansi migration distances do seem to follow an exponential distribution (Harpending 1976). "Migration distance" among these highly mobile people is defined as the distance between the birthplaces of spouses, not the pattern of band movement around the land. As Fig. 4 illustrates, the Ju/'hoansi migration data (Harpending 1976) fit a single negative exponential function quite well ($R^2 = 0.97$). In the simplest terms, this tells us that the probability of two individuals marrying declines exponentially with the distance between their birthplaces. Of course, marriage patterns are influenced by the network of kin relations among the

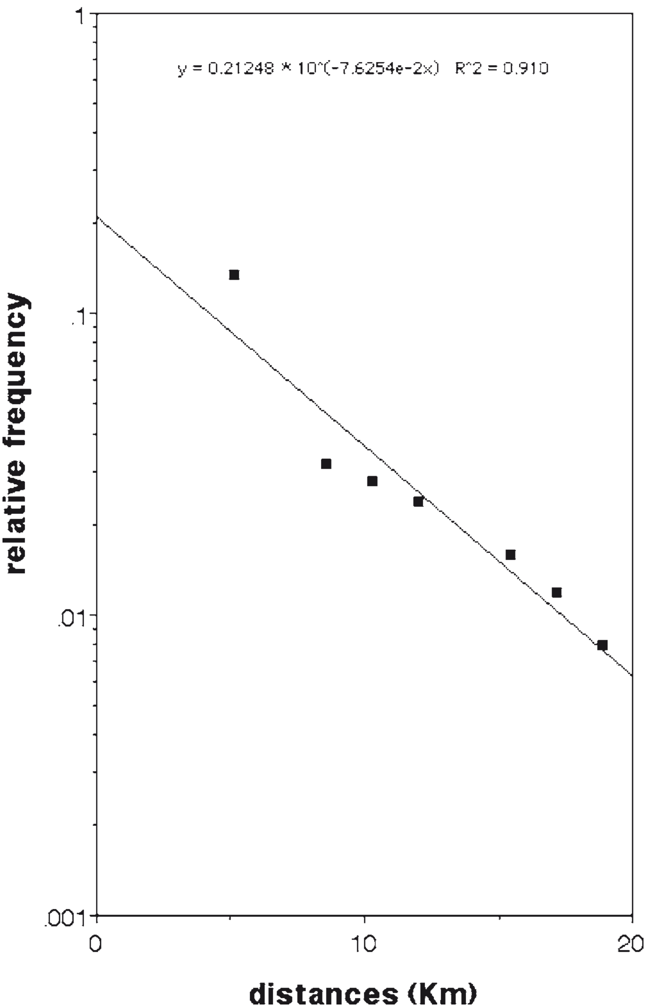

Fig. 3 The distribution of distances between campsites fit to an exponential distribution

Ju/'hoansi, including factors such as rules of exogamy and marriage preferences. So the migration distance data must relate to the Lévy flight foraging model in an indirect and complex way that is difficult to specify based on the available data.

Second, we find it extremely interesting that the power law exponent of the step distances is very close to −2. An exponent of −2 implies a maximally efficient search for randomly placed, scare targets that can be revisited (Viswanathan et al. 2000, 1999). We were surprised to find this because, notwithstanding the extensive theorizing about optimality in human behavior, concrete empirical cases of optimizing behavior in the literature are scarce (Salmon 1989). The case discussed here may be an instance of optimizing behavior. We hasten to add, however, that we do

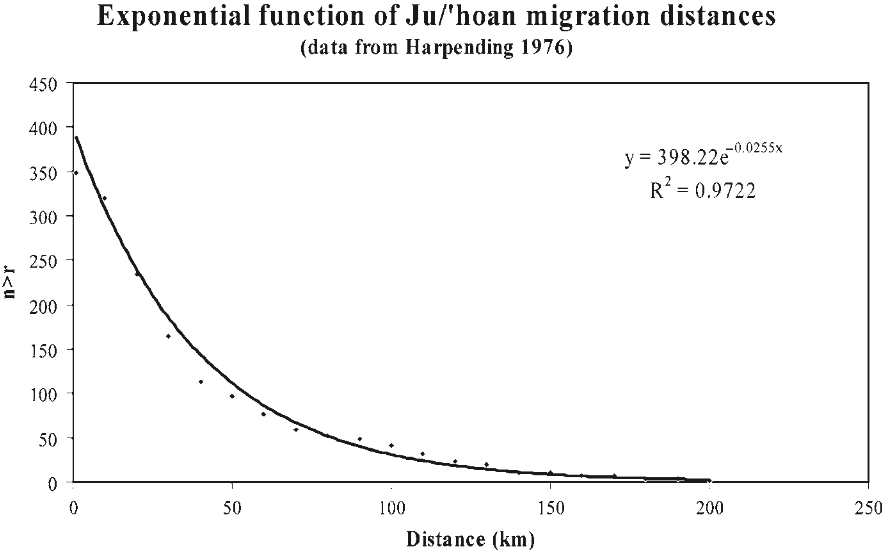

Fig. 4 Statistical distribution of Ju/'hoan migration distances of spouses showing a fit to an exponential function

not interpret this finding to imply that Ju/'hoansi are automatons whose behavior has been programmed by natural selection. The only reasonable interpretation is that the Ju/'hoansi achieved an optimal search pattern while behaving rationally in adapting to a spatially complex and unpredictable environment. Indeed, the Ju/'hoansi know where the waterholes, mongongo groves, and salt licks are in their territory, and they place their camps accordingly. Thus, the Ju/'hoansi Lévy flight exponent may reflect the spatial distribution of resources as well as their decision-making processes.

Third, we believe that the conclusions drawn here should influence the application of optimal foraging theory to hunter–gatherer studies. In optimal foraging models, search times or travel times are essential elements in the basic equations. Both prey and patch models derive from Holling's disk equation. This equation assumes a linear relationship between search time and the number of prey/patch encounters. The power law function of the travel distances documented here clearly violates that assumption of linearity.

The nonlinearity inherent in Lévy flights presents other challenges for conventional optimal foraging models. For example, the prey and patch models commonly assume that prey or patch encounters are distributed as a Poisson process. This cannot be true if the Ju/'hoansi are foraging in a Lévy flight pattern because it is so strongly nonlinear in space and time that it cannot be reconciled with a Poisson process.

Travel times figure prominently in patch models, which, as we observed earlier, are directly relevant to understanding Ju/'hoansi camp movements. The model examines how patches are chosen and at what point a forager should leave an exploited patch for a fresh one. This model is clearly relevant to understanding Ju/'hoansi foraging behavior in the Kalahari given (1) the scarce and patchy distribution of food in the Ju/'hoansi environment, (2) the tendency for the Ju/'hoansi to camp in or at resource patches, and (3) the propensity for the Ju/'hoansi to "eat out" (substantially exploit) an area before moving on to a fresh patch. The generic patch model predicts that a forager will leave a patch when the marginal rate of gain declines to the point at which it equals the long-term average rate of energy intake in the habitat. In the basic and common formulation of the model, the average travel time between patches is taken to be the inverse of the patch encounter rate. Thus, when the encounter rate is maximized, time is minimized, and in fact some models have explicitly examined time minimization as a model goal (e.g., Abrams 1984). So, average search time is a key variable in the calculation of most models. In the case of a Lévy flight, however, there is no average travel time between patches. The mean simply does not exist because power laws do not have stable means (Liebovitch 1998, pp. 74–105; Liebovitch and Scheurle 2000; Liebovitch and Todorov 1996; Liebovitch et al. 1999). This tells us that the standard formulation of the patch model cannot be accurately calculated for a forager who forages using a Lévy flight pattern. We do not assert that this "disproves" optimal foraging theory, but we do believe that optimal foraging models that analyze human behavior should employ more realistic assumptions about forager behavior.

How might models of human optimal foraging take into account these kinds of assumptions? A number of existing models do take into account Lévy flights of foragers (e.g., Bartumeus et al. 2005). For example, da Luz and his colleagues (2001) define foraging efficiency as the ratio of total energy gained in visited sites to the total distance traveled by the forager. They then show, relying in part on the theoretical work and simulations performed by Viswanathan et al. (1999), that foragers performing Lévy flights maximize their foraging efficiency when their Lévy flight exponent is $\mu=2$. Difficulties remain, however, in applying this model to humans. As the model is designed to apply to animal or insect searching, it assumes little or no learning or memory, assumptions which are clearly not justified in the case of human foragers. As the Ju/'hoansi do know their environment well, their movement patterns are unlikely to be analogous to a random search. This leads us to consider the other possible cause of their Lévy flights: a fractal distribution of resources. Fractals are closely related to Lévy flights because the turning points of a Lévy flight form a fractal pattern of points. The mathematical relationship between them is simple. The exponent of the Lévy flight, μ, relates to the fractal dimension of the pattern by $F_D=\mu-1$. Viswanathan et al. (1999, p. 914) examined the Lévy flight model for a fractal distribution of resources and found it consistent with their model. There is a modest literature describing models of foraging (e.g., Hoddle 2003; Russell et al. 1992) that examine foraging in a fractal environment.

Fourth, and last, because the turning points of a Lévy flight form a fractal pattern, we can predict that the spatial distribution of camps will form a fractal pattern. This fact is of primary importance to archeologists because they, more than anyone else, quantitatively study hunter–gatherer settlement patterns. Archeologists not only conduct surveys to find hunter–gatherer archeological sites, but they are also concerned with sampling the landscape to locate these sites and with analyzing their spatial distributions.

Summary

We analyzed published data on Ju/'hoansi settlement patterns and showed that the shifting of their rainy season foraging camps formed a Lévy flight pattern. This finding is consistent with recent observations for a variety of other foraging species. Startlingly, the exponent of the step lengths of the Lévy flight implies that their search pattern is highly efficient and approaches maximal efficiency. This discovery carries significant implications for optimal foraging theory as applied to hunter–gatherers and for archeological studies of hunter–gatherer settlement patterns.

We suspect that Lévy flights may also serve as a robust model for the migrations of sedentary peoples (Lilley 2008). The qualitative model of migration dynamics developed by Anthony (1990, 1997, 2007, pp. 102–120) describes spatial patterns, such as chain migration (leapfrogging), migration streams, and return migration, that may be part of Lévy flights.

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What is Biocultural Diversity? A Theoretical Review[1]

Michelle Cocks

Introduction

Over the past decade, scholars from various fields have increasingly emphasized the detrimental effects of global socioeconomic processes on biodiversity. The industrial revolution, the demographic explosion of *Homo sapiens*, and the rise of the global exchange economy are all implicated as major factors that influence the loss of species diversity. From the late 1980s onward, biosystematics and conservation biology have successfully brought this concern to the attention of the public. Biodiversity is increasingly recognized as an essential resource on which families, communities, and nations depend. Biologists, ecologists, and conservationists have further recognized that solutions to biological problems lie in the mechanisms of social, cultural, and economic systems, which has led to attempts to place a monetary value on species and ecosystems to calculate the cost of using and conserving biodiversity.

These approaches, however, often fail to take into account the various ways in which different groups of people make use of biodiversity (Posey 1999). Consequently, greater attention is now being paid to the relationship between biodiversity and human diversity because many of the planet's areas of highest biological diversity are inhabited by indigenous and traditional people, providing what the (Posey 1989) calls an "inextricable link" between biological and cultural diversity (Posey 1999). Although the term biocultural diversity is increasingly used to denote this link, there has been inadequate reflection on what precisely it refers to. There appear to be several misconceptions and inaccuracies in case studies of what might be termed "exotic" communities, which are remote and isolated (Posey 1999).

[1] The original article *Biocultural diversity: Moving Beyond the Realm of* "Indigenous" *and* "Local" *People* appeared in *Human Ecology* Vol. 34, no. 2, April 2006.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_5, © Springer Science+Business Media, LLC 2010

This review is structured in three parts: Firstly, in light of the manner in which the theory has been applied to date, I argue that key concepts, particularly the use of the terms "indigenous" and "local" people, need careful attention. Secondly, I demonstrate how the concept could be used beyond the realm of "indigenous" and "local" people. Finally, I discuss the implications of these extensions and evaluations on what constitutes a cultural value of the environment in terms of management strategies that can be used to promote the conservation of biocultural diversity in developing countries.

Interpretations of Biocultural Diversity

The Role of "Indigenous" and "Local" People

Biocultural diversity denotes the link between biodiversity and human diversity. Different cultures and peoples perceive and appreciate biodiversity in different ways. Most analyzes of the intricate relationship between conservation of biodiversity and cultural diversity are based on the claim that cultural diversity can sustain a wide variety of use practices and conservation of natural resources (Posey 1999; McNeely 2000). Examples of how "indigenous" and "local" people around the world have protected both individual trees and entire habitats have led to interest in linking biodiversity to human diversity. In many parts of the world natural features and habitats, often protected by religious taboos and considered sacred by community members, have survived due to strong cultural forces and today act as reservoirs of local biodiversity (Laird 1999). For example, the American Indian Menominee tribes have successfully held onto 100,000 ha of their native territory, almost all of which is still forested and contains the only significant concentration of old-growth tree stands in the now mostly deforested region of the upper mid-Western states (Groenfeldt 2003). These areas generally form part of the surrounding communities' ancestral domains and contribute towards their cultural identity. From a more general perspective, they contribute to a people's sense of place (Kusel 2001; Wiersum et al. 2004). For instance, the Menominee tribes have a spiritual relationship with their forest representing a twinned identity for both the tribe and the forest. Thus, "indigenous" and "local" are understood to ascribe symbolic significance to their surrounding landscapes and consequently perceive and value nature differently than ecologically trained conservationists and biologists (Posey 1999; Infield 2001).

The importance of recognizing traditional values of "indigenous" and "local" communities in forest and biodiversity conservation has been officially recognized by the Convention on Biological Diversity. Following this a UNESCO report states that "Sacred groves have served as important reservoirs of biodiversity, preserving unique species of trees, forest groves, mountains, rivers, caves, and temple sites and should continue to play an important role in the protection of particular ecosystems by local people" (Laird 1999, p. 352). In contrast, industrial societies draw on a wide range of ecosystems, and if supplies from the one source are exhausted or destroyed, they turn to another, and consequently are less likely to feel the need to protect any one resource or ecosystem (Milton 1996).

Although the notion of an "ecologically noble savage" has been challenged as overly romantic, many researchers and conservationists argue that numerous studies have proven how traditional ecological knowledge and practices have effectively served to protect and maintain natural environments (Posey 1999; Wiersum 2004; Berkes 2001; Cunningham 2001). However, the strong claims that indigenous and local people are by nature conservationists can be easily undermined by counter-examples – species extinction due to human hunting in the prehistoric past, indigenous people who grant large timber cutting or mining concessions on their lands, etc. Moreover, indigenous and local people themselves have a variety of reactions to these claims (Cunningham 2001, p. 6). More recent writings adopt a more pragmatic stance that stresses the practicality and urgency of coordinating local communities and conservationists. For example, Infield (2001, p. 801) argues that "promoting conservation in the context of local culture would endow protected areas with significance that an emphasis on biological diversity, landscape, or economies does not." The recognition of the close links between lifestyles of indigenous and local people and biodiversity is seen as crucial not only for the survival of biological diversity but sometimes also for the protection of cultural diversity by those who argue that the very same processes of global socioeconomic development that destroy biodiversity also cause local cultures to be swallowed up in the expansion of the global economy.

Moving Beyond the Realm of "Indigenous" and "Local" People

However, the definition of the term "indigenous" is itself problematic. Within the Convention on Biological Diversity the general consensus is that the term indigenous has been used to apply to people

> who have historical continuity with preinvasion and precolonial societies that have developed on their own territories, and who consider themselves distinct from other sectors of society now prevailing in those territories, or part of them. They form at present nondominant sectors of society and are determined to preserve, develop, and transmit to future generations their ancestral territories, their ethnic identity, as the basis of their continued existence as peoples, in accordance with their own cultural patterns, social institutions, and legal systems. (Posey 1999, p. 3)

Their modes of production and relations are typically subsistence and kin-based, respectively. As a result it is assumed that they demonstrate restraint in resource exploitation and show a respect for the environment that is characteristically reinforced by an animistic world view that regards the spirit world as infusing all of nature. Similarly, according to the International Union for the Conservation of Nature (http://www.iucn.org/themes/ceesp), local communities are

> commonly referred to as representing a socially and geographically defined group of people, not necessarily homogeneous, living close to natural resources and protected areas. These people may have customary rights of use, distinctive knowledge and skills, and direct dependency on natural resources as individuals or groups of individuals. They are also described as having a close and unique relationship to their natural resources as a community.

Willett in Posy (1999) stresses the need to avoid becoming side-tracked by who qualifies as "indigenous" or "local" as the task at hand is rather to rekindle and enhance the spiritual and cultural values that cultures have effectively used to conserve biodiversity. Despite these calls for caution, less consideration has been given to the cultural values of forests and resources for communities that cannot be considered as indigenous or local according to the above criteria, and whose lifestyles have been affected and transformed by modernization (Cocks and Wiersum 2003). As the classification currently stands it fails to incorporate large sectors of the global population.

At present rural conditions are changing rapidly in many tropical countries, and the livelihood strategies of local communities are diversifying and becoming increasingly integrated into a cash-based economy. However, despite the effects of rapid urbanization, increased westernization, and access to conventional western medicine and health care facilities, in southern Africa the use of traditional medicine remains high among urban black populations. The trade in traditional medicines has been described as greater now than at any time in the past (Cunningham 1991; Mander 1998; Dold and Cocks 2002), estimated to be worth approximately $44.4 (US) million per annum, and as meeting the demands of approximately 27 million indigenous consumers in South Africa. Nevertheless, the world views, cultural values, and knowledge of large sectors of the population in Africa can no longer be classified as "traditional" or as representative of western culture, even though many of these communities are still reliant on wild resources both for utilitarian and cultural needs. Unfortunately, the focus of biocultural diversity theory on the more "exotic" sectors of the population can potentially lead to the failure to comprehend the resilience, or rather the persistence, of culture and how the networks of globalization are often used to maintain aspects of cultural practices linked to the use of natural resources.

Extending the Significance of the Concept of Biocultural Diversity

For biocultural diversity theory to have relevance and applicability to communities other than indigenous or local, it is necessary to rethink two of its key components. The first is the meaning of the word culture. At present, biocultural diversity theory fails to take into account the multiple dimensions of culture, for example, how aspects of culture can be modified, adapted, and maintained despite changes a community might experience in its social and material context and its removal from precolonial residence areas. This is the result of a failure to acknowledge the resilience or persistence of certain dimensions of culture in the face of change, and the implications this might have for biocultural diversity.

Secondly, biocultural diversity theory makes repeated reference to the cultural functions and values of natural areas because the studies using the theory focus predominantly on areas such as sacred forests, rainmaking sites, landmarks, etc. (Posey 1999; Goebel et al. 2000). Cultural values are seldom extended to the resources harvested from natural areas and how these resources fulfill an important cultural value within the communities that utilize them. This is surprising in view of the fact that during the last decade there has been a greater focus on the role of forests and non-timber forest products (NTFPs) in fulfilling livelihood needs and affective needs such as a sense of belonging and identity (Douglas and Isherwood 1997). Recent studies have even demonstrated that urban-based community forestry arrangements in Europe provide a sense of place and belonging (Kusel 2001; Wiersum et al. 2004) thus illustrating that a nature-related sense of cultural identity remains applicable to modernized communities. A review of the concepts of culture and cultural value will show how this is possible.

Culture

The concept of culture is multidimensional. As noted above, it can be related to specific lifestyles and dominant modes of interaction with the natural environment, and to specific aspects of behavior, such as veneration of sacred forests. Traditionally the study of cultures was considered to be the specific domain of anthropology. But with the advent of interest in the cultural dimension of natural resource use, today the concept of culture forms the foundation of scientific disciplines such as ecological anthropology and scientific concepts such as biocultural diversity. In both cases, a basic premise is that the relationship between humans and their environments is mediated by culture (Laird 1999; Posey 1999; Berkes et al. 2000).

Despite growing interest in the cultural dimensions of natural resource use there is still no clear common agreement on what the concept of culture encompasses. Culture is commonly referred to as a system of values, beliefs, and ideas that social groups use in experiencing the world in mutually meaningful ways. As a primary starting point, this approach fails to stress that these systems are creations of the researcher and not of the people described (Rapport and Overing 2000). Furthermore, what researchers do not find are neatly bound and mutually exclusive bodies of thought and custom, perfectly shared by all who subscribe to them, and in which their lives and works are fully encapsulated (Ingold 2002). Thus, the definition of culture as an integrated system of values and beliefs fails to reflect culture as it is experienced. Groenfeldt provides an excellent example: “A Cherokee Indian medicine woman who lives in a solidly middle-class suburban community in Washington, DC has worked off and on in administrative jobs within the US Air Force, and has a growing clientele of mostly White Anglo patients with various physical and mental aliments. She heals by invoking spirit forces from the Cherokee pantheon and serving as a medium for their healing powers, as her grandmother taught her" (2003, p. 921). Clearly the medicine woman's religious world view is highly traditional, while her social and material cultural context is basically that of a mainstream American. Therefore, she is deliberately choosing from the cultural assemblage at her disposal. This approach to the concept of culture as a selective force has particular merit when trying to explain the phenomena that occur within societies where lifestyles have been affected and transformed by global processes and where livelihood strategies of communities have become diversified.

The argument for considering culture as a selective force rather than as an integrated system is supported by Canclini (1995), who argues that the dominant substitution–retention models of cultural change associated with modernization and dependency theory have tended to direct attention away from the critical and complex processes of "intercultural hybridization." This view is also illustrated in case studies from South Africa that describe "traditional" cultural practices and activities still present in communities that have experienced social, economic, and political upheaval as a result of the policies of the former apartheid government (Bank 2002; Cocks and Wiersum 2003). However, despite the onslaught of the apartheid regime and the ongoing impact of global economic change, cultural practices and activities have been recorded as taking on new forms, for example, women taking charge of certain rituals that had been largely men's responsibility in the past (Bank 2002), although what is of more interest here is the resurgent importance of these practices within their respective communities. It cannot be assumed that incorporation into an industrial environment results in the complete overturning and replacement of what existed before. It is clear that within the discourse of biocultural diversity theory culture needs to be recognized as dynamic and adaptable in response to change.

Cultural Values of the Natural Environment

If it is accepted that different and dynamic cultural perspectives are possible under the all-embracing umbrella of culture, the question then becomes how best to conceptualize cultural values in respect to the natural environment. Thus far, the cultural values of natural resources are often only related to components of the vegetation or fauna, e.g., forests as dwelling places for spirits, burial places for ancestors, sites for ritual ceremonies, and sacred natural features such as springs and caves. Case studies from South Africa, however, reveal that cultural values also relate to harvested wild resources. For example, wild resources play a significant role in the construction and maintenance of cultural artifacts within periurban households (Cocks et al. 2006). Vast qualities of woody material are collected annually by male members of the households for the maintenance of a kraal, often assumed to be merely a cattle enclosure, but in fact maintained foremost as a scared place for the male lineage of the homestead to communicate with their ancestral spirits and receive their blessings and protection. The maintenance of a kraal is also a visual display of the households' ethnic affiliation and the significance the occupants attach to their ancestral beliefs. Similarly female household members of *amaXhosa* communities maintain an *igoqo*, often considered a stockpile of fuelwood located within the homestead yard. It is, however, seldom used as such, but represents a woman's domain where her ancestral spirits reside.

These examples clearly indicate that cultural values of the natural environment may relate not only to the religious roles of forests but also to wild resources that are harvested for household use or traded with consumers living in periurban and urban communities. The fact that these practices are maintained in urban and resettlement areas demonstrates these cultural values are not restricted to traditional communities. Moreover, people do not have to live geographically close to the natural environment for it to hold spiritual, social, and cultural values for them. In southern Africa, migrant families frequently return to their ancestral lands to participate in cultural festivities and ceremonies involving wild resources (Wiersum and Shackleton 2005).

Implications for Biocultural Diversity Conservation in Developing Countries

I have argued here that the concept of culture must be understood as a dynamic process of transcultural exchange with constant rearticulations of tradition resulting in the persistence of certain cultural practices amongst any group of people. In developing countries traditional indigenous communities are changing (often rapidly) due to the impact of socioeconomic processes such as the increase in diversification of rural livelihoods and of rural and urban linkages. Notwithstanding, as the examples above have shown, even people who have migrated to urban or periurban areas and have become involved in modern economic sectors still to varying degrees maintain certain cultural practices, including the use of wild resources for maintaining a sense of well-being and identity. Thus, biocultural diversity theory should extend the terms "indigenous" and "local" people to include more varied social groups.

Several authors have noted that approaches to conserving biodiversity that are based on cultural and religious values are often more sustainable than those based only on legislation or regulation (McNeely 2000; Berkes 2001; Cunningham 2001; Infield 2001). The recognition of the role of value systems has greatly contributed towards the development of community-based natural resource management schemes (Fabricius et al. 2004). However, we need to be particularly wary of the uncritical assumption that indigenous resource use systems are inherently superior for sustainable use and preservation of plant and animal diversity. As noted by Redford (1990), Amazonian Indians have no cultural barriers to the adoption of techniques to "improve" their lifestyles even if the long-term sustainability of the resource base is threatened. Such improvement strategies might include the sale of timber and mining rights on indigenous lands, commercial exploitation of flora and fauna, and invitations to tourists to observe "traditional lifestyles," etc. This note of caution is of particular relevance to communities in developing countries which have undergone rapid social, economic, and political changes.

Interpretations of these observations are often taken as an indication that continued use of natural resources based on traditional cultural values cannot be maintained if traditional livelihood strategies are threatened due to socioeconomic dynamics and increased rates of commercialization. Well-known examples include the call for a halt on international trade of ivory and rhino horn, or the abolition of bush meat consumption in Central Africa. This indicates some ambiguity concerning the importance of biocultural values. On the one hand, the use of indigenous values and practices of traditional communities is often heralded as a means of biodiversity conservation. But on the other hand, the continued use of such values and practices under more modern conditions is often considered to be detrimental to biodiversity conservation.

It might be more useful to consider an alternative view taking the dynamics in biocultural values as a starting point for additional approaches towards community-based conservation. Such approaches should not only focus on preserving wilderness areas, but also on conserving locally valued biodiversity in agricultural landscapes. In this way, biocultural values could contribute towards the creation of diversified landscapes which transcend the accepted dichotomy between wilderness areas and cultivated fields. Within such landscapes, local people may purposefully conserve the biodiversity which they value. An example of such an approach is the recent effort to stimulate domestication of medicinal plants in South Africa. While procedures surrounding the collection of medicinal plants from the wild are an important dimension in their cultural use, observations of farmers experimenting with growing medicinal plants indicate that the cultural beliefs regarding the collection of medicinal plants in the wild are probably less resilient than the beliefs in their impact on personal well-being (Wiersum et al. 2006).

In developing countries it is of paramount importance that biodiversity conservation programs develop awareness campaigns that illustrate the link between cultural and biodiversity conservation as well as the diversity and dynamics of cultural values regarding biodiversity. Design of biodiversity conservation programs should accommodate the multitude of cultural values regarding biodiversity to newly emerging socioeconomic conditions. Local communities and individuals as well as outside conservationists need to be made aware not only of the link between the loss of natural habitat and cultural practices, but also of the options for incorporating cultural values held by non-traditional communities into novel approaches for biodiversity conservation. It is believed that the implementation of such educational campaigns would have far greater success than species-focused conservation approaches.

I therefore conclude that culturally conscious programs for conservation of biodiversity should pay attention to the links between the values of biodiversity and the cultural values within both indigenous communities and non-indigenous communities. My identification of a variety of cultural practices in the use of wild plant resources by people living under non-traditional conditions underlines the more theoretical argument that biocultural discourse must extend its present focus of "indigenous" people. This is necessary to ensure an increased understanding of the role of wild resources in the lives of users, as well as to identify new approaches to link the continuation of multifaceted cultural practices relating to the use of wild resources with biodiversity conservation.

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The Conservation Catch-22: Indigenous Peoples and Cultural Change[1]

Flora Lu

Introduction

Catch-22, the title of Joseph Heller's 1961 novel, has come to signify a paradoxical situation from which any apparent means of resolution leads inevitably back to the starting point – a "no win" situation. Often people concerned with biodiversity conservation ascribe conservationist ethics to societies with limited technology, subsistence levels of production, and low population densities relative to resources. Conversely, as these societies experience demographic growth, adopt modern technologies, and become increasingly involved in market economy, they come to be regarded as a threat to the ecological sustainability of their environments. This puts these populations in somewhat of a *Catch-22*. As we know from common property theory, when pressure on a resource is low due to few users, limited procurement technologies, and subsistence production, there is little incentive for the development of coordinated resource use behaviors that characterize conservation. In other words, the conditions under which people are seen as ecologically friendly from this viewpoint *are precisely the conditions where we would not expect conservation to develop*.

I argue here that conservation is not a state of being, but rather a social process inextricably linked to social and political institutions influencing resource management. Conservation awareness arises when people exert pressure on resources and recognize the potential for overexploitation – conditions concurrent with population growth, adoption of western technologies, and market production. I use the case of the Huaorani Indians of Ecuador's Amazon region to illustrate the conservation Catch-22.

[1] The original article *The Catch-22 of Conservation: Indigenous Peoples, Biologists, and Cultural Change* appeared in *Human Ecology* Vol. 33, No. 2, April 2005.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_6, © Springer Science+Business Media, LLC 2010

A Conservation Catch-22

Wilshusen et al. (2002) describe a "resurgent protectionist argument" among conservation biologists and ecologists who, in response to failures in people-oriented approaches in conservation, advocate a return to strict protection of ecological areas through a focus on protected areas and authoritarian enforcement practices. Of the five key elements of this argument that they identify as socially problematic, I focus specifically on the fourth: that "harmonious, ecologically friendly local communities are myths" (Wilshusen et al. 2002, p. 21). This view is nicely articulated by Oates (1999, p. 55):

> …there is little robust evidence that … "traditional" societies anywhere in the world… have been natural conservationists. On the contrary, wherever people have had the tools, techniques, and opportunities to exploit natural systems they have done so. This exploitation has typically been for maximum short-term yield without regard for sustainability; unless the numbers of people have been very low, or their harvesting techniques inefficient, such exploitation has usually led to marked resource depletion or species extinction.

Oates is correct to point out that there are few examples of people acting as "natural conservationists." This begs the question: what does it mean to practice "conservation," to be a "conservationist"? For some, conservation depends solely on characteristics such as consumption patterns, demographics, and contact with or insulation from forces such as the market economy. Alvard (1993, 1995) calls this "epiphenomenal conservation" stemming from an inability or lack of incentive to put significant use pressures on a resource, for instance when a population lacks sufficient storage, transport or processing capacity to make use of more than a fraction of available resources. While epiphenomenal conservation can result in low levels of resource exploitation, it is not resilient in the face of demographic increase, or economic, technological, cultural, or other sources of change. For his study of hunting among the Piro of Amazonian Peru, Alvard operationalizes "conservation" as hunting decisions that are costly in terms of short-term harvest rate maximization, yet increase the long-term sustainability of the harvest (1993, p. 358). By asking whether Piro hunters sacrifice present returns to foster the viability of game populations in the future, Alvard focuses attention on the intentional and behavioral aspects of conservation, in contrast to earlier studies which emphasized religious and ritualistic aspects. Studies of conservation need to marry both beliefs and behavior in examining people's relationship to the environment: people do not always act in accordance with norms and beliefs, and even if they do, they are not always successful in attaining the desired result. Alvard's use of optimal foraging theory as a null hypothesis to test whether the Piro hunt in a conservationist manner, although clever, is incomplete. People's resource related behaviors do not occur within a social vacuum.

Conservation and Common Property

Instead of trying to establish whether or not people are natural conservationists, efforts should be made to identify the conditions which foster conservation practices. Conservation practices comprise a set of social understandings and behavioral patterns that can emerge when there is agreement by a group of people to temper their resource use in the expectation that others will do the same. Wilshusen et al. (2002) point out that designating protected areas with fences and fortifying them with guards largely ignores the past and present decision-making, organizational, and governance processes that structure resource use within and among local communities. In other words, if we view conservation as inextricably linked to social and political institutions which influence resource management, then it is possible to move beyond the static perception of "natural conservationists" to a more accurate understanding of resource use regimes. In an examination of the social relations of property, resource use rules, and conceptions of ownership, a common property theory framework is invaluable.

The classic theory used to explain how local users relate to shared resources makes grim predictions about users' ability to avoid the "tragedy of the commons" (Hardin 1968). When there is a resource held in common by a group of people, such as a fishery, forest, or pasture, each individual user receives the full utility of extraction (e.g., the extra fish, timber, or head of cattle), while the costs of a degraded resource base are borne by all. Thus the rational course for each user is to keep extracting, and the tragedy is seen in the ruin of the resource. Policies based on the acceptance of this line of reasoning have advocated privatization of property or take-over by the state as means to create incentives for sustainable management.

This belief has been challenged by those who assert that the "tragedy of the commons" refers to open access, not common property regimes (e.g., McCay and Acheson 1987; Berkes et al. 1989; Ostrom 1990; McKean 1996; Ostrom et al. 2002). Instead of a free-for-all, common property regimes are structured ownership arrangements within which management rules are developed, group size is known and enforced, incentives exist for co-owners to follow the accepted institutional arrangements and sanctions work to ensure compliance. Such a social institution can promote ecological conservation by assuring that users coordinate and regulate use patterns, monitor and invest in the resource, and place limits on the numbers of legitimate users – all without having to parcel the resource into small units. Examples from across the globe of successful common property regimes demonstrate that conservation does not necessitate top-down approaches from the state or an international police force.

What are the requirements for such conservation-promoting institutions to emerge and function? Hames (1987) emphasizes three conditions under which conservation is likely to evolve: first, territoriality (defence of land and resource against those who may try to thwart conservation plans); second, mechanisms for dealing with cheaters (e.g., from social to supernatural sanctions); and stress on the resource base, made tangible through scarcity and/or increases in work effort, with significant repercussions for the user group such that conservation awareness emerges. Common property regimes that regulate resource use involve "transaction costs," e.g., efforts to reach consensus among members about needed actions, to monitor resource conditions, and to identify and punish cheaters. Thus, the implementation and maintenance of a functioning common property regime which will regulate resource use and promote conservation requires time and effort, and has to be deemed worthwhile. At a minimum, people need to recognize that a resource is becoming scarce, that their exploitation of the resource is having deleterious consequences, that the resource is of importance to their survival and well-being, and that they have the capability to regulate their use such that the overexploitation can be remedied. Thus, a sense of resource scarcity is a critical component for conservation.

The Huaorani Case

In Ecuador's Amazon region, the Huaorani Indians offer a lens through which to investigate some underlying assumptions about indigenous peoples and conservation. As one of the most "traditional" of the indigenous peoples in Ecuador, and arguably, the Amazon, the depiction of the Huaorani in publications (Kane 1996) and film (e.g., Walker, 1996, *Trinkets and Beads*) has captured the imagination of outsiders. It is not difficult to see why. Fiercely independent and protective of their territory, the Huaorani are known for spearing oil workers, missionaries, and *cohouri* (non-Huaorani) in general. It is this reputation for violence that gave the Huaorani command of a large territory. Yost estimates that in 1958, when sustained peaceful contact with missionaries began, about 500 Huaorani controlled a territory of 20,000 km^2, with a population density of 0.025 persons per square kilometer (1991, p. 99). With their raided metal tools, blowguns, spears, digging sticks, chambira nets and bags, the Huaorani obtained their sustenance from the forest and rivers. Living in autonomous *nanicaboiri* (long houses comprising close kin) they hunted game, fished, gathered forest products, and cultivated sweet manioc, plantain and other crops. Indeed, with their low densities, limited technology, and subsistence orientation, the Huaorani would appear to have been practicing sustainable resource use.

Having experienced generations with a large land base at their command, the Huaorani believe in an idea of the forest's bounty, of natural abundance. For the Huaorani, the natural environment is inextricable from the social environment. The peach palm (*Bactris gasipaes*) fruit feasted upon in the beginning of each year is one symbol of this natural abundance; each tree is associated with the relative who planted it, and their labors reinforce the notion of the environment as "giving" (Rival 1998). As one Huaorani man stated, "Here you live well, there is everything."

In two communities along the Shiripuno River with whom I have worked, the idea of natural abundance resonates. For example, when residents were asked what their children's standard of living will be in the future, responses were uniformly optimistic: the youth will have the same resources that people enjoy now. This is because Huaorani territory is so extensive, and because they take care of the trees and waterways. When asked to give their definition of "conservation," most people (14 of 17 heads of households interviewed) did not know. The three who gave a definition said: "to care for the trees so they live;" "to maintain the forest for children and grandchildren;" and "to have plenty to eat from the garden and the land." People shared their perception of the role of humans in the forest, which they see as intimately tied to using resources: "to serve yourself of the animals, fish, and resources to live, this is the role of humans…animals serve to eat and sell, rivers to bathe, drink, fish, and navigate…the role of humans is to live and eat animals…in the forest, find wood, in the river, find water, and in the forest, find materials to make crafts." In 1996–1997, when asked about resource use rules, the interviewees denied having set limits on hunting or fishing, or areas off limits to exploitation. In my study of the social relations of property and ownership among the Huaorani, I found that although they have a common property resource management regime, it is geared towards the clear delineation of social boundaries and ownership rather than promoting resource conservation (Lu 2001). However, it was not uncommon that institutions for managing the commons had their genesis in efforts to mitigate user conflicts rather than to promote resource sustainability, but these same institutions can provide experience and infrastructure that may be used to handle problems like overexploitation. Regimes developed to reduce user conflict and protect groups from potential competing users can essentially promote conservation as an unintended consequence. Although the Huaorani with whom I have worked deny having rules governing resource use, they are clear that this applies only to those *bona fide* members of the community (i.e., Huaorani residents and their Quichua kin by marriage), and that they need to "watch over the limits of the territory so that others don't steal what is for our children and grandchildren."

However, like many indigenous populations in Amazonia, the Huaorani are now experiencing population growth, adopting outside technologies, and are increasingly involved in the market economy. Following missionary contact, they have largely ceased practices of warfare and infanticide. Moreover, the introduction of modern medicines and the availability of aircraft to evacuate medical emergencies have contributed to an increase in Huaorani population in the past few decades, roughly estimated at an annual rate of 2.5% (they now number approximately 2000) (Lu 1999, p. 26) Demographic growth is not the only change. By 1991, oil extraction activities spanned nearly one million hectares in Ecuador's Amazon, including over 300 producing wells and 30 production camps, producing roughly 282,000 barrels of crude per day (Kimerling 1993). The resulting circumscription of land, along with increasing population density, development of market infrastructure, and the availability of wage labor opportunities have changed the Huaorani's economy and resource use. Today, the blowgun has been replaced by the shotgun, and households are engaging in the labor market through employment for oil companies and the sale of meat, handicrafts, and live animals (Holt et al. 2004).

Huaorani belief in natural plenty is starting to change in light of these developments. Their concerns were apparent in interviews conducted in 2001. As one man said, “There are many animals now, but when there’s a road, it will be difficult and the animals won’t return.” Besides roads, Huaorani informants cited the noise of gunshots and chainsaws as other causes which “drive animals away.” Some are adamantly against the oil companies and the damage they cause, from road building and illnesses to “rotten air, polluted rivers, and cars that kill animals.” Similarly, opinions about logging companies are negative: they damage the forest, the noise of the chainsaws drives away animals, they take fish and game from Huaorani territory, and leave locals with no cedar trees with which to build canoes. For most of these residents, the threat to the environment is external, not internal, but that is not always the case. When asked about the population of game still remaining in the forest, one man gave a response indicative of this changing perception about resource scarcity. He said, “Within the last 25 years the population has grown; now the community has become large. In 20 years game is going to become a little scarce. Peccary and monkeys are going to become hunted out a bit. Pacas and agouti are going to tolerate this pressure more. Trumpeters and guans are going to disappear more quickly.” His response indicates an awareness of hunting pressure resulting in changes in game abundance as well as a grasp of differences in various species’ ability to rebound.

Ironically, it is precisely when groups like the Huaorani are becoming more aware of the need for active conservation efforts that according to the protectionist view they become enemies of nature who have lost their “pristine” and “traditional” ways. Locals are caught in a conservation Catch-22. Western culture and all its trappings are considered both the problem and the solution, and as indigenous communities broaden their economic activities and technologies for survival in changing circumstances, this is taken as evidence they have lost their “natural conservationist” tendencies.

As Vickers states, “… ‘conservation’ is not a state of being. It is a response to people’s perceptions about the state of their environment and its resources, and a willingness to modify their behaviors to adjust to new realities” (1994, p. 331). Conservation develops as a result of experiences and learning, sparked by negative changes in resource characteristics which are accompanied by a belief in the possibility to remedy these changes and the presence of social and political institutions to do so.

Western Culture as Both Problem and Solution

According to Terborgh (1999), study after study shows that once a pre-modern society trades bows and arrows for firearms, and stone axes for chainsaws, the overexploitation of natural resources ensues. Such a view denies agency to indigenous people, making a deterministic prediction about technological change and not allowing for the possibility of another outcome – e.g., perhaps people hunt for less time with a more efficient technology, taking the same amount of game as before. Moreover, concomitant with the introduction of any new item into a culture, there is a dynamic process of learning and reconfiguring. Current scientific insights about minimum viable population sizes and habitat fragmentation are the result of learning from mistakes. As a society, we have established rules about the use of resources, implemented sanctions for non-compliance, developed governmental and non-governmental institutions, etc., but these have all been hard-won accomplishments. Terborgh calls for the scientific management of natural areas in this time of ecological crisis. He advocates "rational, scientific criteria" and "reason and objectivity," and grants priority to (western) scientists and their explanations and strategies for protecting biodiversity. However, these arguments for conservation leave little room for other cultures to learn for themselves and develop their own conservation institutions. It can be argued that this learning process is a luxury Earth simply cannot afford, given the extent of environmental degradation and the potency of current technologies; there simply is no time for indigenous cultures to develop a conservation consciousness. Following from this line of reasoning, I would argue to the contrary that efforts at conservation should use as many allies as possible, rather than discounting entire constituencies with strong vested interests in intact ecosystems.

Conservation biologists and others should work collaboratively with local communities to make a meaningful, concerted, and committed effort that involves more long-term timelines (on the order of a decade or two rather than a few-year funding cycle), nuanced understandings of inter- and intra-cultural diversity and indigenous knowledge (Brosius 1997), a recognition of the current reality of mixed subsistence and market economies, and participation of local people in meaningful decision-making, and clear definitions of the goals, methods, and measures for what constitutes "conservation." Not only is this model more likely to avoid social conflict and political instability than simply denying people access to their traditional lands, but, as Colchester (2000) points out, such collaboration based on a respect for indigenous self-determination also is in accordance with international law.

Conclusions

In Ecuador, the Huaorani were traditionally characterized as a small, highly dispersed and seminomadic population living at low densities, with social organization centered around extended kin groups autonomously producing for subsistence consumption and technology centered around blowguns, spears, and the occasional raided machete. Today, like many populations in Amazonia and elsewhere, they experience rapid population growth, adopting outside technologies (including firearms for hunting), and are increasingly involved in the market economy. For some professionals in the field of biodiversity conservation, the traditional patterns of Huaorani life were compatible with conservation, whereas their current situation places them at odds with goals of preserving the rainforest. Using a common property theory framework, I discuss how this viewpoint places the Huaorani and other indigenous groups in a "conservation Catch-22:" the conditions some biologists extol as compatible with conservation are precisely the ones in which we would *not* expect conservationist behaviors to emerge. Instead, the emergence of conservation practices *is* likely to occur in the current situation of increasing resource use pressure and increasing awareness of resource scarcity. In describing this conservation Catch-22, I highlight the value of approaching conservation as not a state of being but a social process involving experience and learning leading to the development of institutions and arrangements. Additionally, I call into question the usefulness of an approach in which western culture becomes both the problem – in corrupting the supposed "natural conservationism" of indigenous populations – and the solution – in designating and protecting areas from possible indigenous overexploitation. The purpose of this discussion is to emphasize the fundamental role that a social science perspective can play in illuminating the human context of conservation, a role that complements scientific insights into natural ecological systems.

Just as Terborgh argues for a moral imperative to protect nature (and not just a utilitarian or economic one), local communities ought to be included in the process of conservation not just because it is key long-term success, but also because it is morally correct. As Alcorn (1993, p. 426) states,

> …conservationists are acting as gatekeepers to a discussion table that does not have a place set for those whose homeland's future hangs in the balance…In the real world, conservation of forests and justice for biodiversity cannot be achieved until conservationists incorporate other peoples into their own moral universe and share indigenous peoples' goals of justice and recognition of human rights.

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Does Environmental Talk Equal Environmental Knowledge? An Example from Newfoundland[1]

Craig T. Palmer and Reed L. Wadley

Introduction

To paraphrase Roepstorff, composite concepts consisting of a catchy or value loaded first word such as local, indigenous, traditional, environmental followed by *knowledge* have recently become popular in the environmental literature (2000, p. 165). Indeed, the recognition of "the value of traditional knowledge of indigenous peoples, and particularly their traditional environmental knowledge [has] unleashed a flood of research" (Johnson 1992, p. v). This has been motivated in part by the possibility that such knowledge serves as a guide to better resource management (McGoodwin and Dyer 1994), combined with an awareness of "the erosion of indigenous knowledge (IK) systems" (Grenier 1998, p. 4) and of their potential use in securing resource tenure rights for marginalized peoples worldwide. Despite this recent surge in interest, the "concept of Traditional Environmental Knowledge or TEK [and similar acronyms] draws on two older traditions, namely ethnoscience and cultural ecology" (Neis et al. 1999, p. 217).

Local environmental knowledge (LEK) research is often built upon the unwarranted but implicit assumption that *talk* about the environment is the *expression of knowledge* about the environment. We question this assumption because (1) talk may or may not accurately correspond to the knowledge inside the speaker's mind, and (2) talk is a primary form of human communication designed to influence the receivers of such communication. We argue that two further acronyms will help draw explicit attention to this, perhaps fundamental, issue: first, LET – local environmental talk; and second, LES – local environmental skepticism, or more precisely skeptical statements local people make about what other local people say about the environment. Our approach here simply views talk about the environment

[1] The original article *Local Environmental Knowledge, Talk, and Skepticism: Using "LES" to Distinguish "LEK" from "LET" in Newfoundland* appeared in *Human Ecology* Vol. 35, No. 6, December 2007.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_7, © Springer Science+Business Media, LLC 2010

(LET), including making skeptical comments about what other people say about the environment (LES), as being one of the ways humans influence the behavior of other humans in order to solve sociopolitical problems linked with ecological conditions. The primary reason, however, for formally distinguishing LET from LEK, and for paying explicit attention to LES, is not the theoretical basis of the argument, but the simple fact that local people themselves do these things.

The Newfoundland Case Study

The Great Northern Peninsula of Newfoundland (GNP) was once home to the Beothuck and other aboriginal populations. It was also visited briefly by the Norse and used as a fishing area by the French before being populated by the British ancestors of current residents in the late eighteenth and early nineteenth centuries. Since that time, it has been a relatively isolated area relying primarily on marine resources (especially cod) and secondarily on lumber and mining. Many of the traditional patterns of culture and social interaction are on the basis of this ecological adaptation of domestic commodity fishing in an island environment (Palmer 1995; Palmer and Sinclair 1997). The semi-isolation of the area helped maintain distinctive traditional patterns of fixed gear fishing techniques, land inheritance, and other activities into the 1960s (Firestone 1967).

Traditional patterns of fishing started to change during the 1960s and 1970s with the introduction of new fish harvesting technology, particularly the use of draggers by a minority of the population. Further changes occurred with the decline in cod harvests in the late 1980s, at least partially because of overfishing (Felt and Sinclair 1995; Palmer 2003). The official closure of the commercial cod fishery in 1994 caused intensified competition for resources, especially within the dragger fleet because it now had to rely on various alternative species such as shrimp. Although some fixed gear and dragger fishers have managed to survive, the area has experienced significant out-migration because of the collapse of the cod fishery (Palmer and Sinclair 2000; Palmer 2003).Today the region includes several dozen villages with populations of several hundred people or less in addition to the slightly larger communities of Port au Choix and St. Anthony. Many of the remaining residents have turned to tourism to earn a living (Fife 2002, 2004a,b). Much of the difference between LET and LEK among residents is a combination of traditional styles of social interaction and the general sociopolitical context created by technological changes over the last several decades that have resulted in increased social stratification and depletion of marine resources.

Traditional Newfoundland Styles of Speech

The large amount of ethnographic fieldwork conducted in Newfoundland during the 1960s and 1970s focused mainly on the complexities and subtleties of traditional Newfoundland social interaction. This is perhaps best exemplified by the complicated and paradoxical ritual of “mumming” (also known as “mummering” or “Janneying”) where local residents would dress so as to disguise their identity and then visit a household in the community where they would engage in ritualized mock violence until the residents correctly identified them (Firestone 1978; Palmer 1992; Palmer and Pomianek 2007). Although not explicitly related to environmental knowledge, mumming serves as a potent reminder that human communication is far more complex than the simple assumption that talk is the expression of knowledge. With this in mind, we turn to some of the traditional forms of verbal interaction on the GNP and other areas of Newfoundland directly related to the relationship between LEK and LET.

Felt points out that on the GNP there is traditionally a general reticence to talk about one’s knowledge, and that “not to understand this runs the risk of confusing cultural rhetoric with ignorance” (1994, p. 261). Local residents are also traditionally reluctant to disagree with what other people, locals or researchers, say about the environment. Firestone (1967, p. 119) states that “individuals tend to agree with direct statements as a matter of course, and an attitude of consensus is most often overtly maintained – even though it is sure that this is not the case in actuality.” This traditional manner of verbal interaction is particularly significant for researchers assuming that LET is LEK whenever there is consensus (see Nadasday 1999; Atran et al. 2002). Similarly, Chiaramonte (1970, p. 15) reports that “throughout the monologues [about the environmental factors encountered on a hunting trip], no one would comment on what another said, even if one of the men in the group had been on the same hunting trip and knew the description was faulty. He might, however, speak to one of the listeners at another time, and voice his criticisms of the account.”

Faris (1966, p. 241) points out additional traditional styles of speech that are gender specific. While women engage in “gossip” men exchange “news.” While the potential discrepancy between gossip and knowledge is obvious, the same may be true of “news” about the environment. In regard to seal hunters and furriers during the 1830s, Faris quotes Jukes’ (1842) observation that “it seems to be a stain on a man’s character if on coming into a harbour he has not a budget of news; so that if he knows none, he immediately draws upon his imagination,” and then states that the same observation could be made at the time of his research in the 1960s. The full importance of this observation is made clear when Faris (1966, p. 237) adds that “there is very little verbal exchange save ‘gossip’ and ‘news.’ Learning [including learning about how to earn a living from the environment] in Cat Harbour is largely by way of observation, not conversation.”

Perhaps the most elaborate traditional Newfoundland form of speech is the “cuffer.” Faris (1966, p. 244) explains that to tell a cuffer is to “introduce some exaggeration or twist to an item of history or contemporary event in order to keep the conversation going.” For example, “humor is frequently used, as are ‘cuffers,’ or exaggerated stories told in competition with other fishers. As an example, [there is] the cuffer about setting fish nets anchored to icebergs, an unlikely practice” (Berkes 1999, pp. 45–46, citing Felt 1994, p. 259). As Sider (1986, 2003) has discussed, cuffers are complex forms of interaction that may be related to power relations within Newfoundland society. Cuffers are particularly important here because they often consist of exactly the type of LET so widely assumed to be LEK. For example, Sider (1986, p. 163) writes that cuffers are often about the environment, for example "the bounteous catches of fish and seals."

Local Environmental Skepticism and the Sociopolitical Environment of Newfoundland

It is crucial to realize that in Newfoundland all of these traditional forms of speech frequently mix with political reasons for LET to differ from LEK. Many of these political reasons are understandable only within the changing sociopolitical context of the area outlined above. The development of social stratification between draggers and fixed gear fishers followed by the collapse of the cod stocks and the blame for the collapse the fixed gear fishers attributed to the draggers have produced a situation where nearly all talk about the environment is politicized. Further, the realization of this fact by local residents means that LES is a pervasive part of LET. For example, during one interview with Palmer in 1990, an interviewee stated: "The big problem is dishonesty – no one ever tells the truth about what they know, what they do, and why they do things in the fishery." Several specific examples of LET and LES about the local environment recorded by Palmer between 1990 and 2005 will illustrate our central argument. These statements are from various structured and semistructured interviews and participant observation during fieldwork.

Does Cod Spawn During Winter Fishery?

As described above, the draggers are in general highly controversial because of the view that they are responsible for the collapse of the cod stocks. During the 1980s and early 1990s, the draggers' winter fishery off the southwest corner of Newfoundland was a particularly frequent object of criticism because the draggers caught a great deal of cod there. The winter fishery was also regularly criticized by fixed gear fishers for being particularly ecologically disastrous because, they asserted, it disrupted the spawning of cod. During the early 1990s, the LET of fixed gear fishers concerning this issue consisted of statements such as:

> Yes [the cod spawns during the winter fishery]. They [dragger fishers] had to shovel the spawn off the decks. . . . And at the same time then, the deputy minister in Ottawa comes out and says we got no scientific evidence to suggest that [cod spawns during the winter fishery]. . . .You know, that's a pretty stupid remark. (fixed gear fisher, 1990)

Not surprisingly, dragger fishers responded to this kind of LET by fixed gear fishers by engaging in LES that often included the assertion that fixed gear fishers had a political motive behind their LET:

> All I know is I've never seen spawn in the winter. That's just something the fixed gear fishermen came up with to blame the draggers [for the decline in the cod stocks]. (dragger fisher, 1990)

Are Seals to Blame?

Throughout the period of fieldwork (1990–2005), another highly politicized subject of LET has been the role of harp seals in the depletion of the cod stocks. This usually takes the form of asserting that the cessation of the large-scale seal hunts due to international protests during the 1970s (Patey 1990) led to a huge increase in the number of harp seals during the time that the cod stocks declined. When this argument was combined with the assumption that seals are major predators of cod, an increasing number of seals became a possible cause of the decline of cod. Thus, the decline of the cod stocks can be blamed on an increased number of seals rather than overfishing by the draggers.

Predictably, the LET of many fixed gear fishers is that seals are *not* more plentiful now than they were in the past when cod were abundant. For example, one fixed gear fisher stated: “No, you don’t see seals now, not like in the old days” (fixed gear fisher, 1991). Then, in agreement with this answer, a second fixed gear fisher said, “Yes boy, the seals [in the old days], well my son, you used to have to push seals out of your way just to get to your cod trap.” This LET is an example of a combination of current political concerns and traditional cuffer-like exaggeration. The LET of fixed gear fishers also often includes LES about assertions that seals are a major predator of cod: “Now the draggers, they’ll tell you it’s the seals destroying the cod, but I heard the scientists say seals don’t eat much [cod]” (fixed gear fisher, 1991). In some cases, these LET and LES again take on a cuffer-like form:

> No, you hear this stuff about the seals eating the cod and all this you know but [it is] political bull as far as I’m concerned. When John Cabot came over, a little over five hundred years ago, according to my information that I got, there was cod then. He had a job to get into shore they say. . . The boat going on the cod. Now, that’s the story. . . . And I haven’t heard anyone say that there was no seals at that time. . . . To blame seals for the destruction in the cod stock is nothing more than political bull. (fixed gear fisher, 1991)

Again predictably, such statements are in stark contrast to the LET of many dragger fishers when describing the diet of seals: “Well my son, they don’t eat turnips!” (dragger fisher, 1991). The LET of dragger fishers on this topic would also include LES about the LET of fixed gear fishers: “Well, I can tell you what most people are telling you [about what destroyed the fishery]: the draggers. But it’s actually . . . [the] seals and whales that have reduced the stock. We need to educate people that it’s not just the draggers” (dragger fisher, 1992).

Are Shrimp Small?

The above examples of both LET and LES could be anticipated by anyone knowing only the general outline and history of the sociopolitical conflict between dragger fishers and fixed gear fishers in the area. However, an understanding of other LET requires a more detailed knowledge of the local sociopolitical context. Although the categories of dragger fisher and fixed gear fisher formed a large part of the cultural identity of Newfoundland fishers during the study period, there were many other aspects of cultural identity that influenced what any given individual might say about the environment in a certain situation. In addition to the typical sociocultural variables of age, gender, class, and religion, fishery related divisions within the categories of dragger fisher and fixed gear fisher were also of paramount importance in some cases.

In the following example, despite several years of participant observation in the fishery, Palmer had to have the reason for LES explained to him. As noted, the closure of the cod fishery in 1994 meant that most dragger fishers had to rely on the shrimp fishery (see Palmer and Sinclair 1996, 2002). When they brought their first catches of shrimp to the processing plants, many dragger fishers were very distraught to hear that the shrimp were too small and that the shrimp fishery would have to be delayed until larger shrimp were brought in. There were even rumors that the shrimp fishery for that year would be canceled all together. There was considerable variation in the LET concerning the size of shrimp. Several female fish plant workers told Palmer that the shrimp were indeed unusually small: "Small, well my dear, sea lice! That's what I call 'em" (fish plant worker, 1994). Fish plant workers also engaged in LES about the LET of some dragger fishers: "The sensible fishermen say it's small, but others say it's not" (fish plant worker, 1994). Some fish plant workers also suggested that Palmer should engage in LES if, in the future, he heard fish plant workers saying that the shrimp was no longer small: "Well [a certain fish plant worker] is in trouble with [her boss] for saying this catch is just a little bigger than the first batch. Since [her boss] wants them to go fishing he wants her to say the shrimp was huge!" (fish plant worker, 1994).

The most interesting pattern of LET occurred in the conflicting statements by the dragger fishers from different areas of the coast – the area around Port au Choix and the communities along the Strait of Belle Isle. The LET of dragger fishers from the former tended to be similar to the LET of fish plant workers: "Yes, its small, the smallest I've ever seen!" (Port au Choix dragger, 1994). However, the LET of dragger fishers from the Strait of Belle Isle was very different:

> I heard the shrimp was small but the ones we brought home seem normal. (Strait of Belle Isle dragger fisher, 1994)

> The shrimp is not that much smaller than normal. (Strait of Belle Isle dragger fisher, 1994)

> Well, it was small last year [and they still bought it]. (Strait of Belle Isle dragger fisher, 1994)

When Palmer asked a dragger skipper from the Strait of Belle Isle why the LET of dragger fishers from his area was so different from that of the dragger fishers from Port au Choix, he provided an answer that illustrates the potential complexity of LET, LEK, and LES:

> The Port au Choix boats are mainly paid off, see? Therefore, they want to force the other shrimpers out of business by messing up the shrimp fishery. That's why they are the ones saying the shrimp are small . . . and the government, they want that too, so they go along. (Strait of Belle Isle, dragger fisher)

Such internal divisions within the dragger fisher and fixed gear fisher categories also influenced LET regarding other fishery issues such as the need for the closure of the fishery in the early 1990s and the overall state of the cod stocks (see Palmer and Sinclair 1997).

The importance of using LES to help distinguish LET from LEK might be limited if LES was restricted to verbal interactions in informal settings and interviews on topics broader than LEK *per se,* such as the above examples, and thus absent from formal interviews focused explicitly on LEK. Not only was that not the case in Newfoundland, but there was also an almost ritualized reference to the possibility that LET would not be equivalent to LEK in formal interviews. The following quotes are typical:

> So do you want me to separate out the truth from the lies? (dragger fisher, 1990)

> Now that the interview is over I can stop telling lies. (retired fixed gear fisher, 2000)

> So what are the rest of them telling you? (dragger fisher, 1994)

> Well now I know what others been telling you, but I'm going to tell you the truth. (fixed gear fisher, 1990)

> I'm not going to say anything about cod because I don't want to say anything to make anybody mad. (fixed gear fisher, 1990)

> I knows that [what ruined the fishery], but I run a small business, see? So I can't say what I knows. (ex-fixed gear fisher, 2005)

> Now I knows just what my husband knows, so what did he say? (wife of ex-fixed gear fisher, 2005)

These quotes suggest that using LES to help distinguish LET from LEK is just as important in formal interviews explicitly concerning LEK as it is in more informal observations.

Finally, as the examples provided above illustrate, there are many reasons for LES. Much of the LES in the previous examples is on the basis of the assumption by local people that other local people will be motivated by economic self-interest when talking about the environment. Other reasons for LES include assumptions about personality characteristics of certain individuals (i.e., individuals who are not "sensible") and the assumption that an individual lacks the necessary experience with the aspect of the environment under discussion (e.g., the abundance of seals). Perhaps the most interesting reason for LES is the view that LET based upon the statements of scientists is suspect because scientists are assumed to be either untrustworthy or lacking in knowledge (e.g., scientists make "stupid" remarks). In the study area, much of this skepticism of local people about the statements of fishery scientists is due to fishers feeling that their own knowledge has been "neglected" by scientists in the past (Neis and Kean 2003, p. 69). Attempting to correct this situation is one of the reasons for the abundance of recent LEK research in Newfoundland. Thus, the statements of LEK researchers, both in their interviews with local residents and in their scientific writings, must also be seen as LET that takes place within a complex sociopolitical environment.

Conclusion

We fully recognize that we are not the first to raise the points stressed in this paper. Fischer (2000, p. 42), for example, states "a thorough appraisal of the interests of fishing people and related risks to the provision of reliable information should be performed before data are taken." Our position is also consistent with the more general position that there has been "too much emphasis on an approach that privileges linguistic means of knowing and ordering, even to the point of considering them the only ones. Thus, naturalistic knowledge seems to be overly reduced to the operations of naming, classifying, and categorizing" (Angioni 2004, p. 243). We also agree that, in addition to studying LES and using it to distinguish LET from LEK, it is important to focus on nonverbal behavior as an indication of knowledge. Palsson (2000, p. 30) illustrates this point nicely by stressing that successful navigation requires more perceptions than could possibly be put into words.

However, we argue that these points and their implications for the study of LEK have not been fully appreciated. Instead, the difference between LET and LEK has been little more than a footnote in the overall literature on LEK. Indeed, our main point is essentially summed up in a footnote by Faris (1966). In regard to his description of the chronic inaccuracy of "news" in Newfoundland communities, he notes that "there is always room for more speculation [about the environment] – which of course, may be preferred to the 'facts' . . . Government officials introducing programs in the outport should keep this in mind" (Faris 1966, p. 242).

This does not mean that researchers should ignore what is said by local residents regarding their environment. It only means that the study of LEK should "focus on persons in lived situations, rather than discourse" (Wikan 1992, p. 460) removed from the sociopolitical context of human existence. That is, the study of LEK should take into consideration the entire knowledge of local people, the social dimensions of which are much deeper and more complex than assumed when researchers merely record LET as the expression of LEK. This complex view of the environmental *and social* knowledge possessed by all humans is exemplified nicely by Gerald Sider's caption for a photo of a Newfoundland "mummer":

> A Newfoundland mummer . . . A village fisherman who is famous for the number of songs he knows. . . . When folklorists come to record him, he always leaves a verse or two out of each song for the songs are his, and a part of who he is. He is a good fisherman, an exceptional hunter, and an extraordinary master of local wisdom, who husbands his skills carefully, choosing whom to take hunting and how he uses his knowledge. (Sider 2003:179)

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Section II
Dynamics of Local Food Procurement Systems

Section Overview

With exception of the first two chapters, all the studies in this collection address some aspect of the dynamics of local food production. The five chapters selected here are chosen not to illustrate what are usually termed "modes of production" but rather to draw attention to important issues faced by people who are producing or procuring food. We will elaborate further below, but briefly: Stiner and Kuhn, archeologists, document a much overlooked dynamic, namely that for at least the last 500,000 years hominids have been a permanent presence over most of the globe that and have historically heavily impacted their habitats and continue to do so. Bird, Bird, and Parker, working with a foraging population in Western Australia, examine how even without relying on a market economy, people they manage common property and build incentives for individuals to invest in delayed returns and to defend community control of resources. Yasuoka, a Japanese ethnologist with a formidable talent for collecting detailed dietary data, documents how foragers can build a solid nutritional base using widely dispersed food sources as long as they can manage a key species – in this case, wild yams in the Congo Basin of Cameroon. Boyd, building on long field experience, demonstrates how people make decisions at the individual level which can change, against all expectations, the fundamentals of land use and animal husbandry. Norwegian geographers Pedersen and Benjaminsen describe some of the organizational imperatives that select for specialization in food production in the Sahel, and show that attempts to combine specialized farming with animal husbandry (a strategy frequently advocated by international aid agencies; see also Fratkin et al. 2004) generally fail to provide improved food security.

Clearly, human ecological research focuses on a wide range of issues and problems – population dynamics, health, nutrition, sustainable production, and risk management to name a few. But with the exception of urban studies, most involve seeing human decision-making and behavior in a context in which the major parameters are set by food procurement concerns. When ecologists note, in only semi-jest, that "you are what you eat," they mean that the sources, variety, and reliability of foods used by a population are critical to its maintenance. While food production practices vary hugely throughout the world, it is possible to identify some common, although not exclusive, sources of important production variables. One cannot assign an a priori order of significance as this depends entirely on context.

1. The extent to which domesticated crops and animals are utilized as opposed to nondomesticates, which greatly influences the deployment of labor and the significance of seasonality.
2. The degree of spatial mobility required to secure resources and procure food.
3. The accessibility of external and internal energy and material inputs including, very importantly, water.
4. The organization, relative importance and costs of human labor, animal traction, and mechanized processing.
5. The nature of storage technology.
6. The form and degree of market integration and the role of external political institutions in determining local production.

In considering these factors it is common to use various groupings or typologies, such as irrigated versus dry farming, tropical forest and savannah-based swidden or slash and burn agriculture, various forms of specialized animal husbandry, market-centered production as opposed to household directed or "peasant" farming, small-scale versus industrialized agriculture. Here, we present a familiar short typology of procurement strategies that is widely used in anthropology, cultural geography, and environmental sociology:

- *Hunting and gathering*: the collection of wild vegetable foods, hunting of game, and fishing, generally assumed to be the mainstay of hominids until the Old and New World Neolithic periods, about 12,000 years B.P. and 10,000 years B.P., respectively. This involves, in most instances, a high degree of spatial mobility and, until more recently, a high degree of local self sufficiency. While it used to be assumed that such procurement systems had limited environmental impacts due to limited storage technology, it is now recognized that this is not the case.
- *Horticulture*: a simple form of agriculture (sometimes called extensive agriculture, long fallow agriculture, swidden, or slash and burn) based on the working of small plots of land without much reliance on draft animals, plows, or irrigation. In contrast to hunters and gatherers, horticulturists produce food by managing domesticated plants and animals and, in comparison with most foragers, maintain larger, more permanent settlements and higher population densities. Today horticulture is associated with tropical zones, although historically is was also practiced in temperate zones. With very few exceptions, such farming is closely integrated into market economies.
- *Pastoralism*: an economy based on herding livestock. Pastoralists maintain herds of animals and use their products and by-products (milk, curds, whey, butterfat, meat, blood, hides, and bones) both to maintain themselves directly and to utilize in exchange with other, carbohydrate-producing populations. The nature of animal production includes the potential, if not the necessity, for a high degree of mobility, an inherent capacity for rapid growth in capital as well as high risk of decline. Specialized pastoralism may have developed in tandem with agricultural

intensification since most pastoralist diets are grain based (the Masaii of East Africa being a major exception).

- *Intensive agriculture*: a form of agriculture that involves the use of draft animals or tractors, plows, and often some form of irrigation. Intensive agriculture produces far greater yields per acre of land, although labor requirements may be very high. Settlement size and population densities are also high and intensive agriculture is universally associated with high levels of market integration and political centralization. Markets effectively increase local storage capabilities exponentially, thus increasing the value of production in excess of immediate household needs.
- *Industrial agriculture*: food production and manufacturing through the use of machines powered largely by fossil fuels and today often focused on commodity production with a global reach. The actual owners or controllers of production are usually at a remove from the land itself, a fact that frequently has implications for long-term sustainability.

The attraction of typologies of this sort is that they draw attention to globally shared features; for example, foragers often do experience similar problems, as do people practicing large animal husbandry in arid zones, or tropical forest horticulturalists. While conceptually tidy and seemingly offering a rough fit with historical progression from a total reliance on nondomesticates to the industrial food production practices of today, our typology can be misleading for a number of reasons. Most communities, let alone regions or local populations, do not fall neatly into one or another of these patterns; people typically combine several food procurement methods and frequently alter them. As during the politically induced famine in the Ukraine in the 1920s or in many regions of the Caucasus and Central Asia following the collapse of the Soviet Union in 1991, people may appear to have reverted to a "domestic mode" of production geared at self-sufficiency, leaving fields uncultivated and labor underutilized, whereas in reality they are simply coping with lost market connections. Researchers today find an "actor-oriented" perspective more productive than dealing with social or economic categories. Our typology also may obscure the degree to which people actually shape their habitats: foragers or hunter–gatherers in precolonial Australia may have actually invested more labor and skill in shaping their landscapes through fire management, selective hunting and harvesting practices, and water diversion than agriculturalists in many other parts of the world (see Bird et al., this volume). Horticultural production, generally regarded as small-scale, may entail more labor inputs than what is often described as intensive farming. The perhaps misleadingly termed "blue revolution" has led to more fish being farmed than are caught in the wild, with increasingly dubious environmental impacts. And the return of home gardening in industrial societies highlights growing concerns at the costs, both financial and environmental, of food transportation, and a new emphasis on local production and consumption.

However diverse the strategies employed in food production, people have to contend with some of the same basic challenges. Within any localized system, some resources needed to sustain the population are less abundant than others. Those which are least abundant (most notably water) establish the limits to the growth and/or dispersal of a population – sometimes called Liebig's law of the minimum. As a consequence, a large number of historically discrete populations share quite similar settlement patterns; for example, seasons of settlement nucleation followed by dispersal in search of water, grazing, game, or other resources. Resource fluctuation is a major problem almost everywhere: rainfall may deviate from expected patterns or arrive sooner or later than anticipated by planting schedules. A harsh winter may decimate livestock or lead to a shortened growing season. Producers usually have to "hedge" against a number of possible threats usually by diversification of livelihood strategies, for example, keeping livestock in addition to farming, storage, trading partnerships, and social alliances (sometimes called social storage), and "backup" strategies such as preparing for rapid movement and resettlement, venturing into raiding or crime[1], selling household labor, or even shedding members. International waves of "illegal" migration are partially the result of households having too many mouths to feed. Finally, whatever the mode of production, members of every population must adjust to the presence and activities of neighboring peoples, be they cooperative or aggressively competitive. Often, the outcomes of such relationships have to be looked at on a global level, as even production at a subsistence level often requires inputs from distant sources or sales to distant markets; not to mention the fact that local resources themselves may be owned by corporations based outside the district, and frequently even outside the country or the continent.

Turning once more to the five chapters in this section, Mary C. Stiner and Steven L. Kuhn take a long perspective in showing how Paleolithic societies in the Mediterranean Basin changed their social organization and their habitat. It is now understood that foraging or hunting populations profoundly affect their habitats, perhaps as much in terms of total landscape architecture as preindustrial farmers. Stiner and Kuhn conclude from their archeological analysis of the long Paleolithic period in Europe and the Mediterranean Basin that this may also true for early *Homo*. Hominids established a permanent presence in northern habitats by 500,000 years ago. This adaptive radiation required specific technological and economic prerequisites such as, probably crucially, fire (see also Wrangham 2009). But these early populations also had to survive long Eurasian winters, when foraged food is limited or difficult to gather and process, and to do that their biggest challenge was to cooperate in hunting the large animals necessary for survival. The long archeological record they examine here indicates long-term adaptive changes by humans as they cope with their own impact on the prey populations by shifting hunting strategies from large animals to small game and increased foraging approaching the Neolithic period, when the shift to agriculture dramatically changed the cultural and physical landscape. The focus here, as in the study of contemporary populations, is on demographic changes, niche shifts, dietary and nutritional issues, and intraspecific competition and conflict as modern humans replaced earlier hominid populations. Our modern ecological crises, the authors suggest, have roots in the

[1]For example, the current spate of piracy by Somali fishermen who claim their livelihoods have been negatively impacted by commercial fishing fleets operating in their traditional fishing grounds.

ancient history of foragers. The methods and models employed here include optimal foraging assumptions and systems processes, such as positive feedback relationships which may affect predator–prey interactions, ecological resilience and stability.

As with many field studies, the one carried out by Douglas W. Bird, Rebecca Bliege Bird, and Christopher H. Parker in the Western Desert of Australia is rich in insight at more than one level. Primarily, they field test the popular hypothesis that Aboriginal cultural knowledge and use of fire functions to increase the efficiency of hunting large, highly mobile prey. It is widely held that during the 45,000 years of human activity in Australia, human-managed fire played a central role in that continent's biodiversity. This study attempts provide an explanation of aboriginal burning practices without simply assuming that they are part of long-term habitat maintenance. In addition to a fine-grained analysis of observations of 422 forager days among the Martu documenting their burning, hunting, and foraging activities, the authors delve into the larger realms of land management, collective action, future discounting, and the ever bothersome problem of freeloading. The crux is how to account for collective actions where the costs, for example, here the effort required for systematic burning, are borne individually but the benefits are shared more widely. They also address the issue of an individual's incentive to invest in a future benefit that he or she may never fully realize. In other words, precisely the central issues of the current global economic crisis and much disputed "bailouts" for nonperforming banks and industries are very visible shapers of decisions at the local group level here. We will return to the issues of common property management and conservation in later sections, but this study provides insights into how sex and gender roles affect motivation, how access and rewards are structured, and offers a graphic look at how a potentially marginalized population decided to retain community control of their own territory and how they went about it.

Hirokazu Yasuoka also looks at a population which, until recently at least, were hunter–gatherers in the Congo Basin, and who still incorporate a great deal of foraging and hunting into their annual round of food procurement activities. Given the millennia of human existence as hunter–gatherers, it is understandable that populations pursuing this now disappearing way of life have been somewhat over-represented in the research literature. Still, the question persists of how representative present-day hunter–gathers may be of prehistoric societies, since all are affected and usually marginalized by the influences of industrial socioeconomic systems. The San of the Kalahari have been used to model prehistoric societies of the African Savanna, but a major question has been whether or not foragers could fully exploit the world's vast tropical forests without access to at least Neolithic levels of agricultural production. Yasuoka's study, while not attempting to conclusively settle this issue, does show that foragers in the Cameroon region of the Congo Basin can survive the difficult dry season by utilizing a key species of wild yam. The unique accomplishment of this study is the fine attention to nutritional detail as Yasuoka accompanied a long-term foraging expedition (*molongo*) by members of a Baka village. While exciting data in themselves, this study still leaves open the larger question of to what extent the composition of the Congo Basin rainforest and adjacent savanna is the result of human activities, including a long history of cultivation.

One hallmark of ecological field research by anthropologists and geographers in general is that the researcher and members of the study population develop close relationships, often spanning generations. David Boyd has had more than 30 years experience with the Papua New Guinea people he describes here and close academic relationships with some of the pioneers of ecological study in anthropology, notably S. Lindenbaum, R. A. Rappaport, and A.P. Vayda. Highland societies in New Guinea have practiced various forms of subsistence horticulture or gardening in conjunction with domestic pig husbandry for at least 6,000 years and possibly for as long as 9,000 years. The social and ceremonial aspects of pig feasts and pig meat exchange systems are as much studied as the direct utilitarian value of the animals as a source of protein in a diet based mainly on carbohydrates. In short, pigs could be seen as a "keystone species" either in the biological sense of a population which has profound impacts on the structure of other species in an ecosystem or as a cultural complex central to a host of other institutions and behaviors. So it was something of a surprise to Boyd when young Irakia Awa men told him in the 1980s that they were actively planning to do away with village pigs altogether. Under the influence of Christian missionary activities in the region as well as time spent as wage laborers on the coast, they wanted a total break with the past in order to revitalize their community. Illustrated in this case is something that is often overlooked in environments of centrally planned change: individuals can and often do undertake radical changes in how they manage their subsistence production. Human adaptations are inherently subject to rapid change no matter how conservative they may appear at any given time. This illuminating case study also illustrates how outside ideologies, here Christian religious belief, can play a major role in shaping important local changes.

Arid zone nomadic pastoralism may well be the most highly specialized mode of food production to have developed following the Neolithic. With very few exceptions, nomadic herders rely for the bulk of their diet on carbohydrates, specifically grains, which they acquire through trade or tribute from settled agriculturalists. In many respects, as Jon Pedersen and Tor A. Benjaminsen suggest, animal husbandry is the underestimated (and undervalued) component of economies in the Sahel region of Africa. The ambivalent attitude of local and national authorities towards nomadic populations is understandable. Not only throughout Africa north of the equator, but in the vast arid reaches of the Middle East and Central Asia, armed and mobile groups can and historically often did threaten central regimes, raid neighboring populations for plunder and slaves, and seek control of transcontinental trade routes. Less understandable is the almost knee-jerk reaction of international development agencies which regard the settlement of nomadic peoples as key to economic diversification and hence improved food security and better health. This research carried out among the Tuareg of northern Mali found those Tuareg who persisted with their nomadic lifestyle enjoyed both better nutrition and better food security and health than their settled counterparts. Labor is a scarce resource, as studies of pastoralists elsewhere have consistently shown. This study is unusual in its detailing of the overall social division of labor among the Tuareg and its examination of the individual household as a unit of production. Pedersen and Benjaminsen's analysis details how the organization of labor within and among the hierarchically organized Tuareg households is critical to subsistence production, and makes it very inefficient for households to combine both herding and effective cultivation. In fact, they show that the diversification invariably advocated by development agents not only does not yield greater food security, but also frequently contributes to *decreased* food security and thus poorer health.

Tracking the Carbon Footprint of Paleolithic Societies in Mediterranean Ecosystems[1]

Mary C. Stiner and Steven L. Kuhn

Introduction

There can be no question that the rise of agricultural economies some 10,000 years ago redefined humans' relationship with nature. Such economies greatly amplified the potential of human cultural behavior to reshape ecosystems. Yet the earliest demonstrable impacts of humans on animal and plant communities – and on the nature and resilience of coupled human and natural systems – are traceable to Upper Paleolithic hunter-gatherers some 45,000 years ago or earlier (Tchernov 1992b) (Fig. 1). Sometime during the late Pleistocene epoch, more or less concomitant with the spread of anatomically modern *Homo sapiens* beyond Africa and the Levant, we see the evolution of novel technological and social mechanisms for buffering or redistributing environmental risk. These developments have resulted in permanent changes in human demographic potentials and the carrying capacities of a wide variety of habitats throughout Eurasia. Even quite early in this period, there is evidence that human foragers affected the relative abundance of prey species and biotic community composition more generally.

This paper reviews evidence for fundamental changes in the ecology of early humans and human ancestors in Eurasia through the end of the Pleistocene geological epoch (Table 1). Direct evidence from food debris and artifacts found in archeological sites and indirect evidence pertaining to habitat diversity, demography, and rates of culture change point to several watershed transitions in hominid–environment relations. Some of the most important shifts involved movement into, and then out of, a rather specialized form of big-game predation. With the appearance of Upper

[1] The original article *Changes in the 'Connectedness' and Resilience of Paleolithic Societies in Mediterranean Ecosystems* appeared in *Human Ecology* Vol. 34, No. 5, October 2006.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_8, © Springer Science+Business Media, LLC 2010

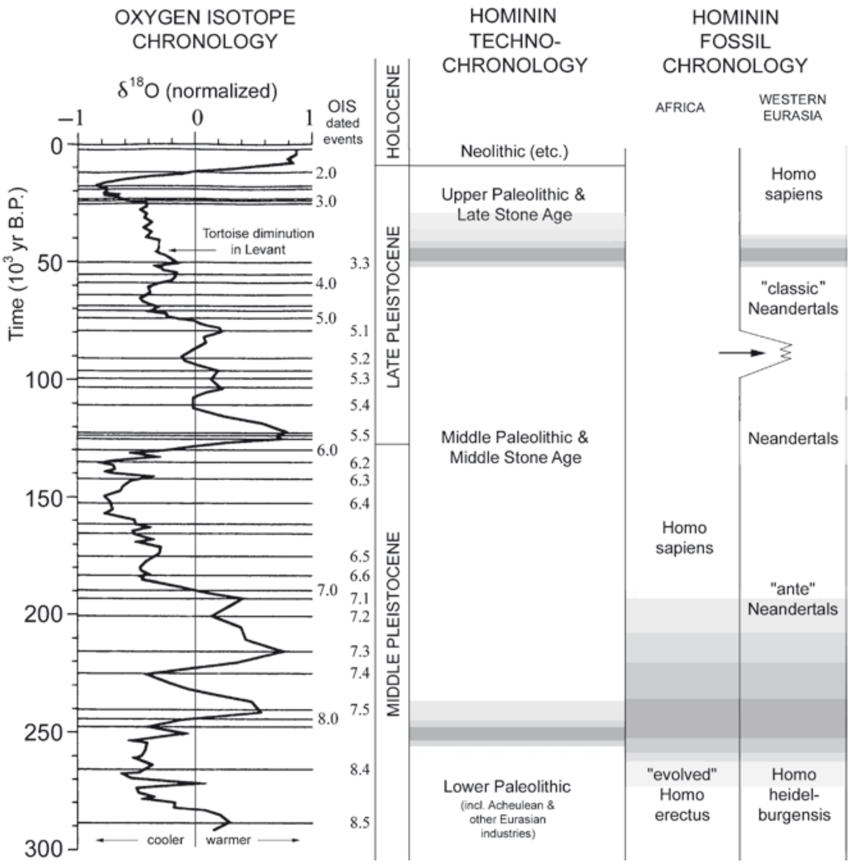

Fig. 1 Pleistocene human cultural and biological chronology together with oxygen isotope chronology indicating global temperature changes

Table 1 General chronology of Paleolithic cultures in Eurasia

Paleolithic culture period	Duration
Neolithic	10 KYA or later, depending on region
Epi-Paleolithic/Mesolithic	20–10 KYA
Upper Paleolithic	50–35–20 KYA (earliest in Levant, closest to African continent)
Middle Paleolithic	250–30 KYA
Lower Paleolithic	2,600–250 KYA

Note: (KYA) thousand years ago

Paleolithic cultures, the very rules of the game seem to have changed. This more recent set of behavioral and ecological transitions was due largely to changes in the degrees of “connectedness” within human behavioral systems.

Paleolithic Background

The genus *Homo* emerged roughly 2.5 million years ago in Africa. The oldest archeological and fossil remains outside Africa date to roughly 1.8 million years ago or after. Prior to their expansion beyond the African continent, hominids were confined to tropical and subtropical habitats. The spread of early *Homo* across tropical and subtropical southern Asia may have been comparatively rapid, at least into areas with similar temperature ranges and patterns of resource availability. The earliest known sites outside Africa occur at relatively low latitudes or in areas with sheltered microclimates, and the available data suggest that populations expanded from south to north much more slowly than they moved west to east. Hominid sites exist but are very rare in temperate and sub-arctic areas prior to half a million years ago, and those few that exist seem to date to the warmest interglacial climatic intervals (Dennell and Roebroeks 1996; Roebroeks 2005). Clearly, cold environments presented a fundamental barrier to the early expansion of the genus *Homo*, unlike the tropical and subtropical habitats of southern and eastern Asia. By 500,000 years ago, however, hominids seem to have established a more permanent presence in northern habitats.

Technological and economic changes were necessary prerequisites for the success of hominid populations in cold environments. Fire would have enhanced hominids' ability to survive temperate Eurasian winters. Perhaps most challenging to the first hominids that spread into Eurasia, however, were the novel variations in seasonality, punctuated in many areas by winters of intense cold and snow-covered or frozen ground. Colonizing populations of *Homo* could only have survived northern Eurasian winters by exploiting large mammals, as few other foods would have been available to them during the cold season. Nuts and other large seeds, though energy-rich, long lasting, and locally common in temperate forests, can be laborious to process, and snow cover greatly raises the winter search costs of these resources.

How hominids of the early Pleistocene obtained the bulk of the meat they consumed is an open question. The technology of the Lower Paleolithic period was comparatively simple, and included no obvious weapons other than wooden spears. Yet many of the archaeofaunal accumulations dating from 750,000 to 300,000 years ago are dominated by the remains of megafauna such as elephant, mammoth, and woolly rhino.

Beginning around 250,000 years ago and possibly somewhat earlier, there is widespread evidence of ungulate hunting in the archeological record. Of course observations about recent human diets show us that large game hunting is only one of several potential dimensions of the human predatory niche. Over the final 250,000 years of the Paleolithic, other trends are evidenced in foraging technology and predatory behavior, especially with respect to small game animals. The temporal focus of this discussion, from 250,000 to 10,000 years ago, encompasses the Middle Paleolithic culture period, associated with Neanderthals and their contemporaries, the Upper Paleolithic, generally but not exclusively the product of anatomically modern *H. sapiens,* and the Epi-Paleolithic or Mesolithic. The interval under consideration therefore traverses the biological and cultural transition in which *H. sapiens* supplanted other forms of the genus *Homo.* Not without interest, these trends in human economic and social behavior have important demographic correlates.

Humans as Large Mammal Predators

The foraging interests of humans overlapped considerably with those of large carnivores during the Pleistocene, particularly in the exploitation of hoofed animals such as deer, wild cattle, horse, and bison. Hominids' impacts on ungulate prey populations eventually became quite distinct from those of other large predators such as felids, spotted hyenas, and large canids. Recent humans are the only predators who frequently target the reproductive core (prime adults) of ungulate populations. Spotted hyenas and large canids of the recent and Pleistocene periods generally focus on the juvenile and old adult age groups in the same prey species, and most cats apart from cheetahs tend to take prey more randomly on an encounter basis. From the viewpoint of general predator tendencies, humans' focus on prime adult prey is ecologically unprecedented and is partly complementary to the niches of longer established non-human predators.

This emphasis on prime-adult prey emerged at least 400,000 years ago (Stiner et al. 2009), and it became geographically ubiquitous after about 100,000 years ago (Stiner 1990). The general pattern of prime-age-biased hunting appears to have been stable through the Upper Paleolithic culture period, though there may have been a mild reduction in the mean age of animals taken, possibly beginning in the late Middle Paleolithic (Speth and Tchernov 1998; Stiner 1994). It was only after the Last Glacial Maximum, and particularly after 13,000 years ago, that human hunting pressure on some ungulate populations led to unsustainable distortions in prey population structures, as indicated by mortality patterns in archeological sites (Stiner 2005)

Prime-biased hunting might seem a relatively fragile predator–prey relationship, because it targets adults of reproductive age, including females. Such practices can have negative consequences on the reproductive resilience of prey populations if predators exist at high densities. Even under the latter conditions, prime-focused hunting may be sustainable for omnivorous predators that can switch to other foods when the population densities of favored prey decline; the more versatile the predators' diet and search images, the more sustainable the relation becomes. In this sense, the human predator–prey relationship described above may not contradict the predictions of "prudent predation" models. It is significant that Middle Paleolithic populations were quite carnivorous based on zooarcheological evidence, more so perhaps than most human populations of later periods. These observations suggest that Middle Paleolithic foragers (including the Neanderthals) existed at the top of the food chain, and that Middle Paleolithic populations would have existed at very low densities.

Variation in Prey Body Size, Biomass and Diet Breadth

Humans are generalists in that they tend to eat a variety of animal and plant foods, and there is much flexibility in dietary breadth among recent foragers. Narrow diets, in which low-quality prey are usually ignored, are possible only if the chances of finding more profitable prey types are high. If the encounter rates with preferred prey decline, humans should and generally do broaden their diets by taking more lower-yield types. Dietary diversification is especially likely to occur when and where foragers put excessive pressure on preferred (highly ranked) resources, forcing them into decline. A reduction in the predator population may occur as a result. Alternatively, changes in adaptation may occur.

Early indications of increasing dietary breadth in humans seem to coincide with the transition from the Middle to Upper Paleolithic culture periods in Eurasia. Evidence of this transition is identified in at least three distinct areas of the Mediterranean Basin based mainly on the relative exploitation of small quick animals, such as birds, hares and rabbits, relative to slow-moving collectable small animals such as tortoises and shellfish. The bulk of meat consumed by all Paleolithic peoples came from large game animals. Small animals generally served as back-up resources, apparently essential for adjusting to variation in the availability of large game.

The classic models of prey choice and diet breadth assume that resources can be ranked in the energetic terms of the predator according to the amount of nutritional return the prey item yields relative to the cost of procuring it. Broadly speaking, prey rank is directly related to some combination of body size and search and handling costs. Ethnographic and experimental evidence suggest that human hunting of large animals provides returns on effort that are several times those from smaller animals, and an order of magnitude larger than many vegetable foods (Kelly 1995; Kuhn and Stiner 2001).

The relative emphasis that Paleolithic humans placed on small prey types grouped according to predator defense traits – slow-moving or "sessile" animals, fast-running hares and rabbits, and quick flying game birds – shifted dramatically across the eastern and northern Mediterranean Basin within a relatively short time. Zooarcheological evidence from Italy, Turkey, Greece, and Israel indicate that Middle Paleolithic foragers seldom pursued small prey except for those that could be collected with little effort. The situation changed abruptly around 45–50,000 years ago in the eastern end of the Mediterranean Basin coinciding roughly with the beginning of the Upper Paleolithic culture period and spreading with it into adjacent regions of Eurasia. The proportional contribution in biomass of small game to Paleolithic diets was constant at about 3% until the late Epi-Paleolithic (after 15,000 years ago), when it rose to 17% or greater, but the mix of small prey was decidedly different between the Middle Paleolithic and the early Upper Paleolithic.

A close look at biomass variation in the prey spectrum of Paleolithic hunters reveals a progressive decline in the ungulate body sizes hunted. This pattern precedes somewhat the rising dependence on small game biomass. Towards the end of the Upper Paleolithic, after the Last Glacial Maximum at roughly 20,000 years ago, biomass of hoofed animals was obtained primarily from medium and small artiodactyl ungulates, and later from small ungulates alone. While the most obvious changes in subsistence ecology occurred after 15,000 years ago, the trend in biomass-to-prey size began in the early part of the Upper Paleolithic.

While the proportional contribution of small game animals to Paleolithic diets was constant at 3% until the Epi-Paleolithic, there was a continuous downward shift in prey size overall, and a correspondingly greater emphasis on the more biologically productive ungulate taxa.

Differences in the productivity of prey species are a key to understanding the implications of the economic trends for Paleolithic demography, and rising population densities in particular. An important quality of small prey animals that reproduce quickly is their greater potential reliability as a food source. Warm-blooded small animals, mainly partridges, hares, and rabbits, mature in a year or less, and their populations rebound easily from heavy hunting by humans. All things being equal, hare populations can support proportionally seven times greater off-take by predators than tortoises can support, and partridges ten times greater off-take than tortoises. This means that humans' reliance on tortoises is only sustainable if human population densities are very low. Humans' reliance on partridges and hares is sustainable in both low- and high-density conditions.

It is striking that virtually all Middle Paleolithic foragers in the Mediterranean region focused on slow-growing prey types so consistently, to the extent that they pursued small animals at all. Moreover, where tortoises were an important food source in the Levant, there is no evidence for over-harvesting of the tortoises (no diminution or reduction in the mean body size of individuals) until the very end of the Middle Paleolithic. The consistent use of slow-growing tortoises during the Middle Paleolithic with no evidence of negative impact on prey populations implies that hominid populations were very small and dispersed. Between 50,000 and 40,000 years ago, however, at the threshold of the Middle–Upper Paleolithic cultural transition, one sees the sudden addition to the diet of many fast reproducing but difficult to capture small animals. This development is accompanied by evidence of diminution in tortoises, implying that human populations began to exceed the availability of high-ranked, high-return resources needed to support them. The zooarcheological evidence testifies to further demographic growth in the Mediterranean region over the remainder of the Late Pleistocene, accelerating particularly 15,000 years ago.

Technological Efficiency and Managed Risk

The archeological evidence from Eurasia indicates that some of the major radiations in Paleolithic hunting equipment evolved in response to the shifts in hominid subsistence behavior described above. Humans routinely hunted large mammals long before the undisputed or regular appearance of elaborate stone- and bone-tipped weapons in Paleolithic archaeological records. Prime-age focused ungulate hunting is evidenced by 200–250,000 years ago, for example, and the main hunting weapon of the Lower Paleolithic and, apparently, for most of the Middle Paleolithic was the simple wooden spear. In Eurasia Middle Paleolithic hunting weapons sometimes were tipped with pointed stones, and some bifacial stone and bone points have been recovered in the later Middle Stone Age of Africa. In contrast, Upper Paleolithic hunting weapons exhibit great diversity in design and complexity, and many of them represent significant investments in manufacture. Also contrasting to the Middle Paleolithic is the fact that many of the tool designs of the Upper Paleolithic diversified rapidly in time and space.

Oddly, the elaborate weapons traditions of the Eurasian Upper Paleolithic greatly post-date the emergence of prime-focused ungulate hunting, an impressive and often dangerous endeavor, by more than 200,000 years. Even the remarkable and apparently precocious examples of weapon tips from Middle Stone Age sites in Africa are much too young to bridge this temporal gap. It is noteworthy that the designs of Upper Paleolithic foraging technology were very sensitive to environmental variation, quite unlike Lower and Middle Paleolithic technologies. One sees greater abundance of and variation in Upper Paleolithic and Epi-Paleolithic bone points, for example, in high latitude areas in conjunction with a heavier reliance on hunting. Low-latitude sites contain fewer points but more grinding equipment for processing nuts and seeds, not unlike the global patterns of economic variation among recent hunter–gatherers. In contrast, little variation in hunting technology is apparent within the Middle Paleolithic, even though the sites of this earlier culture period span a geographic range similar to that of Upper Paleolithic humans. The late onset of the technological radiations indicates that the increasing volatility in hunting weapons designs was largely independent of the evolution of human's basic capacity to bring down large prey. Cooperation among hunters, rather than a reliance on elaborate technological aids, must have been essential for the capture of large game animals during the Middle Paleolithic. In fact cooperative hunting tactics are common among social non-human predators, such as lions, spotted hyenas, and wolves, and such tactics were likely to have been complex in the case of the Neanderthals. It also seems that Middle Paleolithic populations were always sufficiently small and dispersed that their need for meat could be met through a narrow focus on highly ranked game animals.

Many of the changes in weapons design of the later Upper Paleolithic certainly were connected to hunting, but the radiations in technology were not a gateway to big prey. In fact, improvements in weapons design and efficiency seldom raise the number of large prey animals available to hunters over the long run, as the carrying capacity of environments for herbivorous prey is controlled by a large combination of factors. A heightened investment in weapons efficiency is more likely to reduce individual's procurement time and risk per foray when pursuing large prey or quick small prey, and possibly also the minimum hunting party size needed to capture large animals. This implies a change in the value of forager's time – time that could be allocated to other tasks. Thus weapon innovations may have been driven partly by a need for greater mechanical efficiency, but the incentives for doing so may have originated from the pressures of time allocation for diverse social or economic concerns. Large scale resource pooling could also have permitted greater individual task specialization.

Many technological innovations of the Upper Paleolithic seem to relate to the exploitation of small prey, particularly quick-moving aquatic, burrowing, and flying types. Because some of these prey populations rebound quickly, even if hunted heavily, they can be reliable resources to humans if the work of capture can be reduced with new technology. A different side of the technological record concerns innovations in technologies for processing seeds and animal carcasses, which also grew much more complex in the late Upper Paleolithic and especially during the Epi-Paleolithic. Significant increases in carcass processing efficiency included grease rendering via stone boiling, evidenced by the thick litter of fire-cracked stones in some later Upper Paleolithic sites. Such heat-in-liquid techniques are labor-intensive, but they can raise the protein and fat yields per carcass well beyond what is possible from cold extraction techniques. During the Middle Paleolithic and earlier periods, only cold-extraction techniques that focused on the concentrated marrow reserves in large medullary cavities were practiced.

To summarize, Fig. 2 outlines some of the more important ecological and cultural developments in hominids from the later part of the Middle Pleistocene to the early Holocene. The earliest niche shift documented within this time span occurred about 500,000 years ago. Though conjectural, this is when fire technology may have first appeared, and hominids became at least seasonally reliant on meat in the temperate and colder zones of the Old World. Numbers of sites and hominid fossils in Eurasia also generally increase around this time range to form an unambiguous record of occupation. A second and more certain group of shifts centers on 250,000 years ago and includes the coalescence of a distinctly human predator–prey relationship called prime-dominated ungulate hunting. Middle Paleolithic technology, which likely included hide working and tanning, appears around 250,000 years ago. Narrow diets with a heavy dependence on large ungulate game, as well as a lack of impact on sensitive small game resources, indicate that hominid population densities stayed very low throughout the Middle Paleolithic; evidence from site numbers per unit time corroborates this (Mirazón Lahr and Foley 2003; van Andel et al. 2003). Human behavioral adaptations of this period display great stability, persisting for 200,000 years or more with only minor behavioral variations across a wide range of environments.

Upper Paleolithic cultures first appeared between 50,000 and 45,000 years ago in the eastern Mediterranean and they replaced all Middle Paleolithic adaptations in Eurasia by roughly 30,000 years ago. Early demographic pulses clearly accompanied this cultural transition, and expanding Upper Paleolithic populations must have squeezed some Middle Paleolithic populations in the areas of contact. From the Upper Paleolithic, the pace of change in material culture accelerated on multiple fronts, along with the novel additions of body ornaments, decorated tools, and art

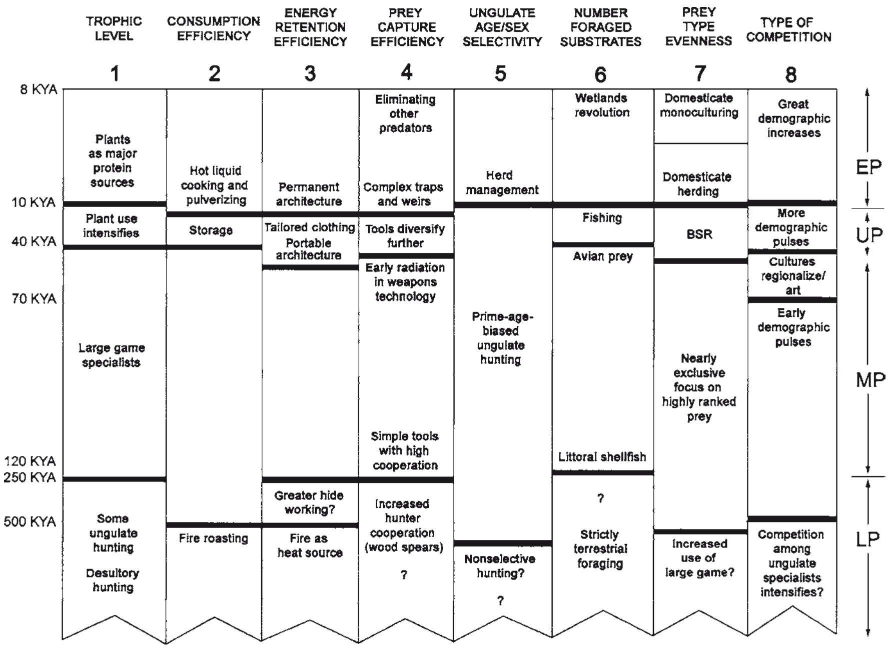

Fig. 2 Threshold shifts in eight niche dimensions of hominids on a logged time scale, lasting 500,000–8,000 years ago. Niche dimensions generally follow those outlined by Pianka (1988). Annotations refer to particular behavioral and trophic developments associated with each transition (ky) thousand years before present; (my) million years before present, (EP) Epipaleolithic period; (UP) Upper Paleolithic; (MP) Middle Paleolithic; (LP) Lower Paleolithic. (From Stiner, 2005)

(there is virtually no evidence of art in the Middle Paleolithic). After 50,000 years ago, the rates of change in the eight niche dimensions listed above seem to accelerate. The final series of shifts seems to have been stimulated by extreme climate oscillations, beginning with the Last Glacial Maximum, roughly 20,000 years ago, and followed by rapid global warming. The shifts in energy retention and consumption efficiency, and the rising importance of intraspecific competition, are almost certainly linked to demographic increase. Just how this unfolded remains to be understood, as the evidence presented so far only identifies temporal and geographic relations between demographic pulses and socioeconomic change, not their causes.

Certain correlates in material culture may provide clues as to what allowed this demographic upsurge. The sudden appearance of a myriad of ornaments and other decorated objects in early Upper Paleolithic culture may testify to a need to broadcast aspects of identity in the context of enlarged social networks. Among recent hunter–gatherers, such artifacts also play roles in gifting and alliance networking, a means for formalizing people's expectations of delayed reciprocation. Human demographic increase in the Upper Paleolithic and after may have created feedback situations in which human social networks could be exploited more efficiently in order to spread foraging risk over larger areas and more individuals.

The increasing regionalization of artifact styles that characterizes the latest part of the Pleistocene and early Holocene in Eurasia suggests that the challenges to human survival came from the lay of cultural landscapes as much as from natural ones. While sharing and cooperative foraging must have been a part of Middle Paleolithic lifeways, the social worlds of Middle Paleolithic hominids would have been quite small by comparison. The demographic conditions that make large, open-ended networks numerically possible seem to post-date the Middle Paleolithic and may have contributed to its demise. Whatever the causes of demographic increase in the Upper Paleolithic and Epi-Paleolithic, the conditions of selection on human societies and foraging behavior shifted to a more profoundly intraspecific forum. The resilience of Upper Paleolithic populations may have stemmed in large part from niche differentiation *within* the human species, specialization in activities, and labor allocation between the sexes and probably also by age. This cooperative division of labor became characteristic of all recent human societies.

Cultural Conservatism Versus Volatility

The archeological signatures of the Middle Paleolithic are remarkably consistent across time and space. This apparent uniformity in behavior has been taken by some investigators to indicate significant cognitive limitations of Middle Paleolithic foragers. However, the ecological data on early humans presented here suggest that the "inflexibility" we see in Middle Paleolithic culture was a product of the success and stability of the adaptation and not necessarily a question of intelligence. Estimates of the rates of long-term demographic increase before 50,000 years ago are remarkably low (Pennington 2001), a conclusion that is also supported by the zooarcheological data. There seems to have been a lack of pressure or economic incentive for large-brained, mobile Middle Paleolithic hunters to squeeze more out of traditional food supplies, and little if any long-term selection for greater foraging efficiency. This implies that, like other organisms but unlike recent humans, Middle Paleolithic hominids responded to long-term fluctuations in environmental productivity and population-resource imbalances almost exclusively through localized depopulation, rather than by increasing food yields by intensifying resource extraction or diet diversification. In fact, the demography of Middle Paleolithic foragers was consistent with the population dynamics and low densities of a variety of formidable non-human predators.

Far more difficult to explain than Middle Paleolithic conservatism is the downward shift in trophic level that is so characteristic of many later human subsistence systems. One of the most arresting features of the Upper Paleolithic is the near "irreversibility" of the dietary trends – persistent diversification via the inclusion of lower-ranked foodstuffs (plant and animal) that have greater collecting costs, processing costs, or both. The shift in predatory economics would have resulted in increases in environmental carrying capacity for Upper Paleolithic populations.

How could higher population densities become a permanent condition for humans in the late Pleistocene? Humans have developed an astonishing variety of tactics for insulating social groups from the unpredictable nature of their food supplies. Among these, small-scale storage of consolidated animal tissues and seeds and nuts, or both may have been pivotal in the later Upper Paleolithic. Storage buffers human groups against fluctuations in annual resource abundance, especially in situations where residential mobility, exchange or sharing cannot solve the problem. More efficient carcass processing methods may increase the yield of any given food unit, but the greater amount of work required to extract it normally must be weighed against the prospects of getting more food. Innovations in technology are apparent for most of these behaviors. Human technology today does indeed facilitate overharvesting of food species. However, calling this ability simply the product of invention or 'inventiveness' or an isolated accident of history is insufficient to explain the evolutionary processes that have allowed humans to exert ever-greater impacts on native biota.

Under conditions of population pressure, a shift toward greater dependence on more biologically "productive" or resilient prey populations may also have presented fundamental short-term advantages, even if it meant heavier technological investment to overcome handling costs. A reduction in the variance in the costs of acquisition can lead to a more consistent supply of animal protein and fats and significantly improve child survivorship without an increased birth rate. Meat is one of the very few sources of complete protein in nature, a fact that no doubt sharpens humans' interest in obtaining it in large packages. The human body cannot store undedicated protein as it does the nutrients that yield food energy, nor can the body assimilate protein effectively in the absence of energy supplements. Daily requirements of complete dietary protein are modest but constant, especially for children and mothers. Ethnographic research suggests that the most consistent sources of protein, and in some cases fat, for hunter–gatherer children in arid environments are small animals and nuts and roots that children either procure for themselves or are given by female kin. The opportunities to obtain small animals are also considerably more diverse and widespread than are the opportunities to obtain large game and so often are the personnel who pursue them. As a result, increasing use and diversified exploitation of small game animals implies changes in the division of labor in foraging societies.

The trends in small game use along the Mediterranean Rim may coincidentally have stabilized humans' access to protein as the abundance of highly ranked but relatively unproductive prey declined. The addition of these novel resources to Paleolithic diets may have also allowed a wider range of individuals in human groups to become productive foragers, increasing or evening-out protein and energy intake for the group as a whole. Specifically, the development of capture devices such as snares, deadfalls, and nets may have afforded more reliable access to small protein packages from formerly elusive but perennially abundant small animals.

Of course the price of dietary diversification was higher investment in tool preparation and maintenance as well as direct inputs of labor to capture small animals in quantity. It is doubtful that all evolution in tool design can be explained by superior mechanical performance and efficiency, but it is clear that some of the changes were spurred by the dwindling supplies of high quality resources. In western Asia, we note that human demographic pressure preceded rather than followed the earliest technologic innovations of the Upper and Epi-Paleolithic periods.

Connectedness and Resilience in Paleolithic Systems

The units of behavior that archeologists study are contained within very broadly defined cultural entities, and it must be admitted that these entities probably are not coterminous with biological populations. Moreover, statements about sustained demographic presence or growth in the past require much clarity about the scale at which systems are conceived, something we have attempted to do here within the limits of the archeological data. From this information, we can distinguish some properties of Middle Paleolithic as opposed to Upper Paleolithic and all later cultural adaptations. An essential property of Upper Paleolithic culture appears to have been its ability to reinvent itself, whereas Middle Paleolithic culture seems to have persisted by virtue of widespread cultural conservatism.

The assertion that Upper Paleolithic culture and people were *superior* to or smarter than those of the Middle Paleolithic is widespread in the professional and lay literature on the demise of Neanderthals. It is, however, a bit like arguing that college professors are unintelligent because they tend to have fewer children than other segments of postindustrial human populations. We know that the adaptive systems of the Middle and Lower Paleolithic were very persistent in time and space and must have represented successful adaptations for long periods. Yet these hominid reproductive units probably were not particularly robust at the micropopulation scale. The rather narrow set of behavioral responses that characterized social groups prior to the Upper Paleolithic period almost guarantees that localized extinctions at the micropopulation level would have been common. Upper Paleolithic groups were the quintessential colonizers and, in addition, exceptionally good at holding on to habitat gained – these populations expanded rapidly through Eurasia, apparently originating from subtropical and warm-temperate areas (Africa and West Asia) at or greater than 45,000 years ago, and quietly snuffing out the last Neanderthals by roughly 30,000 years ago regardless of whether admixture occurred.

The demographic robustness of the Upper Paleolithic systems, which permitted their rapid expansion into vast new areas, may have been a by-product of new strategies for evening-out or sharing risk and the exceptional volatility of their technologies. Micropopulations of the Upper and Epi-Paleolithic were more connected geographically, at least based on stylistic evidence, and thus more robust. Larger networks for spreading risk may have set some Upper Paleolithic populations at an advantage, allowing them to grow somewhat faster or at least experience fewer oscillations in population size, disadvantaging Middle Paleolithic populations wherever the two cultural entities came in contact.

The apparent contrast in the flexibility of human adaptations between the Middle and Upper Paleolithic is bound to raise some interesting challenges to theoretical concepts of "robustness" or "resilience" in research on evolutionary dynamics. At issue from a paleoanthropological viewpoint is the question of how systems are to be defined and how one may distinguish adjustments within the bounds of an extant system from evolutionary changes that bring newer system into existence. If the system of interest springs back from perturbations in a slightly altered form, for example, shall we call it a new system, or is this evidence for robustness of the preexisting system? It is striking that the adaptive system(s) of the Upper Paleolithic, to the extent that they are coterminous with archeological "cultures," have shorter histories of existence than those of the Neanderthals and earlier hominids, yet Upper Paleolithic populations were even more widespread geographically and existed at higher densities in many areas. Upper Paleolithic and later cultural systems appear to have reorganized frequently in the service of demographic robustness – resulting from feedback relations with subsistence diversification in diet, technical intensification, and social strategies for spreading risk. Earlier hominid population-level systems look fragile by comparison, even though their cultural traditions appear to have been extraordinarily stable for long periods. Middle Paleolithic and earlier hominid populations of Eurasia were smaller and more scattered, and for this reason more subject to the unique historical predicaments of annual and interannual variation in food supply and habitat conditions.

Demographic factors are an important background to understanding evidence of changes in the connectedness of social entities within cultures and their relations to environmental systems in the evolutionary history of humans. For a very long time hominids were energetically of little significance in the ecosystems in which they lived. The effects of fluctuating environments on hominid populations are detectable over millions of years, but evidence of influences in the reverse direction is much more recent. Distinctly human impacts on community structure and prey populations first become detectible only after about 50–40,000 years ago, with the onset of the Upper Paleolithic. These later humans often responded socially and technologically rather than simply demographically to periodic scarcity of resources. The ecological and demographic crises that seem so unique to the modern world have deep roots in the history of forager adaptations.

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Burning and Hunting in Australia's Western Desert[1]

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Introduction

Even though the central role of fire in the terrestrial biodiversity of Australia is widely acknowledged, we have a limited understanding of the factors that determine the decisions that Aborigines make in maintaining landscape burning regimes (see review in Bowman 1998, pp. 389–390). Discussions of Aboriginal firing practices have generally focused on three interrelated aspects: (1) possible changes in burning regimes indicated by paleoecological records coincident with the arrival of humans in Australia, and subsequent changes in vegetation demography and distribution; (2) the relationship between firing, the primary extinction of Pleistocene mega fauna, and historic declines and extinctions of small–medium-sized marsupials; and (3) the role of Aboriginal burning as a general land management strategy for increasing food supplies and maintaining wildlife habitats. Our aim is to address the fire management issue with data on the immediate and long-term benefits accruing to Martu Aborigines in the Western Desert of Australia.

There is now considerable evidence that regular fire treatment in the spinifex (*Triodia* spp.) savanna of the Western Desert increases the richness of plant species, decreases the potential for devastatingly large wildfires, and has an important impact on faunal populations. Long periods without fire lead to profound changes in the landscape. After Aboriginal burning ceased in the eastern part of the Western Desert, from 1953 to 1981, the number of recently burnt patches fell from 846 to four, while the mean burnt patch size went from only 64 to 52,644 ha (Burrows et al. 2000). Diverse mosaics attract game, so it is not surprising that a number of researchers have argued that Aboriginal burning strategies (and associated beliefs) are designed to create mosaic habitats, stabilize resource populations, and/or maintain diverse assemblages of game and vegetation.

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[1]The original article *Aboriginal Burning Regimes and Hunting Strategies in Australia's Western Desert* appeared in *Human Ecology*, Vol. 33, No. 4, August 2005.

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D.G. Bates and J. Tucker (eds.), *Human Ecology*: Contemporary Research and Practice, DOI 10.1007/978-1-4419-5701-6_9, © Springer Science+Business Media, LLC 2010

In much of arid Australia, burned savanna is quickly colonized by short-lived grasses, forbs, and insects, many of which are important food resources for both humans and large game animals, such as bustard (*Eupodotis australis*), emu (*Dromaius novaehollandiae*), euro (*Macropus robustus*), and plains kangaroo (*Macropus rufa*) (Latz 1996). A good deal of attention to the benefits of burning savanna has focused on hunting larger prey: regular burning is assumed to increase edible forage and facilitate flushing these animals; thus, hunting success should peak with the use of fire and one or two years following a burn. However, no tests of this hypothesis have ever been conducted using actual observations of Aboriginal hunting and burning strategies. We intend to provide the first quantitative data to test the hypothesis that cultural knowledge about burning functions specifically to increase the efficiency of hunting large, mobile prey.

Background and Methods

Martu (or Mardu in many orthographies) conventionally refers to foraging groups whose traditional estates surround Lake Disappointment, the Rudall River, and the Percival Lakes in the northwest section of the Western Desert. Today, the Martu (a population of about 600–800 people) are mostly speakers of Manyjilyjarra, and Kartujarra dialects.

Limited contact between a few Martu and white explorers and settlers began in the early twentieth century with pastoral efforts on the western and southern fringe of Martu territory. In the 1930s, some Martu began a process of migration westward from their desert estates, visiting and eventually settling around Jigalong (a maintenance depot, and later Protestant mission, see Tonkinson 1974 for detailed history). However, many families, especially those from the easternmost part of Martu territory, remained in the heart of the desert until the mid-1960s, when prolonged drought and continuing depopulation drew them into Jigalong and neighboring pastoral stations. While many Martu stayed in European settlements, many also left soon after their arrival. In the mid-1980s, numerous families (mostly those that were the last to leave the desert) returned permanently to their desert homeland. By 1986, they had established two permanent "outstation" camps (Punmu and Parnngurr) in the newly designated Rudall River National Park (another outstation at Kunawarritji, Well 33 on the Canning Stock Route, soon followed). Many Martu felt that their ability to keep sacred law and practice their religion depended on moving back to their homelands (Tonkinson 1991 pp. 174–178).

Return to the desert meant a return to a foraging economy, especially for the families at Parnngurr (comprising a core population of about 100 people). Government rations were trucked out when possible, but often vehicle access to the camp was cut off for months at a time. Throughout the mid-late 1980s and early 1990s, much of the daily subsistence at Parnngurr came from hunting and gathering. Walsh (1990), and Veth and Walsh (1988) conducted critical research on foraging activities in and around Parnngurr during this period, focusing on Martu ethnobotany, seasonal variability, and gathering ecology.

Today, the importance of foraging has declined somewhat compared to what it was at Parnngurr's establishment. The supply route to the community is more reliable (although still precarious, especially during summer rains), regular government funds (e.g., social security and Community Development Employment Program, CDEP) and a small store (usually well-stocked with basic food and household items) have increased reliance on a cash/welfare economy. With permanent settlement, foragers now require vehicles to visit more distant hunting and gathering grounds on day trips, and there are few working 4WD trucks in the community. Martu also face increasing demands on their time: with sedentism, clothing, and vehicles came the need to allocate more time to cleaning, washing, and maintenance; men and women are often involved in ritual activity, with some men spending months at a time away from the community; time is also taken up with various government meetings and functions; and obtaining CDEP wages means at least some time working during the week on various community projects. Nevertheless, Martu at Parnngurr continue to hunt and gather on a regular basis, their foraging frequency limited primarily by their access to vehicles and fuel. Although most people at Parnngurr would like to hunt nearly every day, the majority forage about three to four days out of the week. Foraging trips to "dinner-time camps" within 50 km of the community occur nearly every day, and extended camps at more distant locales are common, especially during the cool/dry season (*Wantajarra*, May–August).

Most of our time with the Martu was spent in Parnngurr and on extended camps away from the outstations. Foraging locales are usually accessed with a vehicle, after which women and children hunt and gather on foot with digging sticks, while men often utilize vehicles and small gauge rifles. On average, 25–50% of the total diet comes from bush foods, and on foraging days, bush foods make up 80% of the diet per participant.

The data presented here were collected in 2000–2001 during camps away from the outstation communities. The analysis covers 422 forager-days in the cool–dry season (*Wantajarra*, May–August). We limit the analysis to *Wantajarra* hunts: foraging during the other seasons does not usually involve burning large tracts of grassland (analyses of seasonal differences are currently underway). All Martu participants aside from the younger children spent most of their lives in the desert and all of their formative years as full-time foragers. Camps averaged 10.5 individuals, ranging in age from three to ~70 years old. A total of 6,882,519,706 kcals of meat, insects, fruit, roots, and nectar were collected during these camps, averaging 1,792 ± 279 (SE) kcals per forager-day (including all children). Researchers supplied an average of 350 kcals per participant-day, primarily in the form of flour and sugar.

Foraging Follows

During extended camping trips we conducted daily, detailed focal individual foraging follows. Each researcher asked permission to accompany a camp member over the course of the day, during which we recorded the time a forager spent *traveling* to and from a foraging locale, *searching* for a range of potential resources, *tracking* a particular prey item, *capturing* a particular item, and field *processing*. We then recorded the weight of each animal captured, the parcel harvested, and the total weight of the catch by resource type at the end of the day. A total of 252 adult focal follows (165 women, 87 men, consisting of 33 different individuals) are used in the analysis. In addition to the focal follows, during each camp day we recorded the duration of all foraging trips in camp and the weight (by item or type) of all food captured by all participants in camp. Edible weights for animals were calculated in the field by weighing uncooked specimens and asking participants to discard the post-consumption waste material from the animals into a receptacle. As much of the variability in energy per animal is a function of animal fat, we estimated an average value for the percentage of fat by weight based on the weights from dissected cooked individuals of each prey type. All weights were obtained with hand-held tubular spring scales accurate to ±5 g. Energy values were taken from published sources analyzing the composition of Aboriginal foods (Brand-Miller et al. 1993). As used below, foraging *efficiency* (overall foraging return rate) is measured as the gross edible energy gained per focal individual follow divided by the total time the forager spent in search, tracking, and capture.

Burning Regimes and Habitat Mosaic

Sandplains and dunes dominate Martu landscapes. Areas that have remained unburned for longer than three years are dominated by (>80%) old-growth spinifex grass (*Trodia* spp.) with characteristic "donut" shaped hummocks. Martu systematically fired older growth spinifex at nearly every camp. Following a fire, the proportion of visible spinifex is reduced to nearly zero, and with any rain, plant diversity (e.g., *Solanum, Eragostis, Dysphania, Trichodesma,* and *Evolvulus*) in a recently disturbed patch increases dramatically. Martu pay close attention to each fire: most adults can recount when, where, and by whom every fire was lit (with details of fire intensity and progression) over at least the three previous seasonal cycles within a radius of about 100 km from the three outstations. Martu also regularly classify regrowing habitat according to anthropocentric evaluations of its utility: *nyurnma* (a recently burnt area with no plant regrowth), *waru-waru* (herbaceous plants are in the process of regrowing, generally following a rain), *mukura* (herbaceous plants have reached maturity and are yielding fruit/seeds), *mangul* (herbaceous plants are declining, spinifex is dominating and capable of carrying a fire-line), and *kunarka* (very mature spinifex-dominated community). Depending upon rainfall, spinifex sand habitats can take up to 10–20 years to reach *kunarka* stage.

To characterize habitat mosaic and burn regimes, we chose a straight 2-km transect in a random direction from each camp. A researcher walked the transect and noted the number of times he/she passed from one patch of vegetative regrowth to another. *Fine-grained mosaics* around camps were defined as those in which a researcher passed into three or more types of regrowth patches on a single transect.

This type of mosaic results from moderate anthropogenic burns at regular intervals. For fine-grained mosaics Martu recounted lighting at least one fire-line in a 10-km radius of the camp within at least the previous two seasonal rounds. *Medium-grained mosaics* at camps are defined as habitats in which a researcher passed into two patches of regrowth on a transect. These habitats result from larger fires (some greater than 20 km^2), usually at intervals of >3 years but <10. *Coarse-grained mosaics* around camps are dominated by a single patch: either old-growth spinifex (*kunarka* habitat) over a very large area, or a recent very large burn (*nyurnma* >50 km^2) (Haydon et al. 2000a). In these areas, a researcher never crossed other stages of regrowth over a 2-km transect. In rare cases, prior to firing, Martu indicated that the area around the camps had not been burned (from their own ignition or by lightning) in over 10 years.

Results

Especially in fine-grained mosaics, Martu often encounter and collect a wide array of fruits (especially *Solanum* spp.), roots and tubers (*Vigna lanceolata* and *Cyperus bulbosus*), larvae (*Cossid* spp.), nectar (primarily *Grevillea eriostachya*), and grass, shrub, and tree seeds (especially *Eragrostis eriopoda* and *Acacia* spp.). For the purposes of this analysis we focus on differences between the major *Wantajarra* "hunt types": *wana hunting* for burrowed game and *gun hunting* for mobile game.

Hunt Types and Sex Differences

Martu hunt for burrowed game on foot with a *wana* (wooden or iron digging stick) exclusively in sandplains and dunes. During the *Wantajarra* season, these hunts almost always incorporate burning tracts of spinifex savanna to facilitate the lengthy search for tracks and dens. *Wana* hunters search mostly for burrowed sand goanna (*Veranus gouldii*), but also python (*Aspidites* spp.), skink (*Tiliqua multifasciata*), feral cat (*Felis silvestris*), and ridge tailed goanna (*V. acanthurus*). Burning during *wana* hunts is highly systematic: the size of the fire-line used and the burned patch (*nyurnma*) that results depend on wind velocity, accumulated fuels, and surrounding firebreaks – in the sandplains and dunes, firebreaks are primarily neighboring patches burned within the last two or three years. Hunters ignite a line of dry spinifex by quickly flicking matches or dabbing a fire-stick into the occasional hummock as they walk. With the ignition of a fire-line, a hunter will immediately begin to search for tracks and fresh dens within the *nyurnma*, often following along just behind the advancing flames in the clear surface of new ash. Ideally this creates a *nyurnma* of about 5 km^2. Generally each hunter will light his/her own line and search independently of others, although hunters often signal to each other in managing their burns and cooperate to extract prey from their dens. Tracking and capturing burrowed prey requires tremendous skill.

Hunting with a gun for larger, more mobile game is typical "encounter" hunting with long-range searching (in vehicles and on foot) across sandplains, low lying rocky ranges, watercourse margins, and mulga flats. If a vehicle is used, usually there is a driver and a shooter; on foot, they hunt alone. Tracking often involves the pursuit of a particular animal over long distances, sometimes over the course of a number of days. During *Wantajarra*, Martu mostly capture bustard (*Eupodotis australis*), but they also track and capture feral cat, euro (*Macropus robustus*), plains kangaroo (*Macropus rufa*), emu (*Dromaius novaehollandiae*), and occasionally perenti (*V. giganteus*). Game is generally taken with small gauge rifles (although spears and throwing sticks are still used on rare occasions). Some larger animals are attracted to recent burns or the new vegetation that follows, but burning is not generally used to find and capture mobile game; a large burn can reduce cover and increase the probability that an animal will detect the hunter, although fire is sometimes used to flush game. Differences in techniques and technology mean that *wana* and gun hunting are for the most part mutually exclusive activities.

During *Wantajarra*, women spent as much time hunting (defined as time spent searching, tracking, and capturing game) as men, but each sex hunted differently. Women spent 179 ± 15 (SE) minutes per forager-day *wana hunting* (usually accompanied by other women), and only 9 ± 6 min *gun hunting* (usually accompanied by men). Men spent 108 ± 16 min per forager-day *gun hunting*, and 83 ± 19 min *wana hunting*. The differences in time allocation of men and women to the two hunt types are significant (One sample *t*-test, Male vs. Female *wana* hunting: DF = 33, $t = -5.403$, $p = 0.0001$; Male vs. Female gun hunting: DF = 33, $t = 6.099$, $p = 0.0001$).

Burning and Hunting Efficiency

Even though much discussion about the Aboriginal use of fire has focused on its benefits in men's hunting, gun hunters burned on only 11% (10/87) of foraging follows. Gun hunters did not significantly increase their foraging efficiency if they burned while foraging: they obtained 2,377 ± 1,036 kcal/foraging-hour ($n = 8$) after lighting a fire-line and 2,178 ± 1,064 kcal/h ($n = 77$) if no burning occurred ($t = 0.067$, $p = 0.947$).

However, firing the spinifex savanna had immediate and significant effects on the efficiency of women's *wana* hunting for burrowed game: 575 ± 35 kcal/foraging-hour ($n = 113$) with burning, but only 409 ± 63 kcal/h ($n = 52$) ($t = 2.47$, $p = 0.014$) without. Gun hunting is associated with higher efficiency (DF = 198, mean difference = 1,626, $t = -1.95$, $p = 0.052$) but has over seven times the variance of *wana* hunting. Gun hunters failed to capture prey on 68% of the focal follows; *wana* hunters failed on only 3%. As a result of these differences in variance, a non-parametric test reveals that the efficiency of *wana* hunting for burrowed game ranks significantly *higher* than gun hunting ($U = 2,659$, $p < 0.001$, mean rank for *wana* hunts = 121, mean rank for gun hunts = 75).

Habitat Mosaic and Hunting Efficiency

If mosaic grain influences the distribution and abundance of indigenous animals, it should have an effect on hunting efficiency (Yibarbuk et al. 2001). Our results show that there were no significant effects on gun hunting efficiency according to the mosaic grain of the habitat (ANOVA, df = 84, $f = 0.124$, $p = 0.884$) (Fig. 1). Gun hunters obtained their lowest hunting returns in fine-grained mosaics (1,174 ± 784 kcal/foraging-hour, $n = 10$ hunts), and their highest hunting returns in both medium (2,058 ± 667 kcal/foraging-hour, $n = 44$) and coarse-grained mosaics (2,701 ± 2,345 kcal/foraging-hour, $n = 33$). Games–Howell post-hoc test at $\alpha = 0.05$ between showed no significant differences in efficiency with mosaic grain treatment ($p = 0.640$–0.778).

However, for *wana* hunting mosaic grain had a significant effect on foraging efficiency (ANOVA, df = 162, $f = 19.00$, $p < 0.001$) (Fig. 1). The highest efficiency was obtained in fine-grained mosaics (656 ± 40 kcal/foraging-hour, $n = 97$), significantly lower returns in medium-grained mosaics (480 ± 67 kcal/foraging-hour, $n = 25$), and lower returns still in coarse-grained habitats with long fire intervals (246 ± 47 kcal/foraging-hour, $n = 43$). A Games–Howell post-hoc test at $\alpha = 0.05$ between treatments (habitat mosaic) resulted in significant differences between fine-grained and medium-grained habitats (mean difference = 177 kcal/foraging-hour, critical diff = 162, $p = 0.033$), between fine-grained and coarse-grained habitats (mean diff = 411 kcal/foraging-hour, critical diff = 132, $p < 0.001$), and between medium-grained and coarse-grained habitats (mean diff = 234 kcal/foraging-hour, critical diff = 181, $p = 0.012$).

Discussion

The Issue of Variability in Hunting and Burning Strategies

The Martu data demonstrate clear sex differences in hunting strategies during *Wantajarra*: men focus on gun hunting for mobile game, women focus on hunting burrowed game with a *wana*. While men's gun hunting yields higher *average* efficiency, it is associated with a high risk of failure. Thus, women's *wana* hunting is more *predictably* efficient than gun hunting. The data also show that burning benefits *wana* hunters more (and more predictably) than gun hunters. Finding tracks and dens of burrowed game while searching in old-growth spinifex is very difficult, and *wana* hunters failed to burn only when they were hunting near ritual sites that proscribed burning or when members of the foraging party were not within their own estates. However, men's return rates while hunting for mobile game did not change with burning. These results suggest that women's hunting strategies may be designed for reliable meat provisioning, while men's foraging goals may include other motivations, such as social attention and religious obligation.

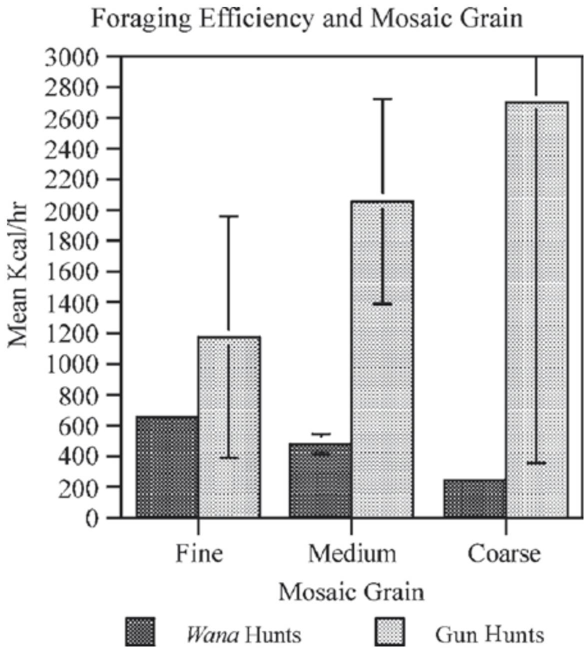

Fig. 1 The effect of mosaic habitat grain on hunting efficiency (kcal/hunting-hour ± SE): gun hunting and *wana* hunting

Younger men are often required to hunt larger mobile game for their elders, and this may have little to do with a "sexual division of labor" designed to reliably provide meat for themselves or others. Testing this will require much more research into the relationship between foraging activities, food sharing, and "social capital."

While the immediate benefits of burning during *wana* hunts are clear, some caution should be used in interpreting the long-term relationship between hunting efficiency and habitat mosaic. Thus far, we only have a rough measure of habitat mosaic at each camp, and 2-km transects are unlikely to capture the full range of mosaics encountered by hunters. Nevertheless, at the coarse-grained end of the habitat mosaic continuum, the results are intriguing. In these habitats, hunters were searching in areas that had not been burned for many years, so they spent all of their time in either old-growth spinifex or very large-scale recent burns with little or no regrowth. There, *wana* hunters experienced significantly lower return rates than in fine-grained mosaics. These patterns were not observed for men's gun hunting. While a "patchier" environment from moderate burning might make mobile game more predictable in time and space, these effects on gun hunting efficiency are muted by definition: game is *mobile* across numerous patches. Thus, the impact of burning and the creation of habitat mosaics on mobile game populations is difficult to detect. Relative to *wana* hunting, gun hunting is inherently unpredictable – for both hunters and analysts.

The primary mobile prey obtained on gun hunts was bustard and kangaroo. Martu men often remarked that these game are attracted to newly burnt grassland to forage for new vegetation (kangaroos) and small lizards and insects (bustard) (see also Lundie-Jenkins 1993, which shows that rufous hare-wallaby, *Lagorchestes hirsutus*, are attracted to burnt areas). While bustard are generally shot on the ground, they are prone to flight at any indication of people. Thus, while bustard may be sighted more often after a burn when there is little vegetation cover, they may be less likely to be captured. The same may also be the case for kangaroos, which tend to avoid open spaces during most of the day, and capturing them in a burn is very difficult. In much of the Martu landscape getting close enough for a clear shot at a kangaroo usually requires stealth that is compromised by a new burn. The use of fire for driving and flushing game may have been more common in the past among the Martu. We observed fire use on only four of the 252 focal follows analyzed here, and in each case it involved the pursuit of feral cat. While skill and ecological knowledge were astounding, burning during gun hunts was not generally systematic and coordinated.

This differs from *wana* hunting where women have strong incentives to control moderate and repeated burns in order to immediately increase the probability of encountering game tracks and dens. As many Martu women reported, a *wana* hunt in a very large burn can be difficult to manage. Each burn is "owned" by the individual(s) that fired it, and rights of access to the resources within that burn at least for that day (but often longer) are exclusive. Usually women search a burn alone, often out of sight of other hunters, although they sometimes signal to others once an animal or den is sighted and cooperate in pursuit. As prey in a burn are dispersed and encountered singly, especially large burns make it difficult to know whether or not other hunters have already searched the area. Hunters keep a close eye out for other people's footprints in their burn, and disputes can arise if too many hunters are thought to be too close together. Women's cooperation while hunting burrowed game is often designed for reducing this type of overlap: well-managed, moderate burns greatly facilitate this and immediately increase hunting efficiency.

The Issue of Land Management

This study was not specifically designed to test the more general hypothesis that burning is a land management strategy that "(a) prevents or mitigates resource depletion, species extirpation, or habitat degradation, and (b) is designed to do so" (Smith and Wishnie 2000, p. 501). However, recent research in behavioral ecology has demonstrated fundamental problems with the idea that small-scale societies often design subsistence strategies to increase long-term resource availability or stability, even if they have such effects. Smith and Wishnie (2000) have shown that the maintenance of this type of long-term land management can be sustained only when the problems of collective action and future discounting are negligible. Collective action problems arise when the costs of providing goods are distributed individually, but the benefits of those goods can be shared by all regardless of whether or not they pay. Also, future benefits are necessarily discounted relative to their current value: delays in consumption decrease the chance that those benefits can be realized. Future discounting among humans has been widely documented by behavioral ecologists, psychologists, and economists (see Tucker 2003 for review).

If people design their burning practices as a strategy for long-term land management, we will need to account for future discounting and collective action problems. Engineering and managing massive landscapes with controlled fire is costly for the individuals involved, but the future benefits from these efforts can be enjoyed by many that did not pay the initial costs. Also, firing is initially destructive, incorporating the immediate loss of time and at least some potential resources, although it is generally assumed that such costs are recouped in the future with increased availability of game and plant foods. Because burning is often associated with increasing immediate hunting returns, there is the possibility that it is not designed to be a land management strategy at all and the long-term effects are only incidental.

However, there is some circumstantial evidence to suggest that certain aspects of Martu burning are indeed designed to be a land management strategy. First, we measured only the long-term benefits gained from hunting: many collected plant foods have very high energetic return rates (especially *Solanum* spp.), and these rates should peak one or two years after an area has been burned. Thus, while hunters may see a small benefit immediately, they may see a larger benefit in the future. It is possible that the immediate economic incentives provided to *wana* hunters serve to eliminate the collective action problem: free-riding non-burners simply may not be able to find enough burned area to hunt when burns are small and hunters are able to search them entirely. With regards to men, it is likely that they may indirectly receive economic incentives to burn in order to increase women's foraging productivity, on which they greatly depend. However, for men especially, burning may provide more social than economic capital: it can be a signal and index of land ownership, an esthetic interpretation of homeland, and an expression of ritual linking events of the past and future.

Secondly, while older, burnable landscapes seem to be "open access," newly burned areas are not. Martu hunters face sanctions against entering a newly burned area without permission of the person who set the fire. A woman who "jumps into" the burn and removes the prey before the burner is likely to provoke an altercation or worse. Anthropologists currently know very little about how successional age in vegetation influences "ownership" over an area. It certainly seems likely that the need to ask permission from the fire-starter to enter the patch declines over time, but it is not known whether it declines prior to the critical one or two year age when fruits and seeds reach their peak production. Foragers entering these areas do know who set the fire, but we do not know whether those "owners" retain the right to grant access to the food available within.

Even if burning was designed to be a land management strategy in the past, it may not currently function as such because environments and foraging methods have changed. In particular, analysis of the effect of contemporary burning on the maintenance of wildlife diversity can be complicated by the introduction of non-indigenous species. In many locales throughout Australia a wide range of introduced mammals (rabbits, sheep, goats, cattle, donkeys, horses, camels, cats, and foxes) are thought to have caused local extinctions and severe declines of indigenous mammals. No data exist on mammalian populations in the northern part of the Western Desert prior to the 1960s, but numerous Martu have indicated that many small to medium-sized marsupials were common before the exodus from the desert, but are now very rare. Whether this is a result of introduced fauna or changes in burning regimes is not known. In Martu territory, foxes are occasionally seen but do not have a viable population; there are no cattle, goats, or sheep, and donkeys and rabbits are very rare. Feral cats are common, but many Martu said they were present and were hunted many years prior to the local collapse of marsupial populations. However, camels are having an effect on Martu subsistence and ecology: Martu claim that a decrease in kangaroo populations in the desert is a result of increased competition with camels for surface water. On the basis of this and the evidence of extreme changes in fire ecology in the Western Desert following Aboriginal exodus (Burrows et al. 2000), we hypothesize that anthropogenic fire was an important factor maintaining small to medium-sized marsupial populations, and that this was primarily a consequence of short-term hunting goals operationalized by burning. Major declines seem to be coincident with the exodus of people from the heart of the desert and not with the introduction of non-indigenous species.

The Issue of Policy Development

This study should add to a growing appreciation of the problems involved in attempting to distinguish between "natural" and "artificial" landscapes. For all intents and purposes, Australian "wilderness" is (and in some cases has been for about 45,000 years) a product of a dynamic relationship between people and the physical environment. Or as the Martu put it, "we are all the environment." Bowman (1998, p. 404) has noted "that… land managers must choose what sort of "natural" landscapes they want, given the backdrop of an extraordinarily long period of Aboriginal burning." Of course, what kind of landscape we want is a matter of cultural practice and belief, esthetics, politics, economics, and problems of collective action, not of wanting to or being able to restore some pristine ideal. Nevertheless, as many Martu have remarked, a "Martu landscape" (people living at very low population densities with relatively high mobility) may be something very different from today's environment of permanent Martu communities, massive mining initiatives, and increasing tourism. Not that the Martu are absolutely opposed to these, but efforts to retain a significant measure of control over *their* environment will continue within the community. This control is inextricably tied to burning.

Development of fire policy needs to focus on a systematic analysis of Aboriginal burning practices to inform and buttress land management prescriptions. Effective fire and land management in this region of the Western Desert will fail along most fronts without incorporating Martu participation and objectives. This will require a broad anthropological and ecological approach, building from within communities and taking into consideration different levels of cultural meaning, temporal and spatial ecological variability, individual conflicts of interest, and tradeoffs associated with different goals – all of which influence burning strategies and their consequences. The Martu data show that even within a single community, different people face different (and not necessarily complementary) tradeoffs relative to their subsistence and burning purposes. If Martu burning is a land management strategy, it does not appear to be designed to enhance men's kangaroo hunting, but rather to promote the productivity of key small animal and plant species. And certainly while many aspects of burning may be designed for land management, other goals also influence the frequency and extent of human-initiated fire. Thus, incorporating both women's hunting goals and men's social and religious priorities into fire policy will be critical for current conservation efforts in the Western Desert. This is more than necessary for developing operative policy: it will provide an opportunity for cooperation between land management agencies and remote Aboriginal communities that retain the skills and knowledge associated with burning and subsistence.

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The Wild Yam Question: Evidence from Baka Foraging in the Northwest Congo Basin[1]

Hirokazu Yasuoka

Introduction

In the mid-1980s, many argued that present-day hunter–gatherer societies had been marginalized and reconstructed under the enormous influences of macro-scale socio-economic and political systems and thus could not be used as models of prehistoric human society. The so-called "Kalahari debate" concerning the San of the Kalahari Desert is of considerable importance because ethnographies of the San were often used for reconstructing prehistoric human society in the African savanna. A concurrent debate concerned the hunter–gatherer societies, which had long been thought to be the original inhabitants of tropical rainforests. Hart and Hart (1986), Headland (1987), and Bailey et al. (1989) questioned the viability of subsistence in the rainforest based solely on foraging, independent of agriculture. Tropical rainforests are known to be extremely productive with an amazing diversity of flora and fauna. Nevertheless, "revisionist" scholars found that in fact food resources for human subsistence are rather scarce, spatially dispersed, and seasonally variable, especially in terms of energy sources. Headland (1987) termed this the "wild yam question" as wild yams were thought to be the major energy source for humans in tropical rainforests but argued that even energy rich yams were insufficient for supporting foragers in the forests. Along with Hart and Hart (1986) and Bailey et al. (1989), he hypothesized that without access to cultivated food subsistence is not viable in tropical rainforests. Further, they argued that hunter–gatherers might not have lived in tropical rainforests until cultivated food had become available (nowhere earlier than 10,000 years B.P.).[2]

[1] The original article *Long-Term Foraging Expeditions (Molongo) among the Baka Hunter–Gatherers in the Northwestern Congo Basin, with Special Reference to the "Wild Yam Question"* appeared in *Human Ecology*, Vol. 34, No. 2, April 2006.

[2] Researchers refuting this hypothesis include Bahuchet et al. (1991), Brosius (1991), Dwyer and Minnegal (1991), Endicott and Bellwood (1991), and Stearman (1991).

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*, 143
DOI 10.1007/978-1-4419-5701-6_10, © Springer Science+Business Media, LLC 2010

While the debate has been the catalyst for many studies of tropical rainforests and their inhabitants, neither side has provided solid, extensive ethnographic evidence. This may be due to the difficulty of conducting research among the present inhabitants of tropical rainforests. Nevertheless, the wild yam question remains of critical importance for two reasons. First, addressing this question will deepen our understanding of the ecological history of tropical rainforests, including the roles played by humans in these ecosystems, involving interactions with animals and plants. Second, if it becomes clear that the impossibility of a "pure" foraging life led rainforest hunter–gatherers to a symbiosis with neighboring cultivators, the interpretation of their sociocultural characteristics as "genuine hunter–gatherers" or "forest peoples" must be drastically modified.

In this chapter, I describe and analyze a long-term foraging expedition (*molongo*) among the Baka of the northwestern Congo Basin as an example of foraging life in tropical rainforests. On the basis of these data, I then discuss the potential of tropical rainforests as a human habitat.

The Baka Hunter–Gatherers

The Baka population in Cameroon is estimated at 25,000, which makes them the largest and the most homogenous of hunter–gatherer or former hunter–gatherer groups in the three adjacent countries (Joiris 1998). They speak an Oubanguian (Adamaoua East) language, while most of their neighboring cultivators, with whom they maintain a close economic and social relationship, speak languages of the Bantu family. Today, the Baka cultivate their own crops, which include plantain, banana and cassava, and sometimes obtain food from their Bantu neighbors in exchange for labor and animal meat. In the rainy season, they organize small hunting camps (ordinary forest camps), consisting of one to five households, at a distance of 10–20 km from the village, where the main subsistence activity is cable snare hunting. They also occasionally hunt with guns borrowed from cultivators, though men always carry spears and hunt with them whenever an opportunity arises. They take cultivated food to the camps, as well as gather wild food resources. In the dry season, most Baka migrate into the forest for a foraging expedition (*molongo*). The *molongo* camp often consists of ten or more households, and they remain in the forest for 2 or 3 months or more at a distance of 20–50 km from the villages. During this time, they subsist solely on wild food, particularly wild yams.

The total Baka population in the study village of Zoulabot Ancien in February 2002 was 138 individuals, more than twice the average size of Baka settlements (Sato 1992; Tsuru 1998), comprising 29 households divided into five patrilineal descent groups (*ye*). An elderly Baka (estimated to be 55) stated that his great-grandfather and grandfather had come from the forest around Moloundou, and that his father and uncles had settled around the village at the present site in the mid-twentieth century. Seven of his father's 14 children were born in forest camps, whereas 17 of his 22 children (he married five wives during his life) were born in the village.

Vehicles could not reach the village before the timber company constructed a logging road in 2002.

The vegetation in the study area is classified as a mixture of evergreen forest and semideciduous forest (Letouzey 1985). Evergreen forests of *Gilbertiodendron dewevrei* (Caesalpinioideae) do occur, mostly along the riverside, but not so abundantly as in the Ituri forest in the eastern Democratic Republic of Congo. Swamp forests of *Raphia* spp. (Palmae) grow along watercourses, and grassland patches grow on sandy soil near watercourses.

Methods

Field research was conducted from August 2001 to September 2002 and from January to August 2003. The location of each household and the subsistence strategies in which they were engaged were recorded from October 2001 to August 2003. Data were obtained retrospectively from interviews for the periods of my absence. The location and activity of adult males (or females, where no adult males were available) of each household were recorded. The study was carried out throughout the period of *molongo*, as well as in periods of residence in the small rainy season hunting camps. Geographical information was obtained through GPS data with *Garmin eTrex*, transposed on a topographical map (scale of 1:200,000) issued by Centre Geographique National of Cameroon. River names were also identified using the map and GPS data in order to ascertain the subjects' areas of activity, as the Baka recognize locations principally with reference to rivers.

Animal and plant food brought to the camp for most of the *molongo* period (March 5–April 23) was identified and recorded. Animals were identified with the aid of Kingdon (1997). The plants eaten were first recorded using vernacular names, and later specimens were collected and identified at the National Herbarium of Cameroon. The scientific names of wild yams were obtained from Dounias (1993) and Hamon et al. (1995), as it was difficult to identify the yams at the species level from the plant specimens only.

To gather data on game caught with snares during *molongo*, I visited all the snare routes with the hunters from the main camp every week from March 9 to April 20, and recorded the game caught at each snare. I did the same for six ordinary forest camps in order to compare the results of snare hunting at each location. Capture rate, which represents the number of snare-nights required to capture one animal, was then calculated by dividing the total number of snare-nights by the total number of captures (Noss 1998).

In order to compare diet in the village and during the *molongo*, I recorded and weighed all the foodstuffs taken at meals by eight households for 13 days in the village and calculated the energy intake per adult consumption-day from the weight consumed. The consumption for infants less than 2 years of age was counted as zero, and that for children from 2–12 years of age as a half man-day.

The energy intake per adult consumption-day was calculated using the following formula:

Energy intake (kcal/consumption-day) = Fresh weight × Edible ratio × Energy value / Adult consumption-days

For data on the locations of the main *molongo* camps, I chose an older man who provided information on all the areas in which he had conducted *molongo*. For mapping purposes I interviewed a further 87 people, older than 10 years of age, about the areas in which they had had *molongo* camps in the past.

The *Molongo* in 2002

The percentage of household-nights spent in each residential mode relative to the total number of household-nights throughout the research period (23 months) were as follows: 48% in village residence, 29% at ordinary forest camps, 9% in gun hunting expeditions, 7% in *molongo*, and 7% visiting other villages. A total of 19 households (66% of total households in the village) participated in the *molongo* undertaken from February 13–April 27, 2002, which covered the middle dry season to the early rainy season. In other periods, 20–50% of the Baka stayed at ordinary forest camps set at 45 different places and/or times, while the other 40–60% remained at the village. Thirty-eight gun hunting expeditions were held from January to August with 10–40% of males participating.

Although *molongo* has been noted as a mode of hunting in previous studies, it is distinct from other types of Baka hunting: first, it lasts for 2–3 months or longer; second, women and children, including infants, participate; and third, the Baka depend considerably more on plant food gathered during *molongo* than on hunted animals. While *molongo* does not constitute a large proportion of the Baka life in terms of household-nights during the full year, it is a big seasonal event in which the majority of Baka households participate.

The 19 households that participated in the 2002 *molongo* comprised 89 people: 17 married men, 22 married women (including two widows and three second wives), 14 unmarried boys and girls over 12 years of age, 27 children from 2–12 years of age, and nine infants below the age of two (including one born during the *molongo*). Thus, the size of the *molongo* group was large compared with that of ordinary forest camps, which consist on average of 2.7 households ($n=45$). The eight households that did not participate in the *molongo* stayed at the ordinary forest camps for snaring, dividing themselves into three groups. Two other households stayed in the village and worked in their fields.

Figure 1 shows the itinerary of the 2002 *molongo*. Most of the participants left the village on February 13, and made the first camp on the bank of the Lebe River. After two nights there, they moved about 5 km to the bank of the Honji River, where some people who had left the village later joined them, bringing the party to 89 individuals. From that point until the end of the *molongo*, no one departed except

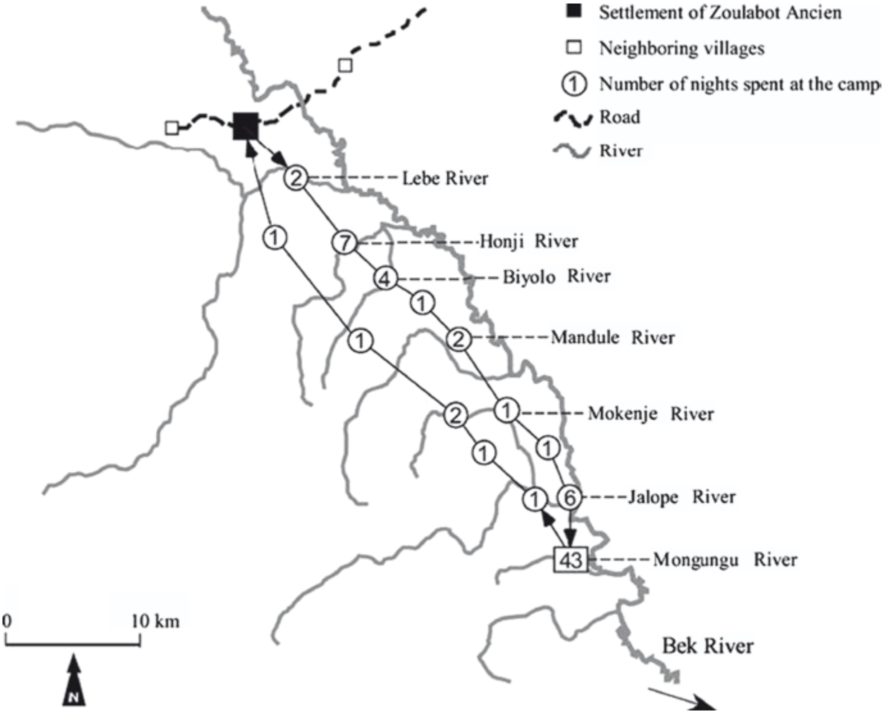

Fig. 1 *Molongo* camps and length of stay at each camp (from Feb. 13 to Apr. 27, 2002)

for two men who returned to take tobacco leaves to the village (a journey of six nights). After seven nights at the Honji camp, they moved about 5 km at a time in the direction of the Jalope River, where they said a large quantity of wild yams would be available. The elders who led the party had initially planned to stay on the bank of the Jalope, but after 24 nights and eight camps, they finally built the main camp on the bank of the Mongungu River because of the convenience of gathering wild yams. If they had traveled directly from the village, even the women would have arrived at the Mongungu in three days. The party stayed at the Mongungu camp for 43 nights. On the return journey to the village, the party divided into two, and the *molongo* finally ended 76 nights after the initial departure.

When on the move, the group would usually decamp at about eight o'clock in the morning, often breaking into several sections to variously hunt such animals as they encountered or gather plants and honey. In the early afternoon when they decided on the location of the new camp, the women began to build huts of saplings and large Marantaceae leaves, while the men again went hunting with spears or to look for honey. When fresh tracks of a large animal were found, the hunter and his assistants pursued it with the gun. The Baka moved the campsite every few days before arriving at the final camp of Mongungu, where they continued to use the forest intensively for their 43 night stay.

Once at the Mongungu camp, the men set cable snares along seven routes of 2–4 km stretching in a radial pattern from the camp. Hunters visited their snares every three days, because trapped animals spoiled within two days of dying. Men searched for honey or hunted with spears on the other days. The women went out digging for wild yams every two or three days, sometimes accompanied by their husbands. The wild yam species harvested most frequently was *Dioscorea praehensilis*, which can be found in large quantities in one place. Almost all of the cable snares and the major gathering sites for wild yams were within 3 km of the camp, so the most intensively used area was approximately ~30 km^2.

Although the men hunted with spears, a gun, machetes, and bare hands throughout the *molongo*, these methods were more important on the way to the main camp than during the stay there. Every adult male had a spear, but there was only one gun, borrowed from a Bantu villager. The Baka procured considerable amounts of meat through gun hunting although they were limited by the number of bullets supplied by the gun owner, who claimed the tusks of shot animals. The total number of animals killed by these four methods was only 19, comprising 14 species, or 17% of the total capture, amounting to 1,002.5 kg (34%).

By contrast, during the stay at Mongungu camp a total of 91 animals were caught with snares, comprising 13 species, or 83% of the total capture during the entire *molongo* period. Of the total animals caught with snares, 71% (65) were "red duikers" (*Cephalophus callipygus*, *Cephalophus dorsalis*, *Cephalophus leucogaster*, and *Cephalophus nigrifrons*). The total prey weight snared was 1,930.4 kg, 66% of the total capture during the *molongo*. The men started setting snares the day after arriving at the Mongungu camp; the total number of snares was 200 by the sixth day, 250 by the 12th day, and peaked at 300 on the 26th day. Twelve married men brought cables with them, and the mean number of snares they possessed was 25. Seven households without snares received meat from the snare hunters.

Although 89 people participated in the *molongo*, the consumption number is calculated at 66.5 (see Methods above). Edible ratio of meat is estimated at 0.6 (Ichikawa 1983), and energy value at 150 kcal per 100 g eaten (Leung 1968). Energy intake from consumed meat can be calculated from these figures. Hunting supplied 0.30 kg of edible meat or 446 kcal per consumption-day in the first period of the *molongo* (i.e., during the nomadic camps), and 0.39 kg or 604 kcal per consumption-day in the second period (i.e., at the Mongungu camp). There was no significant difference between the two periods. The meat supplied 0.36 kg or 536 kcal per consumption-day on average for the entire period of the *molongo*, of which 0.09 kg or 142 kcal per consumption-day was obtained by gun hunting. (It was noted that the gun was not always available.)

The capture rate (the number of snare-nights required to capture one animal) was calculated at 112 at Mongungu camp, whereas the average capture rate at six ordinary forest camps (located within 20 km of the village) was 122. At 71%, the proportion of red duikers to the total capture at Mongungu camp was equivalent to that at ordinary forest camps (74%). There were no significant differences either in efficiency or in the composition of game species between hunting during the *molongo* and ordinary forest camps.

The Baka diet during the *molongo* consisted solely of wild food, especially a variety of wild yams. During the stay at Jalope and Mongungu camps (from March 5 to April 23), they gathered a total of 5,446.6 kg of wild yams and a yam-like plant (*Dioscoreophyllum cumminsii*), which provided them with 1.64 kg per consumption-day. Wild yams gathered during the *molongo* consisted of five species (*D. praehensilis*, *Dioscorea semperflorens*, *Dioscorea burkilliana*, *Dioscorea mangenotiana*, and *Dioscorea minutiflora*, in the order of quantity of the harvest), of which *D. praehensilis* accounted for 85% of the total weight. A woman sometimes gathered as much as 30 kg or more of wild yams in a day. The edible ratio of wild yam is estimated at 0.8 (Kitanishi 1995), and the energy value is 120 kcal per 100 g eaten (Leung 1968).

The total amount of energy acquired from gathering was calculated at 1,786 kcal per consumption-day. This accounts for 77% of the total energy (2,322 kcal) consumed per consumption-day. Wild yams alone supplied 68% of the total energy intake; notably, *D. praehensilis* supplied 56% of the total.

In addition to wild yams, seeds of *Irvingia* spp. and *Panda oleosa*, several types of mushrooms, and honey were gathered. Honey, which the Baka are always eager to find, was not brought back to the camp in large quantities presumably because considerable amounts were consumed on the spot. Fish-bailing was seldom carried out during the *molongo*, probably because of the abundance of wild meat. However, according to informants, a few years earlier in another area, women frequently engaged in fish-bailing during the *molongo*.

Whereas the *molongo* diet consisted mainly of wild yams and "red duiker" meat, the village diet consisted principally of banana (47% of the total energy intake) and oil palm (29%). And according to my observations in the ordinary forest camps (36 meals for 16 days in the rainy season), meals mainly consisted of meat (occurrence = 18), wild yams (14), cassava flour and rice obtained from merchants (14), and honey (13). It is notable that *D. praehensilis*, which is so important to *molongo* life, was not observed in the diet at either ordinary forest camps or the village.

During the 1960s and 1970s, *molongo* was carried out almost every year; and during the 1980s and 1990s, every two years or so. Three areas were mentioned by the elders, used consecutively: the Jalope and beyond, the Loloboy River, and the Lingondo Hills. According to informants, there is a plentiful supply of *D. praehensilis* in the area from the Jalope to the Bosie River, and of *D. semperflorens* and *D. praehensilis* around the Lingondo Hills.

Potential of *D. praehensilis* as the Key Factor for Sustainable *Molongo*

Fifteen to seventeen species of wild yam (genus *Dioscorea*) and two species of yam-like plants (genus *Dioscoreophyllum*) grow in the forest areas of Cameroon. *D. praehensilis* has annual stems and annual tubers. In general, yam species with annual stems grow in the savanna, and those with perennial stems grow in the forest, but *D. praehensilis* is distributed in forest areas (Dumont et al. 1994; Hamon et al. 1995).

According to Dounias (2001), from the beginning of the rainy season (March–May) *D. praehensilis* renews its aerial stems with nourishment stored in the tubers, which then become bitter and inedible. When the stems reach the canopy (June–July) photosynthesis replenishes the starchy reserves in new tubers (August–October). Tubers reach maximum size from November to March, making the dry season the best period for harvesting, coinciding with that of *molongo*. *D. semperflorens*, the second most important wild yam for *molongo* life, has similar characteristics to those of *D. praehensilis*.

The Baka say that *D. praehensilis* plants are locally concentrated and grow in clusters so that once they find a stem they can harvest sizeable amounts of tubers at one location. I have designated these areas "affluent forest zones." A unit area of "affluent forest zone" is estimated as ~30 km^2. I estimated the total area of *molongo* used by the Baka of Zoulabot Ancien as 1,000 km^2; thus, the potential areas for *molongo* cover about 30 times the unit of an "affluent forest zone." Because *D. praehensilis* is unevenly distributed, there is insufficient information to estimate the amount available in the entire area. It is, however, reasonable to suppose that there are several "affluent forest zones" in the area. The Baka themselves mentioned that there are plenty of wild yams around the Jalope, the Mongungu, and other tributaries of the Bek. Moreover, the *molongo* ends not because the yams are exhausted but because *D. praehensilis* tubers become unpalatable in the rainy season. It is likely that if the Baka wished, they could extend the *molongo* in the Jalope–Mongungu–Sobobo areas from November to March or even to April, as long as the suitable season for harvesting *D. praehensilis* tubers lasted. As continuous harvests would eventually lead to decreases in yield, the Baka rotate the *molongo* through different areas at 2–3 year intervals. The decrease of the frequency of *molongo* since the 1980s is more likely a consequence of the introduction of agriculture than to limited availability of *D. praehensilis*. Because the dry season is the time for preparing new fields, undertaking *molongo* more frequently means the Baka cannot prepare fields of a size comparable to their cultivator neighbors' fields. Even so, life in the forest is sometimes more attractive to the Baka than the life in the village, depending on the supply of staple agricultural crops.

While I do not have enough data to examine food availability in the rainy season, there are some studies relevant to this issue. For example, Sato (2001) estimated the biomass of the wild yam tubers at 5.3–8.7 kg/ha in remote forest areas of southeastern Cameroon in the rainy season (surveyed in August and September). In his study site, *D. burkilliana* accounts for 73% of the yam biomass, while *D. praehensilis* accounts only for 8%. *D. burkilliana* have perennial stems and tubers (Dounias 2001; Hamon et al. 1995), which is advantageous when the "waiting phase" for growth is of unpredictable length, such as in tropical rainforests (Hladik et al. 1984). Further, according to the Baka, *D. burkilliana* plants and similar perennial wild yams are scattered through the forest, and do not cluster like *D. praehensilis*. Dounias (2001) suggested that Sato's low estimation of *D. praehensilis* abundance was due to the season of survey. It is also possible that Sato's field area may not have contained many clumps of *D. praehensilis*. Even so, his study indicates that the forests of southeastern Cameroon yield considerable amounts of wild yam in the rainy season.

Moreover, fruits such as *Irvingia gabonensis*, *Ricinodendron heudelotti*, *Anonidium mannii*, and *Bailonella toxisperma* ripen in the rainy season (my observation and Thikakul 1985), when honey and caterpillars are also available in large quantities. Another important consideration is that these food resources are dispersed through the forest so that the Baka have to search for them over a large area. The larger the camp size becomes, the more inefficient their gathering becomes, making it disadvantageous to form a large group in one place. This may be the reason a large-sized *molongo* group is formed only in the dry season and disperses into smaller groups in response to the seasonal change in availability of food resources. Thus, it seems probable that the Baka can subsist in the forest without much difficulty during the rainy season.

Conclusion

This case study of *molongo* shows that the forest of southeastern Cameroon has the potential to support foraging lifestyles in the dry season when the wild yam *D. praehensilis* is available, thus providing evidence that Hart and Hart's (1986) argument that the dry season and early rainy season are extremely difficult for foragers in tropical rainforest areas cannot be generalized for different parts of the Congo Basin.

Headland (1987) defines tropical rainforests as areas of evergreen forest with annual rainfall of over 4,000 mm. This definition is not, however, practical when examining tropical rainforests as human habitat, as "forest peoples" live in a variety of environments in which annual rainfall is less than 4,000 mm. Bailey et al. (1989) working in the northeastern Congo Basin, defined tropical rainforest as evergreen and semi-deciduous forests in the tropical zone. In most African tropical rainforests, annual rainfalls are generally lower than 2,000 mm (Maley 2001), and moist semi-deciduous forests cover large areas (White 2001). If "affluent forest zones" are distributed widely in such a forest environment, hunter–gatherers seem to have been able to live "pure" foraging lifestyles in quite a large area of African forest. However, in attempting to reconstruct prehistoric hunter–gatherer life in the tropical rain forests, we should pay attention to the fact that the rainforest environment in the Congo Basin may have been considerably influenced by the Bantu-speaking cultivators who have lived there for many centuries. As Hart and Hart (1986) and Bailey and Peacock (1988) suggest, shifting cultivation over many centuries may have extended the forest-savanna ecotone into the forest interior, which may have eventually influenced the distribution of light-demanding plants, including wild yams.

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Life Without Pigs: Decisions, Community Action, and Subsistence Changes Among the Irakia Awa, Papua New Guinea[1]

David J. Boyd

Introduction

The Irakia Awa are one of eight Awa-speaking communities totaling approximately 1,400 people who live on both sides of the Lamari River in the southeastern corner of the Eastern Highlands Province (geographical coordinates: 145°43′E, 6°38′S) (Fig. 1). Irakians control a home territory of 21.5 km^2 (8.3 mi^2) that ranges in elevation from 900 to 2,400 m (2,950–7,875 ft). Approximately 60% of their territory is grassland, and the remainder is secondary and primary forest. With a population of 299 in 1996 (gross density = 14/km^2 or 36/mi^2), the Irakia Awa still do not press heavily on their resource base. They continue to depend largely on subsistence production for their daily fare. Their gardens produce the standard array of Melanesian tuber crops (yams, taros, sweet potatoes, manioc), bananas, maize, squash, sugarcane, and a variety of leafy greens and other vegetables, many recently introduced (e.g., scallions, tomatoes, zucchini, potatoes, chayote, carrots, etc.). They also produce modest amounts of coffee beans as a cash crop. Significant developmental initiatives, however, have eluded them. It still is a one-day walk to the nearest road, school, medical aid post, or trade store.

Beginning in the late 1980s, the Irakians began their most recent and most extensive effort to transform local village life. During the prior decade, the community had been disrupted by a number of deaths attributed to sorcery. The fear and animosity generated by these unexpected deaths was a primary cause for the exodus of more than half the villagers. The community also had a prolonged period of hostilities, beginning in 1981 and culminating in 1985–1986, with the neighboring Awa village of Mobuta, during which three men from Irakia and two from Mobuta were killed. When a truce was eventually established, Irakians began to reassess their situation.

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[1]The original article *Life without Pigs: Recent Subsistence Changes Among the Irakia Awa, Papua New Guinea* appeared in *Human Ecology* Vol. 29, No. 3, September 2001.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_11,

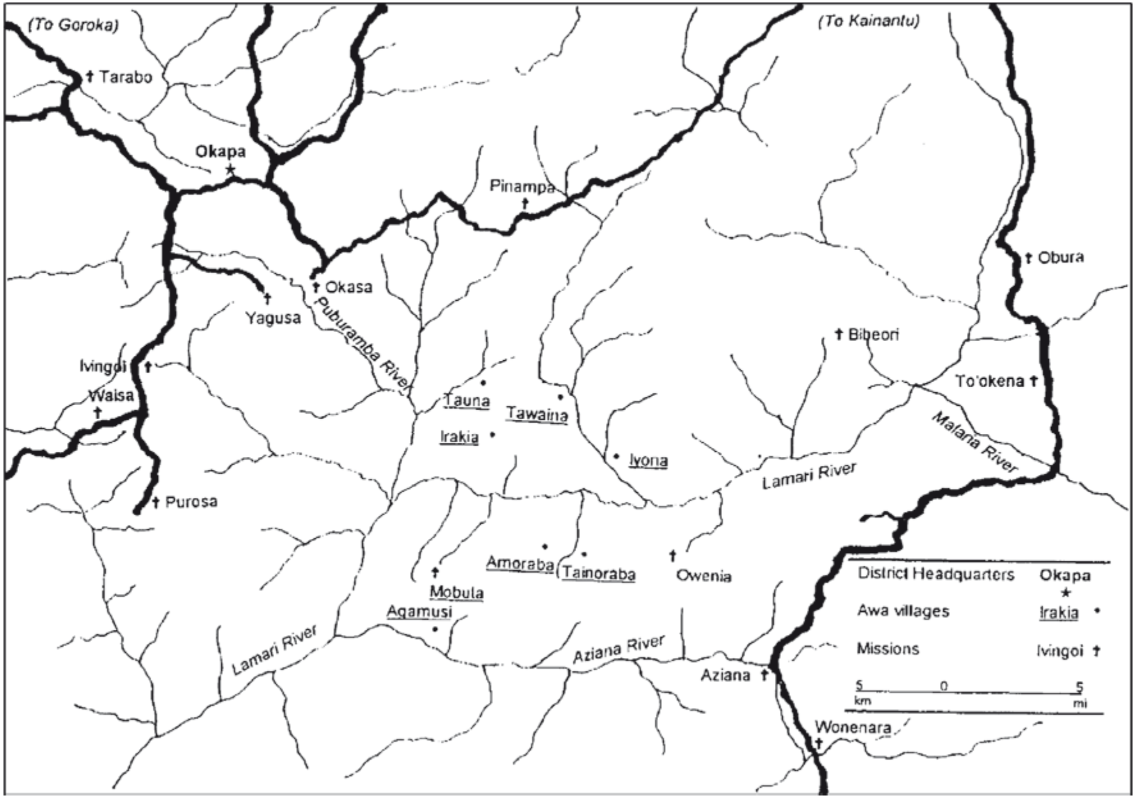

Fig. 1 Awa villages (underlined) and surrounding missions (↑) in Okapa District, Eastern Highland Province, July 1996

In this chapter, I describe the general tenor of this self-assessment and the locally-generated plan for village improvement. A major aspect of that plan – the decision to eliminate pig husbandry – is discussed in detail.

Assessing the Present and Planning the Future

By the late 1980s, most adults and many of the children had had extensive experience living at coastal and urban employment sites. There, despite the often harsh conditions and pressing need for cash, people had enjoyed some rudimentary aspects of modern life. Basic health care usually was available, many children attended schools, retail outlets offered a selection of consumer goods, and sports, movies, and church activities had provided new entertainments. In contrast, for the young adults especially, village life seemed dull and lacking.

Unflattering comparisons also were closer at hand. Irakians realized that their community was not enjoying what seemed to be the substantial improvements in lifestyles taking place in many neighboring communities. Although they had made modest efforts in the past to better local conditions and attract the assistance of government agencies and other outsiders, they still had no nearby road access, no medical aid post, no school, no retail store. In contrast, villages located on or near the regional road system that had been extended into areas to the west, north, and east had much more intensive contact with the outside world (including government services) and greater access to markets for the local cash crop, coffee beans. Also, the roads encouraged missionary groups to settle in the more easily accessible communities bringing with them many desired amenities of the modern world. In fact, Irakia was encircled by what villagers viewed as thriving missionized communities. To the west, an American evangelical mission had set up shop along the Okapa–Purosa road in the South Fore community of Ivingoi complete with a huge church, school, trade store, local health center, and coffee groves. To the north, the long-time mission at Yagusa now had a government high school with an international staff, as well as a church, elementary school, store, and aid post. Across the Lamari River to the south, the Summer Institute of Linguistics (SIL) had maintained a nearly continuous presence since 1960 in the Awa village of Mobuta, which now boasted of a community school, a church, a medical aid post, and a cattle-raising project (although still no road access). A mission group also had settled recently among the Tainoraba Awa. To the southeast, just beyond the bounds of Awa territory, the village of Owenia had two resident mission groups, an airstrip, a store, and what seemed a flourishing coffee industry.

During my visit to Irakia in mid-1991, people were well aware of the changes taking place around them, but were undecided about what steps they should take to become more involved. Many younger Irakians wanted to attract a mission, which seemed the common denominator in more successful communities. To this end they were just completing construction of a small village church. Some village elders, however, remained leery of adopting this new religion. They had rebuffed numerous overtures from mission representatives over the years and argued that they did not understand how paying homage to a foreign religion would help. But the notion was generally shared that a successful move into the realm of local improvement depended on the assistance of outsiders, preferably Europeans. There was a dawning sense, however, that this was not a likely possibility and residents felt that their prospects were bleak. Although one accused sorcerer had died and another had been expelled from the village, 52% (143/274) of village members still were living away from home.

When I returned to Irakia in mid-1993, people were much more upbeat. They had a functioning evangelical church and had hopes of attracting a resident pastor. For the time being, local young men, who had converted to Christianity while working at coastal plantations and had returned home with Bibles and guitars, presided over the weekly services. In addition to the church activities, they had built a new men's house and were preparing for a male initiation ceremony. This was a significant development as men's houses, once central to men's culture, were abandoned some 15 years earlier and no male initiations had been held since the mid-1980s. People also had planted large gardens in anticipation of the coming event, money was being pooled to finance the purchase of rice, tinned fish, beer, and other store goods, and materials were being collected from the forest to build sleeping quarters and bonfires for the anticipated guests.[2] Emissaries also had been sent to various employment sites to encourage migrants to return home, and most migrants – still 52% (152/293) of village members – indicated their desire to do so (see Boyd 2000). It was a time of local confidence and unquenchable optimism.

I again returned to Irakia in mid-1996 and found that the local enthusiasm had not waned. Virtually everyone was anxious to explain to me what community members had accomplished in my absence. They intended, according to many proponents, to make the village a more attractive place to live. They said that shared Christian virtues, as well as a ban on alcoholic beverages and gambling, would reduce social conflict. Their idea was that improved housing, more locally generated income from coffee, and organized competitive sports teams would make life more comfortable and enjoyable for everyone. Also, altering gardening strategies, already underway, would reduce the time that people devoted to food production. It was hoped that such changes would encourage people to remain permanently in the village and entice migrants to return home to stay. In fact, this already was beginning to happen. In 1996, only 22% (67/299) of village members still were living away from Irakia. If, as expected, village life became more agreeable and resident villagers became more numerous and self-sufficient, other improvement projects could be initiated. All these changes are, of course, complexly interrelated. But the one change that has had the most immediate and far-reaching effect on Irakia Awa subsistence practices, was the decision to abandon pig husbandry.

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[2] The initiation did occur a few days after my departure from Irakia in August 1993, and by all accounts was a huge success. Visitors came in large numbers from neighboring communities and were housed, fed, and given appropriate gifts of food. All Irakians felt that their labors in staging the initiation, while demanding, had been justly rewarded. They had regained the respect of neighbors, affines, and exchange partners.

Pigs and Highland Societies in New Guinea

The domestic pig (*Sus scrofa papuensis*) was for long an important feature of human adaptations throughout Melanesia and most especially in the New Guinea Highlands. While the actual location and exact date of initial pig husbandry in the region are not known, archeological evidence from the Manton site at Kuk in the Western Highlands indicates its presence, along with probable taro cultivation, possibly as early as 9,000 BP. This early date rivals estimates of pig domestication in the Fertile Crescent and China, and admittedly is controversial. But it generally is agreed that evidence from Highland sites does support a date of 6,000 BP (White 1972; Golson and Gardner 1990). What is uncontroversial is that domestic pigs have played a pivotal role in the evolution of Highland societies and remain an important element in most contemporary village economies in the region. Given the importance of pigs in human subsistence systems in this anthropologically interesting part of the world, it is not surprising that they also have been an important focus of several theoretical challenges and reformulations in anthropology.

Early observers of societies in the New Guinea Highlands were quite impressed and a bit mystified by the amount of effort devoted to pig husbandry and the curious manner in which the animals were used. Pigs obviously and voraciously consumed an array of local food resources, many of which also were on the human menu, and their husbandry clearly required a good deal of human effort. But rather than being slaughtered and consumed on a relatively regular basis as a protein supplement to a largely carbohydrate diet, they were slaughtered in large numbers on infrequent ceremonial occasions. People gorged themselves on pork, some got ill and occasionally died from an intestinal infection, known as “pig bel,” associated with such feasting behavior,[3] and some of the meat was simply wasted. These massive ceremonial pig slaughters were initially considered to be yet another example of the irrationality of “primitive” economies.

Such views were eventually challenged by various neofunctionalist arguments that asserted the human benefit, or utility, of Highland pig husbandry practices. Pig raising strategies were reinterpreted as a rational way of converting vegetable crops to high-quality animal protein in a protein-poor setting. Pigs might be seen more usefully as “…food resources on the hoof” (Vayda et al. 1961:71). This important corrective stimulated researchers to pay much closer attention to the role of pigs in Highland adaptations. Certainly the most widely known study to result from this reorientation was R. A. Rappaport’s *Pigs for the Ancestors* (1968), which explored the complex relationships between the Tsembaga Maring people and their local environment that seemed to be mediated by pig husbandry and cyclical pig slaughter ceremonies.

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[3] “Pig bel” (*Enteritis necroticans*) is caused by a *Clostridium* bacterium that is spread from the pig entrails to unsuspecting participants during the butchering of the animals. Children under five and adults over 40 are especially vulnerable.

In the meantime, the dynamics of complex regional exchange networks, which seemed to consume the attention of members of the largest Highlands societies, were also being studied in some detail. What we learned is that pigs in these societies are highly domesticated, managed herds (Brookfield 1973; Hide 1981) and that these ceremonial exchange systems, in which pigs play such a prominent role, bring together politically autonomous groups into what arguably constitute the most encompassing polities in the precolonial Highlands.

The place of pigs in the anthropology of the New Guinea Highlands societies became, in many respects, a paradigmatic example of how attempts to explain an important feature of regional social life reflect changing currents in Western social theory. As theoretical interests changed, so too did the interpretation of pigs in the New Guinea Highlands. From being an economically irrational drain on the human resource base, to being a protein storage mechanism, to being a managed resource with important implications for human well-being, to being a possible key variable in explaining historical process, pigs obviously were an important aspect of Highlands societies. All students of the region recognized that little of social importance transpired without the transfer of pigs. Nearly everywhere, pigs or, in some instances, pork, were required to settle disputes, compensate enemies and/or allies for deaths in warfare, cement exchange relationships, finalize marriages, cure the seriously ill, and inter the dead.

The Irakia Awa and Their Pigs

Until the 1990s pigs were an important aspect of the Irakia Awa adaptation. Although pigs were not raised in such large numbers or accorded the attention given in intensive pig-raising societies further west, they were nevertheless the most valuable component of Irakia household production. The Irakian pig-raising strategy, until the early 1970s, could be fairly characterized as one in which nearly all animals were raised at "home" on local village resources, as they obtained most of their sustenance by foraging, and were "semidomesticated" (all male piglets were castrated and village sows were impregnated by wild boars), spending most of their time away from the village, but returning regularly to receive small amounts of foodstuffs from their caretakers. The uses to which pigs were put also were more limited than in societies further west. A live pig was very rarely included in an exchange transaction and then only to comply with the recipients' demands. The usual medium of exchange, however, was pork. Allies, but not enemies, in warfare were compensated with pork for injuries or deaths, male initiations and marriage rituals were celebrated with feasting on pork, curing rituals for particularly intractable illnesses required portions of a freshly slaughtered pig carcass, and mortuary ceremonies for adults usually culminated with a distribution of pork. Also, husbands were required to repay bridewealth contributors with standardized portions of pork and occasionally to present their wife's relatives with a large pig for slaughter to cement the affinal relationship. Although individual men or groups did not engage in formal potlatch-like competitive exchanges, people who were recognized as especially successful pig raisers were accorded enhanced respect. They were considered not only skilled at raising pigs and, therefore, reliable exchange partners, but also superior in their ability to avoid the impact of nature's various calamities.

The importance of pigs to Irakians also is illustrated by the fact that in late 1971 they made a concerted effort to increase the size of the village herd by adopting a pig-raising ritual complex from the neighboring South Fore people. The impetus for this innovation was the increasing demand by affines and exchange partners for live pigs in exchanges, as well as more money in bridewealth payments. This actually precipitated one of the first major crises stemming from the expansion of the nascent cash economy. Groups that lived near the growing road system, and therefore had more access to new economic alternatives, asked for increased quantities of goods, especially pigs and cash, in exchange transactions. The initial reaction of Irakian leaders was to try to meet the new demands by raising more pigs. To further that goal, they borrowed and implemented the neighboring South Fore pig husbandry practices, which involved enacting several rituals to improve the growth and reproductive rates of pigs and provisioning the animals with greater amounts of fodder. These new practices were successful in the short-run, increasing the herd size from 148 to 191 animals (29%) in about nine months. However, this change also initiated a subtle shift from a forage-based to a fodder-based pig-raising economy. Within a short period of time, Irakians began to provide pig fodder twice each day, occasionally cooked food specifically for their pigs, and regularly enacted various rituals to stimulate their growth and reproduction. But by the early 1980s pigs had become secondary to money even though they remained a necessary item of exchange. What is interesting here is that even with the predominance of money for exchange, this intensified pig-rearing continued for the next two decades. Despite the fact that the resident population declined by nearly one-half between October 1972 and June 1991, the number of pigs/household and pigs/resident remained relatively stable. In the early 1990s, however, this began to change. The size of the village pig herd was decreasing, an indication of the declining commitment to village pig husbandry. At the same time, the resident human population was rebounding as members began to return to the village from coastal and urban work sites. While changing numerical averages give important hints of changes in group strategy, they tell us little of how people actually altered their lives.

The Change

The decision to initiate a program of major change in Irakia took some time to garner support. In 1991, while sitting under the shade of a tree on a grassy ridge waiting for my companions' wives to return from their gardens, two young men in their thirties told me that the young people wanted to stop raising pigs. When I expressed dismay, they tried to explain that the effort it took to raise pigs no longer was rewarded by corresponding benefits. Pigs required daily attention, and people had to make large fenced gardens to feed them. And the animals were always causing trouble among villagers. Furthermore, owners then gave their animals to others to eat. It was as if pigs owned people. They told me that they had discussed the idea of getting rid of pigs with other young people, and together they had all agreed that it was time to do so. My companions, like most young adults in the village, had lived for long periods of time in towns or at coastal plantations where they did not have the burden of caring for pigs. However, when they had approached older people with their radical proposition, the elders disparaged the idea and criticized the younger people for being lazy and unwilling to lead proper lives. If you have no pigs, the elders had asked rhetorically, what will you give to the brothers of a woman you wish to marry, how will you show proper respect to your affines, how will you maintain the allegiance of your exchange partners? And, what will women do with their time? The young men in my company admitted that it would be impossible to make such a change with the elders firmly against it, so they would have to wait until the older generation was gone. But sooner or later, they affirmed, pigs would have to go.

Within a few years, support for the discontinuation of pig husbandry was bolstered by the return to the village of a number of young people who had converted to Seventh Day Adventism (SDA) while living at coastal plantations. An important prohibition within the SDA church is the consumption of pork. These young adherents simply refused to have anything to do with pigs and supported the movement to eliminate them altogether from the village. All Irakians certainly were well aware of the SDA injunction against raising pigs and consuming pork. After all, an SDA mission had been located in the nearby village of Okasa since 1956 (Alpers 1965:79) and the fact that members raised goats instead of pigs was a subject of curiosity and mild derision by others.[4] Certainly, for more than three decades, no Irakian had ever seriously suggested following a similar course.

After the deaths of several prominent older leaders, younger families began, in mid-1995, to slaughter their animals, giving the meat to non-SDA community members and to close relatives in other communities. By late 1995, the entire village herd had been butchered, except for one animal – a big sow belonging to a respected man who at that time was the oldest member of the community. He refused to kill his sow, saying that she was the best tempered, most (re)productive pig that he had ever owned. When he died, he said, others could kill the pig for his funeral feast. They would die together. That is exactly what happened. Popo'tara died in early August 1996, as did his beloved sow.

What I soon came to realize was that doing away with pigs was but one aspect of a concerted and deliberate effort to transform village life by reducing the amounts of time and labor people had to devote to subsistence activities. Without pigs to look after, people could spend more time on cash earning activities and

[4] In the early 1970s, Irakians did not yet know a word for "goats," so referred to them, in Neo-Melanesian TokPisin, as "pik bilong Sevende" ("SDA pigs").

recreational pursuits. People in the neighboring Awa village of Tauna, to the north, also had recently killed all their pigs.[5] Village life would simply become more fun without pigs.

The instituted changes in Irakia, however, did not stop there. Irakians also decided to change consumption patterns by focusing their diet more on manioc and sweet potato, rather than yams and taro. Combining the elimination of pig husbandry and the shift towards manioc and sweet potato as primary garden foods resulted in a substantial disintensification of subsistence effort.

Life Without Pigs

Some ramifications of a village without pigs were apparent immediately. When I arrived in Irakia in early July 1996, I did not have to climb a fence to enter the village proper. In fact, what remained of the enclosing fence was totally dilapidated. Also, I did not have to calculate carefully every footfall along the path to avoid soiling my boots.[6] When I asked about the deteriorating village fence, people replied simply that they didn't need it anymore. Given my previous experience during the pre-1975 colonial days, I casually assumed that the end of the colonial era finally had filtered down to these rural residents. They no longer had to fear that colonial patrol officers would arrive without warning and demand stronger village fences and deeper latrines, both of which were now missing. When I inquired further, they said that they no longer needed fences because they had no village pigs to fence out. "No pigs to fence out?" I asked. "Yes," they responded, "We killed all of them."

One of the most important effects of the demise of the village pigs was the reduction of labor devoted to fencing food (and coffee) gardens. Previously, all gardens within the foraging range of pigs had to be strongly fenced to keep them out. This required cutting and transporting to garden sites saplings for fence posts, lengths of bamboo from distant groves for fence rails, and rattan vines from the forest for ties. The building of fences was the most demanding task for men in garden preparation and was exceeded only by the labor required of women in tilling the soil in grassland gardens. In a random sample of 264 food garden plots in 1971–1972, 90% were fenced. That people attempted in the early 1980s to excavate a long (and ultimately unsuccessful) pig-proof trench barrier around a commonly cultivated area attests to the fact that fence-building was a burdensome job. Now, with no pigs, fencing was no longer necessary.[7]

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[5] A visitor to Irakia from Tauna, in 1996, told me that people in Tauna were very pleased not to have pigs to look after anymore. Frankly, he said, it was a relief not to be raising pigs because they demanded daily attention, ate everything in sight, and simply could not be trained, like a dog, to behave properly. According to informants, Tauna and now Irakia are the only Awa communities that have stopped raising pigs.

[6] Incidentally, the largely barefoot Awa consider stepping in pig manure a vile experience.

[7] Wild or feral pigs have not been encountered on Irakian territory since the early 1990s.

Doing away with pigs also relieved women of the daily chore of transporting food and feeding the pigs under their care. Although pigs had always been allowed to forage freely for much of their food, caretakers were expected to feed their animals small amounts of substandard garden produce and household food scraps each morning and evening. I asked women how they felt about no longer having domestic pigs. Older women, who had raised pigs for their entire adult lives, noted that pigs did require a lot of work and said that they really did not mind not having pigs to tend anymore. But skillful caretakers also had been highly respected and now that too was gone. They also expressed concern that the younger generation did not understand the importance of pigs. Pigs brought people together and now what would take their place, they asked rhetorically. Younger women, most of whom had spent their formative years at coastal plantations or in urban areas where families did not raise pigs, said that not only did they not know how to take care of pigs, but they did not want to learn to do so. It was something to which their mothers had devoted themselves, but that was in the past.

One Saturday morning while we were waiting for everyone to bathe and get ready to go to church, a son of one of my closest collaborators in the 1970s (now deceased) put his arm around my shoulder. He said that people were of the opinion that I did not understand why they had killed all the pigs. People recognized that I was from an older generation, he explained, and he would tell me why they had done away with the pigs. Pigs, he said, were simply too filthy and disruptive. They fouled the village grounds, trails and waterholes with their feces and broke into gardens, thereby causing animosity between neighbors. Also, whenever anyone slaughtered a pig for distribution to fulfill some social obligation, invariably someone would feel that he/she had not received the share to which he/she was entitled. This would lead to hard feelings and often to sorcery. It was just like card-playing, he said – if someone was a consistent winner, others would suspect him of using sorcery against his opponents. If such an accusation was made publicly, it could arouse potentially violent reactions. It was the same thing with pigs. Therefore, doing away with pigs would eliminate these tensions and make the village a more peaceful and safer place. No longer would people quarrel over pigs.

What is apparent here is a stark intergenerational difference in the significance attached to pigs. Older people see pigs as essential to the integration of different clans and communities while the younger generation has decided that pigs are something they can do without.

Altered Irakian Gardening Strategies

It is important to emphasize that Irakian subsistence practices had begun to change some years before the wholesale slaughter of the village pig herd in 1995. In the late 1980s, many people already had begun to alter their household garden repertoires and food consumption preferences. But, as I discuss below, changes following the elimination of pigs were more rapid and more dramatic. First, a brief overview of basic Irakian gardening strategies is necessary.

The Irakia Awa food garden repertoire consists of eight different garden types, easily distinguished on the basis of location (forest vs. grassland), soil preparation technique (tilled vs. untilled), presence or absence of irrigation, and principal crop(s). The annual gardening cycle is characterized by two periods of relatively uniform activity by all households and two interim periods during which the gardening activities of different households vary somewhat. During August–November, all households clear and plant at least one forest yam-taro (*to'*) garden, and from February to July, all households make at least one grassland yam-taro (*ongi*) garden. During the interim period, i.e., November–February, each household selects from the six other possible types of gardens those that are compatible with their current household labor supply and anticipated consumption needs for the coming year. In July–August, households round out their selection of gardens by focusing efforts on either a tilled (*o'maka*) or untilled (*topankago*) grassland sweet potato plot.

By 1991, people had largely given up making irrigated grassland taro (*mehko*) gardens. The labor required to till the root-bound grassland soil, build the fences, and transport and construct the bamboo irrigation pipelines was thought not to be worth the effort. Also, the preparation and planting schedule for *mehko* conflicted with that for the *karipe ongi* peanut gardens that many people were expanding. Besides, people were eating more manioc these days and really did not need the additional *Colocasia* taro from *mehko* gardens. "Pitpit" (*Saccharum edule* and *Setaria palmifolia*), a principal crop only in *mehko*, could be planted more heavily in other gardens (i.e., *o'maka*, *to'*, and *topankago*) to cover its loss in the *mehko*.

One energetic elderly man did, however, make a *mehko* in 1991. He said that he had done so because he loved taro and wanted to show the younger generation how to make this type of garden. Every time we passed by this garden companions pointed it out to me. They obviously were proud of it, but no one else had ventured to make this type of garden since then.

Another important change observed in 1991 was a very apparent increase in the planting and human consumption of manioc. In the 1970s and 1980s, manioc was planted at medium densities only in tilled grassland sweet potato (*o'maka)* gardens and most of the tubers were fed to pigs. Although a minor human food source at that time, it was used in preparing a special ceremonial dish, called *apoyeh*, for which 12-foot lengths of bamboo were split and flattened, covered with banana leaves and thin parchment from the inner core of banana stalks. Grated manioc mash was spread over the leaves and topped with small pieces of various savory treats, e.g., pork, game animals, grubs, smoked rodents, etc. The flattened lengths of bamboo were then rolled together to enclose the mixture and carefully slid into long hollowed-out bamboo tubes for cooking over an open fire. When done, the rolled bamboo lengths were pulled from the cooking tubes and the *apoyeh* inside was cut into foot-long portions for consumption. Although it was an infrequent and quite laborious preparation, *apoyeh* was relished by all.

By 1991, *o'maka* gardens were densely planted with manioc and it was also occasionally scattered in *topankago* sweet potato gardens. Also, leaf-wrapped packets of grated manioc were a common meal and late night snack. People explained the increased planting of manioc by noting that it is easy to grow, requires little tending, and does not have to be harvested when it is mature. It can be left in the ground for long periods and therefore is always available when people are hungry. Once people learned how to cook manioc properly for humans, they found it delicious.

When I returned to Irakia in 1996, after the pig herd had been eliminated, I surveyed village lands from a nearby ridge. It was apparent that people had planted huge food gardens as near the village as possible. Some gardens had always been placed next to the village proper, but this location was an area of high pig predation. Households reduced this risk by planting several gardens and scattering them widely over land to which they had access, often at considerable distances from the village. If pigs (or sometimes insects) ruined gardens in one area, food supplies would be available in gardens located elsewhere. But without the threat of pigs, this precaution was no longer necessary. People felt free to make larger, but fewer, gardens and locate them nearer their residences.

People still do make gardens at distant sites, some over an hour away from the village. When visiting a garden at the outer boundary of Irakia territory, I asked the owner why he had chosen to put a garden so far away. He responded that crops had always grown well at that place and that his father had made gardens several times in the same location. He liked the place and enjoyed remembering making gardens there with his father. Also, he added, if he did not make a garden there occasionally, others might challenge his right to use the land.

The lack of any threat of pig predation had another noticeable effect on villagers' placement of their various garden plots. Increasingly, households choose to locate different types of gardens in close, often adjacent, proximity. For example, it now is common for a household to choose a garden site along the grassland–forest boundary and to plant a grassland yam-taro (*ongi*) garden and a forest yam-taro (*to'*) garden next to each other. During the next phase of these gardens, the *ongi* will become a peanut (*karipe ongi*) and/or a tilled grassland sweet potato (*o'maka*) garden, and the *to'* will be converted to a forest sweet potato (*topankago*) garden. Nowadays people often plant contiguously forest yam-taro (*to'*), forest sweet potato (*topankago*), and sugarcane (*ta'kigau*) gardens in the forest zone. These new strategies of placing many gardens near the village and aggregating more distant gardens of different types in the same locations greatly lessen the travel time between house and garden. It is an important reduction of subsistence effort.

Changes in Non-subsistence Related Activities

As noted above, fundamental changes in subsistence practices have taken place in conjunction with important changes in other aspects of the Irakian lifestyle. While basic food production has been disintensified and pig husbandry has been eliminated altogether, other activities have been expanded and new ones have been adopted. Here, I will mention the most important of these nonsubsistence changes.

In an effort to make the village more self-sufficient in money (and thereby reduce the pressure on members to migrate for wage employment), many people planted new coffee gardens in 1995–1996. Coffee sales during the 1995 marketing period totaled PGK8,238 (US$6,179)[8] for the entire community.[9] Irakians understood that if members were to remain in the village, they would need greater local income. Of the 56 resident households in 1996, 47 (84%) had planted as least one new coffee plot. Based on a selective survey in 1996, I estimated that village coffee holdings had increased by about 50%. Of course, coffee market prices fluctuate rather widely from year-to-year, but coffee remains the largest source of locally earned cash for villagers in the region and indeed is the backbone of the entire Highlands market economy.

To augment coffee earnings, many households now plant large *karipe ongi* peanut gardens and market some of the crop for cash. This rather laborious activity involves harvesting, cleaning, and trimming the plants, tying 3–5 stems into individual bundles, and then transporting the nuts on a day-long walk to the periodic market in Okapa for sale. An individual can transport a load of 60–80 small bundles, each of which will be sold for 10 toea (US$ 0.08) at the market. Each seller, then, can expect to earn PGK6–8 (US$5–6) per marketing trip. By 1993, members of only three households had marketed peanuts in Okapa. During 1995, however, members of 49 households earned a total of PGK1,623 (US$1,217) from the sale of peanuts. It is a small, but important, cash augmentation to the village economy.

The elimination of pigs of course raises the question of how Irakians will meet exchange obligations to recipients who demand meat as part of the transactions. The commodity that has replaced pork, evidently in much of the Highlands, is imported frozen lamb flaps or mutton ribs. On occasions when meat is required, Irakians purchase cartons of lamb flaps in Okapa or even as far away as in Goroka. It is considered a prestige food and is acceptable to village SDA members. What is obvious here is that the cessation of pig husbandry has bound Irakians ever more tightly to the cash economy.

A major new focus of daily village activity is sports—basketball (mainly for women) and soccer (solely for men). Again, the influence of experience away from the village is important. People learned to play basketball while working at coastal plantations. When they returned home, they carved out a court in the middle of the village, bought ball and rims in the town, and nailed homemade backboards to logs set vertically in place. Rarely does a day go by without a late afternoon pick-up game usually involving both men and women.

Soccer has become the passion of young (and some not-so-young) men. The game was introduced in 1994 by a young man who had learned to play while living with relatives in a South Fore community. Although there is no level ground within Irakian territory the size of a regulation soccer field, an area has been marked out, and the players' enthusiasm overcomes the imperfect condition of the pitch. Several neighboring communities have also organized soccer clubs and recently

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[8] The Papua New Guinea kina (PGK) was valued at US.75 in 1996. One kina equals 100 toea.

[9] These data are based on seller recall in July 1996. Household coffee sales ranged from PGK10 to 1,110 (US$8–833), averaging PGK147 (US$110) per household, or PGK7 (US$5) per resident.

have gotten together several times each year for week-long competitive tournaments. Each participating team pays a PGK60 (US$45) entrance fee and cash prizes are given to the three top teams. Irakian teams still do not have proper uniforms or cleated footwear, but players and spectators alike enjoy these events.

These sports teams have become a primary focus of village life. Not only are there practice sessions almost daily, but teams can also be hired to perform a variety of tasks. Auxiliary household labor used to be recruited on the basis of kinship – a man would ask his sisters and/or his affines to help clear or plant a new garden and would reimburse them with foodstuffs from his mature gardens (see Boyd 1981:80). Today, sports teams, eager to earn money for uniforms and entrance fees for tournaments, offer their services for a fee. The women's basketball team can be hired to clear, till, or plant a new garden for PGK4 (US$3) per day. The men's soccer teams charge PGK6 (US$4.50) for a day of house-building or garden clearing. If team members do not show up for such work-days, they are fined 20 toea (US$0.15).

It should be noted that not everyone supports the changes underway in Irakia. A few older men and women do not oppose the recent changes, but continue to smoke their home-grown tobacco and occasionally chew wild betelnut. They generally attend the Saturday church services, but admit that they do so to visit with fellow villagers and do not really understand what they are about.

There also is a small group of young unmarried men that openly defies the prohibitions on alcohol and card playing in the village. They float between the village and other venues, make only small gardens for themselves, and occasionally bring beer to the village and host gambling sessions with cards and darts. When confronted by the reformers, they coldly respond that Irakia is their village too, and they will do what they want. It is a source of recurring friction within the village.

Conclusion

The recent changes in Irakia Awa village life are quite dramatic. Faced with the apparently superior progress of neighboring communities and the seemingly stagnant condition of their own community, young Irakian leaders decided to act. No longer hopeful, because of their rather remote location, that outsiders, including government representatives and missionaries, would come to their aid, they formulated their own plan of village improvement. New gardening strategies and consumption practices were adopted. Sorcerers had been expelled from the village, domestic pigs had been eliminated, new coffee was being planted, a church had been established, and competitive sports teams had been organized. With these changes, village members living away as migrants had begun to willingly return home. Irakians believe that these attempts to disintensify subsistence effort, remove the threats of sorcery and warfare, and intensify cash-earning, religious, and recreational activities will provide opportunities previously unavailable to local residents. To date, most residents and returned migrants seem committed to the new ways and express confidence that Irakia has embarked on an effective, locally-generated course of village improvement.

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Food Security and Pastoralism in the Northern Sahel[1]

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Introduction

In African drylands, pastoral livelihoods are increasingly under pressure due to persistent encroachment on pastoral space. In general, modern states tend to see pastoral land use as "messy" and seek to make this form of land use more controllable and taxable through projects of sedentarization. In addition, international development agencies often see sedentarization as a solution to food insecurity and poor health care (Fratkin et al. 2004). However, attempts at controlling and settling mobile pastoral communities have a long history in Africa, using three main arguments. First, sedentarization projects have been driven by exaggerated and often unsubstantiated claims that emerged early in the colonial period regarding pastoralists' destructive impact on the environment. Even though these claims have been undermined by scientific data from the 1980s and 1990s, they continue to thrive as part of African pastoral policies.

Second, pastoral livestock production tends to be perceived as unproductive and therefore not contributing much to the overall economy of a country in spite of official statistics in several West African Sahelian countries showing that animal husbandry is important for national economies. In Mali, for instance, the export of domestic animals to neighboring countries is one of the largest export commodities (after only gold and cotton). Third, recurrent droughts in the Sahel have fostered attempts to make nomadic pastoralists diversify their mode of subsistence. National governments and international development agencies often argue that it is important that nomads do not depend only on one source of income.

[1]The original article *One Leg or Two? Food Security and Pastoralism in the Northern Sahel* appeared in *Human Ecology* Vol. 36, No. 1, February 2008.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_12,

Agriculture is therefore frequently promoted in areas that are dominated by animal husbandry, and ensuing diversification projects have often been carried out in conjunction with attempts at sedentarization.

In this chapter, we address the question of whether diversification of livelihoods is such a good idea for highly mobile pastoralists in the driest parts of Africa. We focus in particular on household food security among Tuareg pastoralists in the Gourma area of northern Mali, comparing nomadic and sedentary population groups. We found that the children of pastoralists are better nourished than the children of sedentary farmers and that the children of the sedentarized nomads seem to be the worst off. Based on these findings, we argue that diversification, wherein we define diversification as an increase in the number of production activities for a particular production unit, does not benefit mobile pastoralists in arid zones, such as the Tuareg in the northern Sahel, because the logistical and organizational costs of combining different modes of livelihood are large and can easily become insurmountable for a single household. More sustainable adaptations may be achieved with specialization of production units and trade. Diversification of production may be useful, but only if it is possible within the division and organization of labor within the units of production.

The Data

The data used in this paper are from several sources and were collected as part of an interdisciplinary research project in the Gourma during 1987–1992. The analysis is on the basis of a number of qualitative interviews with pastoralists as well as surveys on human nutrition. In addition, further interviews were conducted in 1997 and 1999.

A survey was made of the ingredients in the food consumed by nomadic households. Altogether 427 households were interviewed by a local field assistant. Each household was asked what food its members had consumed the previous day and to provide some basic socioeconomic data, including kin-group affiliation and household structure. The survey spanned the period from April 1990 to January 1992, but some periods were covered in much less detail because of social unrest in northern Mali.[2] In addition, we use data from two surveys of the nutritional status of children with sample sizes of 861 and 1,205 children between six and 59 months of age. The first survey was carried out in May–June 1990, i.e., at the height of the dry season. The second was carried out in November–December of the same year, i.e., about the time of the harvest. Data on the socioeconomic conditions of the children's households were also included. The two surveys were each divided into three geographical subsamples – the inner Gourma, the river valley, and Hombori.

[2]The Tuareg rebellion started in June 1990 and lasted until the official burning of arms in Timbuktu in March 1996 (*La Flamme de la Paix*).

We also use data from a small survey carried out in May 1992 among nomads in the Fintrou area of the inner Gourma covering 146 children between six and 59 months of age, and including all children in the nomadic camps that used the Fintrou Lake as a dry season water source.

The Study Area

The District of Gourma Rharous, the main focus of this paper, occupies 65,000 km^2 south of the Niger River, north of the border to Burkina Faso, west of Gao, and east of the Niger delta. The climate is hot and dry, with a highly variable annual rainfall of 50–400 mm increasing from north to south. The main ethnic groups are the pastoral Tuareg and the agricultural Songhay. In addition there are Bozo who fish in the Niger and the lakes, pastoral Fulani in the southern Gourma, and the pastoral Ifoulanen, who appear to be Fulani who have adopted the culture and language of the Songhay, Tuareg, or both. The population of the District of Gourma Rharous approximately doubled between 1936 and 1987, from about 45,000 to 96,000. During the same period, the proportion of nomads in the Gourma seems to have declined (see Pedersen 1995 for a discussion of population trends in the area).

The Gourma was hit by drought several times during the 20th century, most importantly in 1903, 1913–1914, 1930–1932, 1944–1948, 1972–1975, and 1982–1987. Nomads who survived the great droughts during the 1970s and 1980s say that based on what their parents told them, the drought that hit the area in 1913–1914 must have been the worst during the whole century. While nomads in good years stay within a relatively limited area, they have to move more during bad years to find water and pastures.

Tuareg Subsistence Strategies

Pastoralism

Even in good years, nomads move regularly among pastures to keep their herds fed and watered. Most Tuareg pastoralists maintain mixed herds of dairy animals – camels, cows, sheep, and goats – as well as donkeys, which are used for transport, as are camels for those who can afford them. As they are constantly on the move, they solve the problem of storage by keeping larger herds of livestock than they need to provision themselves so that they can sell or trade animals for grain from farmers during the dry parts of the year.

The basic pattern of nomadism in the Gourma is a yearly cycle between dry season and wet season pastures. Dry season pastures are in the inner Gourma around deep wells, permanent shallow lakes, or wells dug into the dry lake bottom, as well as the rich pastures of aquatic *burgu* (*Echinochloa stagnina*) along the Niger River and Gossi Lake. As they are exploiting key resources spread over a wide area, such as pastures, wild grains, crops, and surface water, all highly dependent on the strong rainfall fluctuations in the area, the Gourma Tuareg have to be flexible and opportunistic in the management of their herds in relation to these resources.

Most Gourma nomads follow a preferred migration route along which are *ihanzuzagh* – the places where a group will pitch their tents if conditions permit and which are associated with feelings of attachment and belonging. However, deviations from this routine often occur because of shifts in the availability of pasture and water. Outbreaks of disease in the herds or social unrest also influence the pace and route of the migration, as increasingly does the presence of new groups and herds belonging to absentee owners that have entered the area.

Gathering

Some households gather wild plants to supplement occasional shortages of other foods, but many base their economy predominately on gathering wild plants. The most important plants gathered for food are potentially the main source of energy in a meal, in varying proportions to domesticated cereals. The wild cereals *Panicum laetum* (wild fonio) and *Cenchrus biflorus* (bur grass or cram–cram) as well as the fruit of *Boscia senegalensis* are dietary staples. In addition to food, wild plants also play an important role in the economy as raw materials for crafts and medicines.

Agriculture

There are three main forms of agriculture in the Gourma: cultivation of floating rice along the Niger River, generally an activity of the Songhay, although Tuareg who have settled in the government designated so-called “fixation points” (*points de fixation*) also cultivate rice; rain fed millet farming practiced by both nomads and sedentary agropastoralists; and thirdly, gardening, mainly a result of NGO stimulated development in the area, which takes place in villages and fixation points along the river as well as at some of the important shallow lakes, where lettuce, onions, and tomatoes are the most common products grown.

Rice farming competes for land with burgu pastures, and many burgu fields have been converted to rice plots as a consequence of decreased flooding of the Niger River due to droughts and hydropower development in southern Mali. Burgu grows on deeper water than rice and when water levels decrease, rice fields tend to encroach on burgu fields, thus diminishing a key resource and grazing reserve during the dry season for the pastoralists. The cultivation of floating rice along the river is a fragile system involving considerable risks. The traditional system of rudimentary dikes is totally dependent on a gradual flooding of the river to avoid drowning of the paddy. NGOs, such as the Norwegian Church Aid (NCA), have introduced an improved system with more robust dikes and gates and sometimes diesel-driven pumps to control the water level in the fields, which has decreased, but not eliminated the risks. One of the main obstacles to agricultural intensification and effective flood control management in this area is the low population density. The lack of sufficient manpower is especially conspicuous in the "fixation points," where nomads are encouraged to settle and cultivate rice, sometimes transforming their burgu fields into rice fields. As long as NCA paid people with "food for work" to construct dikes and gates, manpower was available. But as soon as this support stopped, people had the choice between staying and investing more work in a very risky agricultural operation or resuming moving with their livestock. Usually, the second alternative was chosen.

Millet farming, on the other hand, requires little capital input except for the seeds and is carried out by nomads along with pastoral activities. In what must be characterized as "hit and run agriculture," the fields are prepared and planted and then left until the harvest without weeding, fertilization, or other input.

Tuareg Social Organization

Tuareg society is extremely hierarchical and composed of social groups of different ranks. It is commonly described as being stratified into the *imushar* (warriors), *ineslemen* (muslim scholars), *imghad* (vassals), *inhaden* (artisans), and the *iklan* or *bella* (slaves). Bella groups started to receive their independence from their former masters early in the colonial period, but this has been a slow and still incomplete process. There is also a group designated "free of low status" comprising people independent of the imushar and the imghad, but who are not nobles themselves. A subset within this group is the *ifulanen*, who as the name indicates regard themselves as Fulani, but who have adopted Tuareg culture and ways of life.

The Division of Labor

Apart from being gender-defined, the division of labor generally follows the lines of social stratification. At one extreme, the imushar would leave all directly productive activities to the lower classes. The imghad control much livestock and assume imushar-like characteristics, and therefore leave actual herding and other animal upkeep to the bella. Most crafts are in the domain of the inhaden, although both bella and noble women produce a few specific items. Domestic work is still generally carried out by the bella, as is the strenuous work with water in the dry season, gathering, and agriculture.

Work is not carried out at the same time, in the same place, or by the same persons. This is partly due to seasonal requirements for different types of work.

However, it is also because the various resources are located far apart. In general, the resource availability in the Gourma is extremely patchy both in time and space. Many agricultural activities must take place at the same time as herding and various types of gathering. However, in many cases, the locations for each activity are neither overlapping nor are they adjacent to each other; for example, wet season pastures are situated far from the agricultural areas. Similarly, the agricultural harvest coincides with the harvest of *P. laetum*, distant from the fields of rice and millet. Further, while both *C. biflorus* and *Nymphaea lotus* (water lily) are important dietary staples, the former is found on the dunes, and the latter in the shallow lakes and in the Niger River.

Social stratification and the associated division of labor mean that labor is allocated to different productive activities. Some dependants of a noble group cultivate crops, some gather wild plants, while others herd. The salient feature of the production system among the Tuareg was production units that spanned several households and social classes, were spatially dispersed, and controlled by the nobles. Truly independent households with multiple productive activities are a rarity.

Changes in Stratification and Division of Labor

At the time of the field research, the stratified production system was still partly in operation, even though its legitimacy was contested by the state as well as by many bella. However, despite obvious continuities, one may easily discern processes of change. One such process is the erosion of the power base of the imushar, and the corresponding growth of ineslemen power. As local political control based on force is no longer legitimate, the ineslemen, with a claim to authority based on Islam (as religious counselors, judges, healers, sorcerers, and arbitrators) have taken advantage of the government's lack of effective authority after the decline of the imushar. To some extent, different government agencies, in particular the forestry service, operated quite similarly to the various indigenous power groups; that is by trying to build a power base for the exploitation of others, sometimes by force, and sometimes by delivering services. As a result, there is also a strong trend for ineslemen to become large herd owners. Government employees (who often are ineslemen as well) also own some large herds.

A second and quite recent trend arose out of the social realignments that took place in the wake of the rebellion in northern Mali: the greater autonomy of the formerly dominated groups, i.e., the bella and the so-called "low status free." A third trend is the tendency for the division of labor to be increasingly a division between equal units in that households of the same social stratum carry out the full range of productive activities, rather than functioning with a system of labor organized by stratification. This may take one of two forms: either the household attempts to combine several productive activities, i.e., they diversify; or they stick to one, i.e., they specialize. Hence, there is an important distinction between diversification and the division of labor among productive units.

Household Size and Composition

Household size according to the food-survey is fairly small with a mean of 4.9 persons, with 72% of households comprising four, five, or six persons. The definition of a household used here is unit of consumption, and the members were counted if the household head claimed responsibility for them. To a large extent, the definition corresponds to the Tuareg notion of the group belonging to a single tent, although occasionally two or more tents may be utilized. Tuareg household size contrasts somewhat with the sedentary population, which has mean household sizes ranging from five to eight, with six and seven being the modes.

The households are mainly nuclear families, although there are several variations. One is a fairly small percentage (about 7%) of female-headed households, here defined as households without a male in a position to be household head (by virtue of age and genealogical or affinal connections to any woman eligible for headship). Female-headed households have fewer members than other households, with a mean size of 3.4 compared to 5.1 in the male-headed households. Only 6% of households have children who are not offspring of any member of the household and female-headed households are the most likely to have such children.

While one may posit that the existence of female-headed households is related to male labor migration, this turns out not to be the case, at least not directly. Female-headed and male-headed households have nearly equal proportions of migrants. This is partly because a household where the husband has left on labor migration often merges with another household to create a single large household. The household with which the wife teams up will often be that of the brother of her husband, or that of her parents. Female-headed households are often due to widowhood rather than migration. However, in many cases widows are taken care of by their sons. Having labor migrants as household members is predominately a feature of large households. Thus, households are not necessarily small because the men have left. Rather, men leave from large households, which, in general, remain large.

Patrilineal stem households with a couple and their married son(s) and collaterally extended households consisting of two or more brothers with their families are rare. Informants agreed that having two adult married men in the same household creates difficulties in lines of authority. As about 17% of the male bella, and 40% of noble men are unmarried at age 30, there are quite a few single young men in the households. They are often attached to their parents' household, but they are also often recruited to that of their older brother.

These varieties of household composition make sense in conjunction with the hypothesis that labor is a scarce resource. Small, female-headed households acquire labor by obtaining children, larger households can afford to send people on labor migration, and middle-sized households may decide to team up when someone migrates. Nevertheless, given the cultural constraints on household formation, really large households seldom form.

Food Security, Consumption Patterns, and Ecological Adaptation

As we have noted, a main constraint in the production system of the Gourma is the wide spatial distribution of resources. Accordingly, a household has to make choices among resources, and thereby determines its overall adaptation. The effects on food security can to some extent be gauged by the level of malnutrition among children. Malnutrition results from the interplay of several factors. The two most directly important are food quality in terms of amount and variety, and disease. The amount of food consumed is not available in the data sets, due to the difficulties of obtaining such data. However, data on food variety and disease are available. Food variety was ascertained by asking the respondents to supply information on whether or not the household had consumed specific kinds of food the day before the interview. Disease data were collected by asking about the health status of children the day before the interview and during the 14 days prior to the interview.

Nomads and Agriculturalists

Table 1 shows the rates of malnutrition for various types of settlements in the Gourma with data from the three nutrition surveys. The rates for the nomads in the Fintrou area at the height of the dry season in 1992 were strikingly lower than the other rates, regardless of measurement. In general, in the two first surveys, camp dwellers (i.e., nomads) had lower malnutrition rates than the other groups, and, except in the November–December 1990 survey, the sedentarized nomads were the worst off. Among Ariaal and Rendille communities in northern Kenya, Fujita et al. (2004) also found that sedentarization was associated with a decline in nutrition and health status.

As we noted, the system of social stratification is related to the division of labor, but it is also related to food preferences. Thus, nobles do not themselves gather wild foods, and find only some gathered foods acceptable. The social value of different

Table 1 Nutrition measures by type of location. Percentage of children age 6–59 months below-2 Z-scores of WHO/CDC reference population

	Village		Camp		Fixation point		Fintrou
	May–June 1990	Nov–Dec 1990	May–June 1990	Nov–Dec 1990	May–June 1990	Nov–Dec 1990	May 1992
Weight–Height	17	13	15	12	21	9	4
Weight–Age	39	42	36	36	56	42	17
Height–Age	32	41	35	36	49	43	20
Total *n*	587	960	191	91	83	120	146

Sources: NC1 and NC2

types of food is also expressed in their prices. Rice is the most expensive of the staples, followed by millet after which there is a marked decrease in price to cram–cram and fonio, and at the lower end of the scale are wild non-cereals such as *B. senegalensis* and *N. lotus*. The prices do not correlate at all with the nutritional value of the different foods.

The data derived from the survey of food use among the pastoralists show greatest variability in combinations of gathered staples, cultivated staples, and milk at the start of the dry season of 1990 (Fig. 1). It was sharply reduced during the dry season of 1991 when cultivated foods took on a much larger importance.

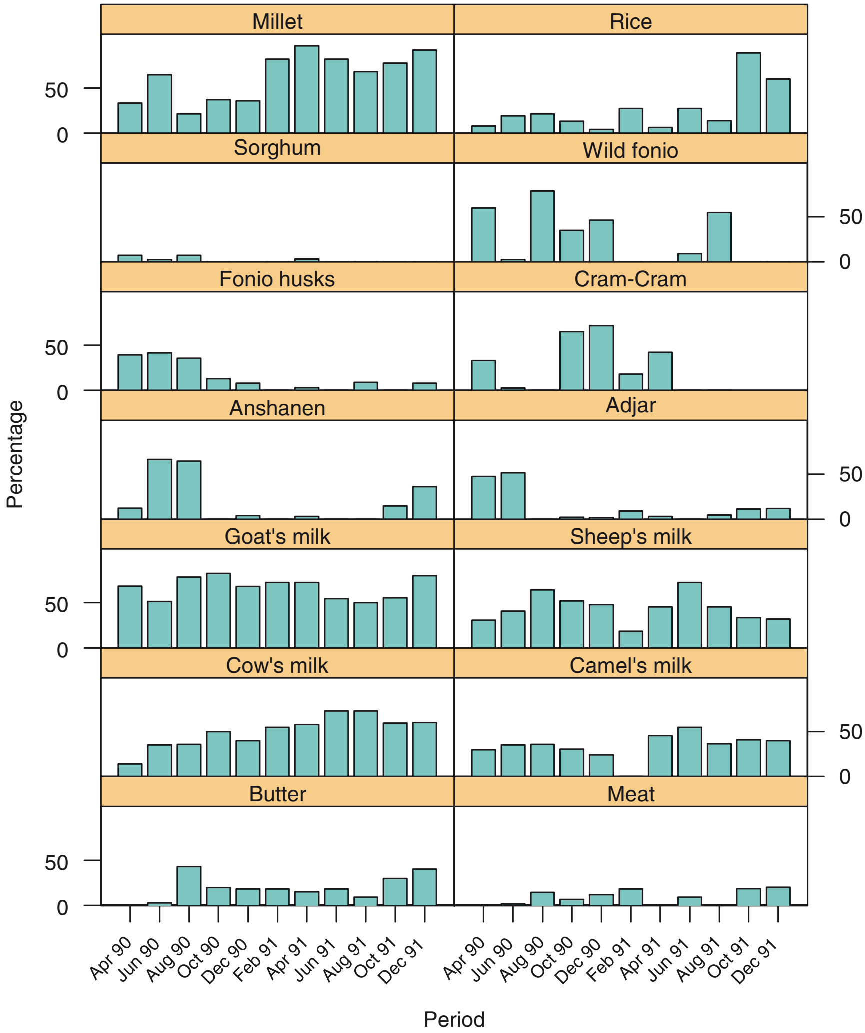

Fig. 1 Use of different foods, April 1990–December 1991. Source: Consumption Survey, $n = 427$

This may be due to several factors. Conditions for the nomads generally improved during the period, thus there is a large shift to milk. Also during this period the composition of the population in the area probably included more rich nomads because an outbreak of anthrax in the Adiora area drove many into the research area at the start of the dry season. A third factor is that the interviewer probably over-sampled ineslemen toward the end of the period, being an ineslemen himself and with reduced supervision because of the deteriorating security situation. Nevertheless, it is clear that during the dry season some households subsist only on gathered food, and that very few use only cultivated food.

Further data analysis revealed a broad scale of consumption patterns, with cultivated grains (rice, millet) and milk of prestigious animals (cows, camels, and sheep) at one end and at the other the lack of cultivated food along with the use of *N. lotus*. This may reflect the ecological constraint referred to above, that it is difficult to combine certain activities. Such a conjecture is also indicated by the correspondence of using milk of large animals and cultivated food. It is logistically complicated for pastoralists with large herds, and for the nobles socially unacceptable, to engage directly in gathering.

The ability to acquire grains is of critical importance for the nomads: those who could afford grains can more easily take advantage of the first wet season pasture than those who did not have the means to buy grains, because the herders need additional food to tide them over until the animals start to produce. Thus, those with sufficient means are able to feed their animals well earlier in the season, and also begin to produce more quickly, yielding a double benefit. The others have to wait until the wild foods were available before they can move with their smaller herds.

In summary, there are quite clear differences in food consumption by social strata, reflecting the different adaptations of each although with considerable overlap. Even though household size was not recorded during the dry season, based on the wet season data there appears to be little difference in household size for the consumption pattern. A similar correspondence analysis reveals that the only difference in resource utilization as regards household size is that small households tend to be associated with use of *B. senegalensis* and *Maerua Crassifolia* only. Households that combine *N. lotus* and the wild cereals tend to be rather larger. The gathering of *B. senegalensis* and *M. crassifolia* is not labor intensive; the plants are easily found all over Gourma, so travel is not arduous, and the harvesting itself is quick.

Shifting Adaptations

Given the fluctuating environment and the associated risks of drought and disease, the risk of herd loss is significant for nomads in the northern Sahel. When the whole herd is destroyed, or if only a few animals remain, there are only three available options. One is leaving the area completely, i.e., moving to town or another rural area (the option commonly exercised in the Sahel at the height of the droughts in the 1970s and 80s). The other two options are trying to rebuild the herd, or remaining in the area but adopting an alternative means of livelihood.

One common option for acquiring the capital for restocking is labor migration. However, this is often not successful because transportation costs, debts incurred while searching for work, and living expenses consume the potential profit. Return migrants we interviewed more often than not reported no profit apart from the fact that they were no burden on their families while they were away.

Another option is agriculture. However, unlike other regions of the Sahel, depending on agriculture for restocking appears very difficult in the Gourma. One ex-herder, a bella who had lost all his animals in the 1973 drought, explained that he planted millet because he had to have something to do, and not because it was profitable. He was unable to acquire a surplus, as the yield was much too uncertain. Of the last five harvests, two were good, and three yielded next to nothing. The result was that he had to buy seeds, and thus had to depend on his former masters, the Kel Gossi imghad, for credit. Most millet farmers we interviewed shared this experience. Rice farming along the river shows the same mixed results as rain fed farming. Our data indicate the uncertainty appears approximately similar, but as the good harvests are better for rice than millet, the long run expectation (in a mathematical sense) should be better for rice. However, when the harvest fails, the farmer must borrow to plant the next year, and the interest charged will easily obliterate any surplus he may have made from earlier harvests.

There are, however, a large number of clearly defined notions of exchange that can be used for herd reconstitution. These include *takutin* (sacrifice), *ashiuf* (gift of animals at birth of a child), *inuf* (help), *tamesadeq* (gift to a poor relative), *banan* (simple gift), *tirgit* (gift with an expectation of a later reciprocity), *amarwas* (loan of animals or other items), and *tiatin* (loan of milking rights). The range of such arrangements is vast, but here we describe only *tiatin*, an arrangement whereby a person gives the right to the milk from one or more animals to another person (see Berge 2000 for a more complete description). The offspring of the animals belong to the owner, but the receiver is able to maximize the survival chances of his own herd by letting the offspring of his own animals have all the milk from their mothers, while using the milk of the borrowed animals for household consumption. This arrangement may easily develop into the owner's livestock being herded by the recipient along with his own. This strategy of reentering the pastoral sector reaffirms social stratification.

Conclusions

Successful pastoral production in the northern Sahel requires people able to move quickly among widely distributed resources. It is therefore not easy to profitably combine flexible animal husbandry and agriculture. Such a combination also requires more labor than most households in the Sahel have available. Labor, not land, is still the limiting factor in farming in large parts of the Sahel. While Maasai and other pastoral groups in relatively more humid environments may be able to diversify their production strategies to include farming, Tuareg nomads live in some of the driest and most unpredictable rangelands in Africa and need to move frequently, especially in the rainy season, making productive agriculture difficult. The pastoral households that do succeed in diversifying their production strategies in the northern Sahel are usually large and comparatively rich. For most Tuareg nomads, specializing in livestock husbandry and gathering wild cereals actually appear to be a more viable adaptation than agriculture. Gathering is both less uncertain and easier to combine with pastoralism than agriculture. Nevertheless, while gathering provides a supplement for the richer nomads, especially during the dry season, trade and exchange – sometimes achieved through domination – are more important strategies.

Crucially, as we have shown, whatever their strategies, both rich and poor nomads appear to weather the dry season well. When food security is measured by anthropometric status of the children, the children of pastoralists were found to be better nourished than the children of sedentary farmers, and the children of sedentarized nomads seemed to be the worst off. These findings contradict the longstanding and still dominant policy approach that nomadic pastoralists should be sedentarized. It also questions the more recent focus in the development literature on the need to diversify livelihoods. In the case of mobile pastoralists such as the Tuareg in the northern Sahel, diversification of production strategies leads to less rather than greater food security.

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Section III
Agricultural Intensification and Large-Scale Population Dynamics

Section Overview

The five chapters in this section concern the causes and consequences of contemporary intensive farming. Robert Hunt addresses the causes in a classic step-by-step test of a major train of thought, namely that early agricultural intensification arose in response to pressure from growth in population. Susan Crate looks at the consequences at the household level when a complex industrially based political system implodes along with the economy which sustained it. Lisa Cliggett and colleagues draw on work spanning several decades to examine the long-term regional consequences of a major dam project designed to further agricultural expansion and intensification. William Loker takes us through the all too common boom followed by bust cycles of commodity production, here the case of tobacco farming in Honduras. David D. Zhang and colleagues use historical sources to analyze the still ever present scourge associated with intensive agriculture and state-level political institutions, that is, large-scale coalitional fighting or warfare with its devastating costs in human suffering. We will return to these studies in more detail later.

Demographers quite appropriately look at population dynamics largely in terms of two independent variables: fertility and mortality, and whatever directly influences these variables. Until fairly recently, some would argue until 1750 in fact, these two variables were generally in sync, with the additive effects of fertility on average only slightly ahead of the culling effects of mortality (Cohen 2005, p 3ff). It was only in 1800 that the world's human population reached the one billion mark, having taken some 120,000 years to do so (ibid.). The second billion came 130 years later (1930), the third billion a mere 30 years later (1960) and the progression continues with the last seven billion coming after an interval of only three years (ibid). Until the industrial period, fertility remained relatively constant but from the mid-eighteenth century public health, medicine, and hygiene improved steadily, reducing mortality relative to fertility, particularly in the so-called third world.

Ecologists and environmental scientists, again appropriate to their interests, look at population growth itself as either an independent variable, as in Hunt's test of Ester Boserup's hypothesis regarding agricultural intensification, or in terms of the environmental factors which, directly or indirectly, drive fertility and mortality.

Population dynamics are a consequence of enabling variables such as food availability, shelter, disease vectors, and the like. But population growth and consequent population density generate their own dynamic: urban growth and sprawl. While only 3% of all land identified by census throughout the world is used for farming, urban settlements occupy almost 2%. This concentration of population pushes the drive for resources leading to overharvesting of the oceans, the cutting of the forests, and indirectly causing global warming. So in looking at the progression of population growth noted by Cohen and many others, ecologists voice concern for food reliability, sustainability and distribution, population movements, and adverse environmental impacts (see, for example, Pimentel this volume).

The interrelated processes of agricultural intensification and ever increasing requirements for food seen throughout the world share a critical variable: human well-being. The most dramatic change to occur following the shift from hunting gathering to farming in Eurasia and the New World was the appearance of a distinctive settlement system vastly altering preexisting ecological conditions: the emergence of settlement hierarchies joining highly nucleated settlements that later developed into urban centers. Scholars have long disagreed over the causal linkages among intensive farming, the development of urban centers, and the rise of states, but all agree that these developments are mutually reinforcing. One element common to all large, differentiated settlement systems is that they are based on the combination of intensive agriculture, economic specialization, and exchange or trade, so that even seemingly remote settlements are closely tied to a larger economic and political context, and their local environmental or ecological arrangements are similarly connected. In fact, most geographers argue that, in general, rural events or activities reflect the influences of regional metropolitan political and economic organizations.

Intensive agriculture involves a massive reshaping of the landscape – a process that continues to accelerate. Clearly, many factors are involved, including the development of irrigation, terracing, mobilization of larger work forces, specialized tools, improved seeds, and storage facilities. As we discussed in the Introduction, in the final analysis, it is the cycling of energy that distinguishes intensive agriculture – both energy inputs in crop production and energy extracted from crop consumption. The increase in energy invested can come from many sources: animal traction used to plow and cultivate, human labor to terrace and bring water and nutrients to the fields or paddies, or from machinery powered by fossil fuels. Intensive farming also entails considerable investment in maintenance. A constant effort is required for production continuity that is not immediately reflected in crop yields: soil to be protected from erosion, drainage maintained to prevent the build-up of salts, crops rotated to maintain soil fertility, and property defended from human and nonhuman predators. These problems are faced not only by early or traditional agrarian systems but remain hugely important today. The Imperial Valley of California, which has been irrigated since 1901 and which today accounts for approximately one-seventh of total US annual agricultural production, now requires massive investments to ensure that salinity does not overwhelm the soils. By 2009, many farmers there seemed to be conceding defeat and moving out, a reversal of the Dust Bowl migration of the 1930s. In New South Wales, Australia's best irrigated farm land is experiencing salinization at rates which might mean the end of agriculture there within 15 years. Large agricultural areas of Pakistan, Iraq, and India have similar problems.

The social consequences of intensive farming have been as far reaching as its ecological consequences:

Stratification: In nonindustrial systems, the absorption of farming communities into the larger society is commonly striking for the asymmetry in life chances, power, and social mobility between those who provide the actual agricultural labor and those, often residing at some remove from the fields, who own or control access to the land. This has resulted in great disparities of wealth and living standards among households within local communities, urban centers, and across regions. Such disparities often underlie mass movements or migrations as people move in an effort to secure resources to sustain their livelihoods.

Specialization: A close parallel to intensification is the tendency for communities and regions to increasingly limit the range of their productive activities; for example, coming to rely on a key commodity crop such as tobacco, tea, coffee, sugar, or cotton. This renders populations vulnerable to price shifts beyond their control and again can force population movements. Where entire regions or political entities come to depend on highly specialized crop production, disruption in demand, reflected in lower prices, or in the harvest, due to disease or drought or floods, can have wide-ranging impacts both politically – governments may collapse or be overthrown – and socially – spreading poverty, which entails serious public health implications, and always the possibility of famine.

Centralization: Centralization of decision-making as an out-growth of political, economic and social differentiation can facilitate orchestrating diverse productive activities, but it can also lead to disastrous environmental decisions, most notably where there is either insufficient feedback from areas affected or local feedback is ignored. The former Soviet Union provides a classic example of the potentially disastrous consequences of centralized decision-making: from the 1920s, centralized planners in Moscow effectively drained the Sea of Aral by diverting the rivers feeding it for irrigation in other regions, so that it had disappeared by 1990 leaving the communities which depended on it for fishing and local agricultural irrigation literally high and dry (see Sect. IV Overview). Similar dire effects can be seen around the world, frequently caused by corporations or centralized state institutions managing distant holdings with little interest in either the local populations or long-term habitat stability.

Hyper-Urbanization: "Mega" cities have arisen on every continent, not only sprawling over what was once highly productive farm land (since that is why most cities are situated where they are) but expanding far beyond any reasonable capacity to provide services for their inhabitants or their hinterlands. Rural migrants continue to seek resources in the cities that they feel they have little opportunity to obtain elsewhere; for example, Istanbul's population was 75,000 in 1964; in 2009 it reached close to 15 million; Cairo, Beijing, Lagos, New Delhi, and Mexico City have also seen their populations soar as impoverished rural migrants pour in hoping for a better life.

A current disturbing trend is for both governments and corporations in wealthy countries to purchase or lease farm land in poorer countries. China, for example, has over four million hectares under its direct control in Africa, much of them actually tended by an estimated one million Chinese nationals. Already, a quarter of the eggs sold in Lusaka are from Chinese farms in Zambia and China plans to lease or purchase of another 2.5 million hectares there on which to grow biofuels (Economist 2009, 5.23, p 61). South Korea, Qatar, Dubai, and Saudi Arabia similarly invest heavily in foreign cropland in South America and Africa, leading some economists to term this trend "outsourcing's third wave." While this development is too recent for its impacts to become clear there is good reason for concern since it appears to replicate the earlier and often very exploitative organization of plantation-based production. Significantly, one fact that drives this form of investment is water scarcity in the home nation; importing food or biofuel crops grown on land owned abroad is equivalent to importing water.

Returning to the studies in this section, Robert C. Hunt explores an important puzzle about agricultural intensification that has long concerned scholars: what induces people to work harder for the benefit of others? Hunt uses agricultural statistics from case studies of rice cultivation to test Ester Boserup's influential hypothesis which, while much cited, has had little exposure to empirical tests. Boserup concluded that it takes rising population pressure to move people to adopt labor-intensive short fallow systems of production. There is no question that food production, labor, and population are closely linked, specifically, labor productivity is a major component of agricultural development from the Neolithic into the industrial age. If one visits the Nile valley in Egypt, one is impressed with the density of human settlements, the verdant fields extending from the river's bank to the edge of the desert's stony wastes, cultivated throughout the year with a prodigious investment of human labor devoted to multiple crops, all to be sown, weeded, watered, and ultimately harvested. These hard-working farmers support huge urban concentrations of population. This system is in striking contrast to less intensive farming elsewhere in the Middle East. In central upland Turkey or Iran, rainfall agriculture limits farmers to one crop a year, and however arduous the tillage in spring and summer, the land lies fallow through the winter with a concomitant diminishment of labor requirements. Move to the tropics of South Asia or South America, where what is often called slash-and-burn horticulture or swidden farming involves even longer fallows – sometimes extending to many years as tropical soils regain their nutrients.

The key to Hunt's success in testing the Boserup hypothesis is in his clear definition of variables and concepts related to productivity, intensification, and units of analysis and units of measurement. As a result, he is able to conclude that higher labor productivity in agriculture is due to technological innovation making agricultural surpluses possible. Thus, rather than population growth driving agricultural development, it appears that in fact agricultural intensification is driving population growth.

Susan A. Crate also looks at economic processes as related to specific environmental conditions, but she focuses on the domestic economy of one population struggling to adapt to new political and economic realities. The Sakha (Yakut), a Siberian Turkic-speaking population of agro-pastoralists, were not consulted when the Soviet regime imposed collectivization in the 1920s, nor were they consulted when the collective system and attendant state support institutions collapsed in the early 1990s. They just adapted as best they could to the prevailing economic and political climate. Crate, using data from her fieldwork among the Sakha, 8 years after the fall of the Soviet Union, shows that the key to their successful adaptation to the collapse of collective agriculture is that the household became the basic unit of production. She uses quantitative and qualitative material gathered from lengthy participant observer fieldwork to test Robert Netting's idea that the household is the most resilient unit for subsistence production. The household can bring together a body of ecological knowledge, organize capital, allocate labor utilizing bonds of kinship, and can structure exchange with kin and non-kin alike. In the Sakha case, for many this entails the raising of family-owned cows, no mean feat in their fragile but harsh, subarctic habitat. Other sources of livelihood include hunting, fishing, small gardens, and also monetary income from state pensions and wage labor. While her study is specific to the Sakha, household economic studies such as this have proven extremely informative in many ecological settings. It is worth contrasting the essentially egalitarian system of the Sakha with the extremely hierarchical Tuareg described earlier.

Lisa Cliggett, Elizabeth Colson, Rod Hay, Thayer Scudder, and Jon Unruh join in a study which spans 51 years of team fieldwork in Zambia and is a classic exercise in political ecology. The building of the massive Kariba Dam on the Zambezi River in the 1950s was one of the first large development projects carried out by the World Bank and caused the forced resettlement of the Gwembe Tonga. The early work of Elizabeth Colson and Thayer Scudder is a unique longitudinal study that, which has been built on by subsequent scholars, some still working in Zambia, as is Lisa Cliggett. A recent time series (1986, 2000) of satellite imagery provided the visual and spatial foundation for examining the sociopolitical world of those living in the study area. Following five months of ethnographic data collection in 2004, the team used a survey to record basic demographic characteristics, livelihood activities, and land access and tenure. The survey included information on each household's primary agricultural resources, and a history of relations among neighbors, conflicts, and movements of household members. What they found was that while their initial migrations and resettlement were involuntary, more recent generations of the Gwembe Tonga are choosing to move as a means of adapting to new resources, and are now settling in lands bordering new park reservations, where in addition to clearing forest for farmland, they supplement their livelihoods with fishing and hunting.

William M. Loker examines the social and environment changes caused by the rise and fall of flue-cured tobacco production in western Honduras. The analysis is based on first-hand observations spanning several years, the mining of land use records, trade statistics, GSI imagery, and aerial photography documenting land use changes. Loker documents the links between the local, national, and global political economy, the decisions made by local actors and environmental change in the Copán valley. The rise and fall of the flue-cured tobacco industry provides a clearly defined starting and end point that enable him to trace the links between causal agents at varying levels of analysis and the local social and natural landscape. In this case, the local social and ecological landscape was transformed by the actions of relatively few, but powerful, local actors – tobacco growers – who linked up with a transnational corporation to harness large numbers of laborers in the production of an international commodity. This production process had substantial ecological impacts in terms of deforestation and the use of a suite of highly toxic agrochemicals. The case draws our attention to the importance of preexisting social structural relationships, especially control over and access to resources, in shaping the nature of environmental change in particular localities.

This case study is thus an example of several trends in human ecology research: the progressive contextualization approach advocated by Vayda (1983) in which the investigator traces out whatever relationships are necessary to understand the given social and ecological questions under consideration (and ignores others). It is an example of "classic" political ecology that links the levels of analysis. It follows other successful examples of a "social life of commodities" approach, pioneered by Mintz (1985), in which a particular commodity or production process is used as the lens to examine social, economic, and ecological relationships, and Bebbington and Batterbury (2001), particularly in recognizing the importance of contingent, historical events that shape local agency.

David D. Zhang, Jane Zhang, Harry F. Lee, and Yuan-qing He offer a macro-level perspective on an age-old problem: warfare. Conflict over territory and resources, not to mention mates, is obviously not a uniquely human phenomenon. But with the advent of agriculture, investment in land resources is many times greater than in foraging economies and thus it becomes much more important to acquire and defend land. Hunter–gatherers or foragers will vigorously defend core areas rich in game or scarce water points; pastoralists, too, usually have access rights to pastures and routes which they will defend against encroachment. So it is no surprise that agrarian empires are militaristic given the stakes involved. Zhang et al. examine the periodicity of war frequency over 1,000 years of well-documented Chinese historical and climatic records. What they find is a highly significant fit between outbreaks of armed conflict, including peasant revolts, nomadic incursions and dynastic strife, and periods of significant climatic cooling which negatively affect the amount of land which can be planted for crop yields. In short, the oscillations of agricultural production brought on by climate change drove historical war–peace cycles. As they point out, most of the world's populations continue to rely on small-scale agriculture, which remains as vulnerable to climatic fluctuations as in the past.

Lester R. Brown, noted food policy expert, agrees that just this sort of calamity is possible, replicating the Chinese historical case on a wider scale. He notes that in six of the last nine years world grain production has fallen short of consumption, forcing depletion of reserves (Scientific American 5/09:50–57). Hunger, he writes, has increased in the world's 70 least developed countries affecting 980 million people. States fail when they cannot provide food security thus spawning further conflict and loss of food production. The interrelated causes of food shortages include water shortages, biofuels production competing for acreage with food production, loss of topsoil, and ultimately population pressure.

Labor Productivity and Agricultural Development: Testing Boserup[1]

Robert C. Hunt

Introduction

It seems fair to say that in the Neolithic age, every household was involved in food production, but during industrial times, only a very small proportion of households (<10%) were involved in farming and feeding everyone. Food producing went from being the activity of everyone to being a sector of the economy employing few people and at the same time producing a large agricultural surplus that is exported to the rest of the economy. This is often called agricultural development, and the process by which this development has been accomplished is often referred to as intensification. There are two positions on what has happened to the productivity of labor in this developmental process: the rise thesis and the decline thesis.

In the context of the industrial revolution, it is easy to imagine that intensification leads to a rise in labor productivity. There is a counter thesis that has been widely applied to what can be called traditional (or nonindustrial) agriculture. Now primarily associated with the economist Ester Boserup, this position holds that labor productivity falls with the intensification of agriculture. The empirical examples have come from contemporary "traditional" agricultures. Boserup published *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure* in 1965. The book presents a model, and the major innovation was her assumption that population growth might drive technological change in agriculture, rather than the reverse. The population as the cause position is not addressed in this chapter, but rather her conclusion that

> …the complex changes which are taking place when primitive communities change over to a system of shorter fallow are more likely to raise labor costs per unit of output than to reduce them. (Boserup 1965, p. 117.)

[1]The original article *Labor Productivity and Agricultural Development: Boserup Revisited* appeared in *Human Ecology*, Vol. 28, No. 2, June 2000.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_13,

The decline thesis has had a major impact on at least some anthropologists, but if true, it presents a puzzle. From the beginning of urbanism, the division of labor has increased, the proportion of households involved in agriculture has declined, and changes in agricultural technology have improved land productivity. If the productivity of agricultural labor is declining with intensification, how do a lower proportion of farmers, with no improvement of labor productivity, produce ever larger agricultural surpluses? This decline thesis thus contains a dilemma, which has not been addressed in the literature.

David Grigg (1978, p.78) observed that the decline thesis remains unproven. This paper presents a comparative study of traditional cases which will yield a test of the relationship of agricultural intensification and the return to labor in non-industrial agricultural systems. Enough useful case studies exist to make such an effort worthwhile. The case studies are from twentieth century field work (mostly by anthropologists), and are confined to traditional rice agriculture in Southeast Asia. The case studies must measure all of the relevant variables on the same plot of ground. One needs to know enough about the data-gathering methods to assess confidence in the results. Ideally, the sample size within each case study is large enough to give confidence. With the small sample size of this study no quantitative analysis will be appropriate.

Comparative Study of Labor Productivity in Rice Agriculture

The hypothesis to be tested is: Sawah[2] technology has the same or worse labor productivity than swidden[3] technology. If the results of this study are robust in either direction, then the hypothesis is either strongly supported, or strongly challenged. If the decline hypothesis works anywhere, presumably it would work on traditional rice agriculture in Southeast Asia. If on the other hand it turns out that the decline hypothesis is rejected in this case, it poses a challenge for its supporters. Since there is no other body of literature that has claimed to give so much support to the decline hypothesis, the case of rice agriculture in SE Asia is very close to a critical experiment.

Concepts

Every scholar who has written on this subject has stated that data are hard to come by, which is true. Equally important are clear definitions of the concepts and variables

[2]Sawah is annual cropping on flat level valley land, with soil preparation by animal drawn plows and harrows, irrigation, seed beds for rice, and transplanting of the seedlings. The harvest cutting tool is the sickle.

[3]Swidden is a long-fallow technique with slashing, felling, and burning, planting by means of dibble stick, many cultivars, extensive hand weeding, and bush knife (or machete), ax, and baskets. The harvest cutting tool may be the finger knife, or the sickle. It is never irrigated, and usually occurs on hilly slopes.

involved. The two major concepts are labor productivity in agriculture, and intensification of agriculture.

Labor productivity (also called returns to labor, and labor efficiency) is always, and by definition, the product of a ratio. The numerator is some measure of output per unit area, and the denominator is some measure of labor input per unit area. Three concepts must be observed and measured before we have a figure for labor productivity: the unit area (usually acre or hectare), the output per unit area (usually volume or weight), and the labor input for that same unit area (usually hours or days of labor).

Two conditions should be noted: (1) because the calculations are done per unit area, the relationship of this unit area to the operations of a farming household are not visible; and (2) merely stating the number of days of labor per unit area or per farm does not constitute a measure of labor productivity. The latter condition is often violated in the anthropological literature.

Agricultural intensification has long played an important role in anthropology, geography, and development studies in general. It is very often used as if it meant the same thing as agricultural development.

Several components of agriculture have been used to modify intensification (labor, land, technology, energy, etc.). The output of an agricultural system could be measured, and one could say that the more intense systems are those with higher outputs per unit area per unit time. Or one could instead focus on the inputs to agriculture, including land, fallow time, technology, and labor. Agricultural intensification is often used to refer to an increase in one or more of the inputs to a plot of land.

Turner and Doolittle (1978) defined agricultural intensity as the amount of output per unit area per unit time. But, noting that output data were scarce, they developed a proxy scale of agricultural intensity based on two input variables: frequency of cropping, and agrotechnology (1978, p. 300). Boserup (1965) used intensification to refer to changes in fallow from long-fallow to short fallow and annual cropping to multiple cropping. It is also possible to increase the amount of labor per unit of land, and this is included under intensification by some scholars (Geertz 1963; Couty 1991; Kirch 1994; Milleville and Serpantie 1994).

Brookfield (1984) proposed a distinction between innovation and intensification: innovation is qualitative, whereas intensification is quantitative (although he himself finds this a difficult opposition to apply). Thus in Brookfield's framework an increase in the amount of labor per hectare is said to be intensification of that agriculture.

Kirch (1994) claims that swidden is more intensive than irrigated agriculture (in Futuna) because swidden uses more labor per hectare. The distinction between intensified agriculture and intensification of one of the components of agriculture is easy to lose sight of. It does not follow that if one of the inputs to agriculture is increased the whole of agriculture is thereby intensified.

Fallow time (or its reciprocal, frequency of cultivation) was used by Boserup as the definition of intensification. Only one comparative study has attempted to measure fallow time (Turner et al. 1977), and none of the studies that have investigated labor productivity have done so (Bronson 1972; Hanks 1972).

It is not possible to shift from long-fallow to annual or multiple cropping without drastic changes in technology. Some shifts of frequency of cultivation can be made without changes in technology (from forest to bush fallow), but most changes in frequency of cropping, demand changes in technology. Virtually all of the comparative studies have measured variations in technology rather than variations in fallow. Technology is much easier to measure than fallow time, and is much more visible in the archeological and historical records. In addition, it is almost impossible to measure long-fallow cropping frequency in the field. Fieldwork rarely lasts more than 2 years, and so the cropping frequency can only be measured by informant's reports. It cannot be directly observed in the case of multiyear fallow cycles. Most field reports do not specify, for each field, the frequency of cropping.

It is clear that several components of agriculture can be clearly defined (technology, amount of labor, frequency of cropping, and crop output per unit area per unit time), and are often invoked in discussions of intensification. Each can vary, and most of the changes can be called increases or decreases. The terms "intensification of agriculture" and "intensified agriculture" thus refer to a large number of different phenomena.

I conclude that "agricultural intensification" is too vague to be used as an empirical variable. Technology, crop output and labor input are clearly defined and can be measured. I propose that output and technology are what are usually invoked by agricultural intensification.

The remainder of this paper presents an investigation of the relationship between variations in technology (including frequency of cropping), crop output, and labor time. The purpose is to test the proposition that labor productivity falls as technology changes (and frequency of cropping increases).

Unit of Analysis

Much modern agriculture in Southeast Asia is close to a monocrop, using a single technology package, and the crop grown is intended to be sold in a market. Traditional rice agriculture in Southeast Asia (and traditional agriculture in most places and times) is quite a different and complex phenomenon. It is characterized by many different crops grown in several different locations by different sets of technology packages, and with a substantial portion of what is grown intended for consumption by the farming household. Traditional in this context means the growing of domesticated rice with locally generated seed, using only human or animal sources of power, and without industrial fertilizers or pesticides.

In the rice-growing swath from Sri Lanka to Japan there is generally a great deal of physiographic relief in small amounts of space. Narrow valley floors and forested hills dominate most of the territory. The major river valleys (Cauvery, Ganges–Brahmaputra, Irrawaddy, Chao Prahyo, Mekong, Yangtse) are very prominent, and so far as rice is concerned lend themselves to a single technology package: irrigation–animal traction–transplanting.

Each traditional farming household in these hilly areas has, in Hanks' (1972) felicitous phrase, a holding. The holding will contain several kinds of terrain, including a house area with its kitchen garden and sheds, some animals (pig, water buffalo, cattle, goats, perhaps even sheep, and various fowl including ducks), perhaps some irrigated land, usually far more hilly land that is cropped with swidden technology, running water (containing fish), and some forested land. There may as well be swamp, pasture, caves, and other terrestrial and aquatic features included in the holding.

Few authors have studied the whole of such a holding, and how the various parts of it relate to the other parts. What is clear from what we now know is that these holdings are systems, using different technology packages in different zones, but with a flow of energy from one zone to another. Green manure, for example, is a critically important part of the fertility of some rice paddies, and it comes from other zones of the holding (in Japan and the Philippines from the forest zone (Conklin 1980)).

Given this situation, it is impossible to talk about the technology or labor productivity of a holding. The holdings are too heterogeneous, and use many technology packages. In some cases the farmers use only one technology package, in other cases the farmers use both swidden and irrigated technologies during the same year. The unit of analysis, then, is not the farmer, and not the farm, but the technology package and labor practices that are associated with it.

Variables

There are four observed variables in this study, land input, technology, labor input, and rice yield.

Land Input. The definition is the extent of land planted, mostly to rice and subject to a particular technology. Land area is measured in each of the case studies, but it is measured by different techniques. In some cases the investigators used surveying techniques (Moerman in Ban Ping, Durrenberger in both Lisu and Shan cases). In others, there was vigorous local resistance to standard measuring techniques (Freeman among the Iban), and the author had to estimate the land area. The units of report in the case studies include the acre, and the rai (a Thai unit of land area). All these case study metrics are converted to the hectare (10,000 m^2, equals 2.471 acres and 6.25 rai). It is a ratio scale.

Technology. Technology always includes tools (and tools made by tools). I use a broader definition of technology, including processes and knowledge as well as the tools. Irrigation then is part of technology, and so are the rice varieties. There are five major packages of technology used in traditional rice agriculture in Southeast Asia: swidden, sawah, broadcast, swamp agriculture, and terraces. The latter three are not included in this study as we have only a tiny number of fragmentary studies, and none of them are well enough measured and documented.

Measuring the technology package is rapidly done (both in the field, and from the literature). The scale is nominal.[4] The scale values are swidden and sawah.

Labor input. Both the definition and the measurement of labor input are problematic. Some aspects or dimensions of human workers include skills, and knowledge, which are essential parts of the technology. Having an irrigation system is of no use if one does not know how to operate it. These skills and knowledge must be developed by the operator if the technology is to be put into use.

What, then, is labor? The operational definition of labor is the time that humans spend working in the fields. It does not measure the force applied in the work, and certainly does not try to measure the skills or knowledge of those humans as they work. Skill and experience are needed for selecting a site for a swidden, timing the burn, leveling the nursery for the rice seedlings, and for every other step along the way. All of this skill and knowledge is implied by the technology package.

The time worked has been separated out and called labor. Perhaps it has been done by analogy with what is taken to be unskilled wage labor, where it is sometimes presumed that only time is operative, and skill and knowledge are not. When one inquires about labor productivity or labor efficiency the focus is on only the time the worker spends, and on nothing else. There must be a great deal else. The labor time is only a small part of what the worker brings to the field.

The time that is spent in production in the fields, however minor in view of the complexity of "work" and the technology package, is critically important for the problem of the evolution of the division of labor. As the division of labor increases the percentage of those directly involved in food production falls. Every one of these societies must then manage to get more food grown by a relatively declining number of workers. Clearly, the most effective way to accomplish this is to increase the productivity of the workers that remain. In this case, then, the amount of labor time is of critical value.

There is another source of complexity. A considerable amount of farm household labor takes place outside the field – construction and repair of tools, constructing various sheds and buildings, participating in markets. One of the uses of labor time

[4] A nominal scale may seem peculiar, given our standard notions of the increase in technology over the *longue duree*. Turner and Doolittle (1978) attempted an ordinal scale of technology, and they claimed to have established an interval scale for cropping frequency. Boserup (1981) also has an ordinal scale for fallow. There is reason to be skeptical on the completeness, and ordinality, of these scales.

Turner and Doolittle's agro technology scale, leaves out genetic materials, metals, traction sources, and engines (water, wind, as well as electric and heat). They mixed competitor control with fertility. And the weights they assign to the traits are unmotivated, in the sense that I have not been able to imagine the dimension involved. If that dimension is labor, then of course it is conflated with the measure of labor input, and no investigation of the correlation of labor productivity with agricultural intensity will be valid.

Boserup has an ordinal scale for frequency of cropping (the inverse of which is length of fallow.) Just in terms of the years (or days) that a field is without a crop it is a good ordinal scale. But the difference between long-fallow and annual cropping is more than a difference in time, it is also a major change in technology, and it is not clear that the necessary technology changes can be described as an ordinal variable.

in swidden is commuting from residence to field and back. So far as I am aware no-one has measured this labor time. Presumably the total commute time for swidden is higher than for sawah, but that is only a guess.

Irrigation work can be divided into work time in the fields and work time on the system itself. Work time in the fields includes leveling, cleaning of field ditches, repair of dikes, managing water levels in the field. System work includes work on the head-works (dam or barrage), and the main canal, both of which have to be worked on at the beginning of the season, and many of which need attention during the cropping season. Part of the irrigation system work, then, is not in the field itself, and should be in the same category as commute time. There is a gap in our knowledge of how much time these activities take.

Only a handful of field investigations have measured the amount of labor time spent on the crop. Measuring actual labor inputs is a tedious job, lasting for one complete crop cycle. While land and technology can be measured in a day, labor input must be measured for each person working in a field over the entire crop cycle of many months. The measuring requires the patience of several men and women for each field, and the patience and systematic application every day or every week of the field worker. Local estimations are not sufficient. Data on labor input are the constraints on this study. Time is the measure of labor input, and it will be done in days. The scale is ratio.

Rice output: There is a serious theoretical problem of how to define a single metric for agricultural output. Money is often used by economists, energy by ecologists. Volume is often used by the farmers, mass by others.[5]

Crops are grown for a variety of reasons. The chili pepper is grown in smaller amounts than is the starchy staple. The chili pepper is not grown for starch or protein but rather for micronutrients and for taste. To apply a kilocalorie standard to chili peppers is not sensible. The root starches (potato, sweet potato, yam, taro, manioc) have far more water in them than do the grass seeds (rice, wheat, maize, barley, sorghum, etc.). Comparing the mass of sweet potato and rice, then, involves massively different amounts of water. 1 kg of grass seed contains on the order of 3,500 kcal, whereas 1 kg of a starchy root or tuber contains on the order of 1,200 kcal. In order to harvest the same amount of usable energy, then, one must harvest about three times the mass of the root than of the grass seed. In addition the grass seeds have more fat and protein than the roots and tubers. Comparing a root with a grass seed using only mass or energy produces a disjunction that is misleading.

How, in a non-monetarized economic system, does one compare the productivities of cotton, chili pepper, and maize? The answer, so far, is that one cannot, and therefore one should not try. There is no valid single metric for the variety of crops found around the world. It seems wise to postpone the attempt to capture the productivity of a holding, or of a whole agricultural system. Until the single metric for the output

[5] There is an old tradition in Europe of measuring crop output by volume (the bushel). This tradition was changed to mass (the kilogram) in the nineteenth century on the continent with the widespread adoption of the metric system of weights and measures. In the USA the bushel is still the major reporting unit for output.

is found the effort is meaningless. Instead the focus should be on the productivities associated with particular crops (a degree of homogeneity in the crop is thereby assumed). In this study the output is rice, and we will concentrate on those examples where the major crop is rice. (There are differences between glutinous and non-glutinous rice. They will be ignored here.)

In most cases, the output measured is the volume of threshed and winnowed, or rough, paddy. Converting the output to mass involves other difficulties. Rice that is properly prepared for storage has been dried for several days. When in the process of the measuring of mass of a particular volume has been done is important for evaluating the results. In consequence, the conversion of volume to mass is fraught with uncertainties that cannot be controlled or obviated. All volumes of rice have also been converted to mass, but the results should be used with caution.

Farmers are always interested in the amount of output. How they measure it, and whether they communicate the results to others, is much more variable. In the cases used for this study the measuring of the output was done by the investigators. It was, with one exception, done in terms of volume, sometimes with a local metric. I have converted all the volume measures to liters. The scale is ratio.[6]

There are three calculated variables.

(1) *Labor input per unit of land per technology*. For each technology package the amount of labor time needed to operate 1 ha of land is calculated. This is the number most often given in early accounts. It is not a measure of the productivity of labor but, instead, is an implication of the technology package.
(2) *Crop output per unit of land per technology*. For each technology package the amount of rice produced per hectare of land is calculated.
(3) *Labor productivity* is defined as

$$\mathrm{P}_{(\mathrm{LABOR})} = \frac{o}{L}$$

where $P_{(\mathrm{LABOR})}$ is the total factor productivity[7] of labor (measured as liters of rice per day of labor), O is the output of rice (l), and L is the input of labor (days). It can be phrased as the volume of rice produced with a unit of labor needed to operate a given technology for one crop cycle (in these cases one solar year) on 1 ha of land.

[6] Both Kunstadter et al. (1978, p. xii) and Moerman (1968, p. 210) state that the tang contains 20 l. Freeman (personal communication) states that he must have been using the Imperial pint for his Iban studies. The Imperial gallon contains 4.546 l (the US gallon contains 3.7583 l). Moerman (1968, p. 210) states that the tang contains approximately 11 kg of rough paddy.

[7] All output is a product of factors of production (land, labor, technology for a start), and it is possible to imagine decomposing that output and assigning some fraction of it to land, another fraction to labor, etc. In fact it is possible, under ideal circumstances, to measure the inputs of the factors, and to analyze the output in terms of the factor proportions. Data that permit this are usually available only under highly controlled experimental conditions. What we will have available to us will be total factor inputs, and the total output. The only ratio we can construct with these data is what is called total factor productivity. The labor input is divided by the total output. But as the technology package differs, and so does land form, all of these inputs are conflated in the ratio.

Universe and Sample

The universe is studies of traditional rice agriculture in Southeast Asia. All the comparative studies to date have included rice in Southeast Asia. Rice is well understood as a crop, and the technologies that are used in growing it are reasonably well understood. The homogeneity of the "rice" harvested is assumed, and thus there is a single metric for the output which is reasonably comparable. There are a number of good studies of swidden rice. Swidden is still a major environmental issue in Southeast Asia (see Leach 1949; Freeman 1955; Dove 1983; Levang 1993), and is still being practiced over substantial areas (Huke 1982b).

A small number of case studies have been located. The swidden cases are (1) Land Dayak, (2) Iban, (3) Lisu, and (4) Shan. The sawah cases are (5) Bang Chan, (6) Ban Ping, and (7) Shan. These are the only cases I have been able to find where all the variables are measured with reasonable confidence.

Results

The results presented in Tables 1 and 2 are quite clear. Labor requirements for swidden are on the order of 150–200 days/ha, whereas labor requirements for sawah are on the order of 100 days/ha. It is also quite clear that the returns to land are very different as well. Swiddens yield on the order of 1.3 metric ton/ha, whereas sawah yields between 2.5 and 3 metric tons/ha. The liters produced per day of swidden labor are on the order of 10, whereas the liters produced per day of sawah labor are on the order of 50. The differences are substantial.

Table 1 Swidden cases

Name	Dayak[a]	Iban[b]	Lisu[c]	Shan[d]
Country	Sarawak	Sarawak	Thailand	Thailand
Year(s)	1949–1951	1949–1951	1968–1970	1976–1977
No. sample farmers	1	4	20	25
Farm size (ha)	0.73	2.2	1.2	0.8
Labor/ha (days)	252	172	135.5	220
Liters/ha	2864	1518[e]	2059	2767
Kg/ha	1776[f]	941	1240	1384
Liters/day	11.4	8.8	15.1	12.6

[a] Geddes (1954). He was in the field at the same time as Derek Freeman. He was in Mentu Tapuh (population, 375) from late July 1949 to January of 1951. The language of field work is not mentioned. He kept daily records of work on four rice fields from October 1949 to January 1951. Two of the fields were swidden, and two were irrigated swamps. There is substantial intercropping in the swidden fields, including cucumbers, pumpkins, beans, maize, cassava, and sugarcane (1954, p. 64). He states that at the beginning of the 1950 dry season he chose four fields at random (1954, p. 65), measured each field with a prismatic compass and tape measure, and each evening made a record of "… the labour expended upon them during the day" (1954, p. 65).

Table 1 (continued)

There is a problem with this. According to Geddes, the swidden crop year starts in June with clearing, and ends in May with the padi harvest. If he started record keeping in October of 1949, he was halfway through the crop year. Therefore it should be the case that his labor records overalp 2 crop years, and do not completely cover either one.

Geddes recorded data for two swiddens, one of 1.8 acres and one of 4.78 acres. The smaller one had a normal year. The larger one did not have access to enough weeding labor, and in consequence, the yield was very small. The dilemma is whether to include the overly ambitious swidden effort, since it was close to a failure due to miscalculation about weeding resources. My decision is to eliminate it, as neither the labor nor the yield was normal, in the sense that they could, in normal circumstances, provide a standard result.

[b] Freeman (1955). Freeman was in the field from 1949 to 1951. The language of field work is not stated, but there is no mention of interpreters. The longhouse of Rumah Nyala contained 25 bilek families and there are area and yield figures for the whole of the longhouse. He also presents more detailed figures for four bilek families (presented here). The four bileks operated an average of 2.2 ha/bilek, whereas the whole longhouse operated 1.4 ha/bilek. The output of the four bileks was 135.1 gantangs/acre, whereas the whole longhouse achieved a yield of 118 gantangs/acre. The sample of four is therefore both operating more land and getting a higher yield.

He measured land with difficulty. The Iban would not permit him to use a chain or compass, so he had to pace them off and then estimate the area. There is the possibility that he calculated, rather than observed, the labor for the whole of a farm. Output is measured in gantangs, a local unit that Freeman says is 1 gal in capacity. Freeman tells me that he was using Imperial pints and gallons (pers. commun.).

[c] Durrenberger (1979). Durrenberger did his doctoral field work in a Lisu village from November 1968 to September 1970. These Lisu cultivated on hillsides, and their primary crops were opium, rice, and maize (Durrenberger 1979, p. 139). The fields were measured by a surveyer. The Lisu measured their yields in baskets called *phit*, which contained 12.04 kg (and are probably the standard Thai *tang* of 20 liters.) Work effort was recorded by weekly interviews with members of every household, asking what they had done day by day for the previous week (Durrenberger, 1979, p. 140, note 1). He recorded area in rai, and work in rice in manday. Twenty households are included in the sample.

[d] Durrenberger (1978). Durrenberger spent a postdoctoral year in Thailand in a Shan village, where both swidden and sawah technologies were in operation. The vast majority of the village households operated both technologies. He was there from July 1976 to July 1977. The swidden agricultural calendar starts in January, is burned in April, planted from mid-May to mid-June, and weeded and guarded until October, and the harvest takes place in October and November (Durrenberger 1978, p. 6). He thus did not get to record a single crop year for swidden, and his swidden labor figures are from 2 crop years. His fields were measured by surveyer. He recorded labor inputs by weekly survey of households. He started this on 19 July 1996 and estimated labor inputs for the previous part of the crop year. The land and the harvest were measured only for 1976 (Durrenberger 1978, p. 13).

[e] A gantang is presumably an Imperial gallon, which would be 4.546 liters (an Imperial bushel is 36.369 liters, and a gallon is ⅛ of a bushel).

[f] Converting volume to mass requires a decision about conversion ratios. Very few of these field studies report empirical examination of various units of measure. One of the few is Kundstadter et al., who measured the volume of the local containers and measured the mass of the rice these containers hold. They report that a liter of swidden rice weighed, on average, 0.62 kg (Kundstadter et al., 1978, p. 109). I have used this conversion factor for all the volume measured cases of swidden (Dayak, Iban). Geddes and Freeman were from the British Empire and were almost certainly using Imperial measures. Freeman states that it would have been inconceivable for him to have done anything else.

Table 2 Sawah cases

Name	Bang Chan[a]	Ban Ping[b]	Shan[c]
Country	Thailand	Thailand	Thailand
Year(s)	1949–1954	1960	1976–1977
No. sample farmers	1	31	25
Farm size (ha)	7.84	1.02	1.0
Labor/ha (days)	725 hr[d]	99 days	111 days
Liters/ha	5357	5637	5143
Kg/ha	2946[e]	3099	2571
Liters/day	58.9[f]	57	46.4

[a] Janlekha (1955). This report on Bang Chan was done by a Thai student of agricultural economy, was his Ph.D. thesis at Cornell, and was published in English in Thailand in 1955. It can confidently be assumed that his field language was Thai. He was in the field for 5 years and collected a massive amount of information on farm sizes and farm yields (*N*—205 households for some years). His information on labor input was gathered from only one household, and for only 1 year, in 1953–1954 (Janlekha 1955, p. 104). Time was measured in 0.5-hr increments. This was the household of a headman, and the farm was much larger than average (7.8 ha, vs. the average of slightly under 5 ha).

[b] Moerman (1968) and his wife spent 20 months in Ban Ping (in Northern Thailand) from January 1960 to April 1961. He returned in 1965 for 1 month in summer (Moerman 1968, p. vii). The population is identified as Lue, and they live in valleys, cultivate glutinous rice with typical sawah technology (Moerman 1968, pp. 16, 18). This village had access to a number of different fields. Moerman's study included all the fields. This case study will concentrate on what Moerman called the Great Field, a securely irrigated large field in the valley bottom, where most of the subsistence rice was grown. The agricultural calendar starts at the end of the dry season, when some farmers move animal manure to the fields. The rice nursery is started in late April, and in May there is cooperative work on the irrigation system. Plowing of the main fields start once the nursery is planted, with the coming of the rains in May. Field preparation and transplanting are finished in June–July. Then there are 4 months when very little must be done. Harvest occurs in November (Moerman 1968, pp. 36–41). The language of field work was Thai, with help from interpreters. The village contained 670 people in 120 households. He selected a random sample of 31 households, to study their agricultural decision-making (Moerman 1968, pp. 8, 199).

The area of farms in the Great Field was reported by the farmers, who regularly underreport their land area to government officials, so there was a strong possibility that the area was underreported to Moerman. (The effect of this bias would be to inflate productivity.) The technology is observed. The labor inputs are the result of a mixture of methods. The efforts prior to preparation of the main fields were a rough estimate, for his systematic recording had not begun. His sample was selected with the aid of a table of random numbers (Moerman 1968, p. 199). Labor during the tillage part of the agricultural year was accomplished with a mixture of interviewing, observation, and estimation (Moerman 1968, p. 201). Tranplanting was recorded every day by an assistant who went to every field, and recorded the types of worker (family, cooperative, wage, etc.) (Moerman 1968, p. 200). At the harvest an assistant went every night to visit those households (within the sample?) that had completed harvesting a field that day. These reports were turned in every day. The yields were reported by farmers, who used the *thang*, a unit of volume (20 liters). Moerman (1968 p. 201) reports that he failed to weight it, so he used the village estimate that the thang weighed 11 kg.

In consequence, his labor measure is probably an underestimate, and his land measure may be an underestimate. He is confident of the yield measure. There is little doubt about the technology.

[c] Durrenberger (1978). The Shan are the same village as in Table III, studied at the same time (1976–1977). In this hilly area there are substantial alluvial flats. The technilogy was typical sawah, with irrigation by run of the river, water buffalo pulling plows, and transplanting. Little manure was used. His sample for sawah was 25 (many of whom also operated with swidden technology). For the conditions of field work see Table III, footnote *c*.

[d] Janlekha measured the labor inputs for only one farmer, and did it in 0.5-hr increments.

[e] Janlekha (1955, p. 179) reports that the standard measure of volume is the tang, of 20 liters, and on average it contained 11 kg.

[f] Converting hours to days requires a conversion ratio, and none was given by Janlekha. I have chosen an 8-hr day. Note that if one instead chooses a 6-hr day, or a 10-hr day, the results are markedly different.

Sawah has much higher labor productivity than swidden. The null hypothesis, that sawah has the same or lower labor productivity than swidden, is rejected. These data clearly reject the decline of labor productivity hypothesis, and support the rise hypothesis. The results are the strongest challenge to date of the fall in labor productivity thesis for traditional agriculture.

Limits to Generalization

These results can be compared with others. Kunstadter et al. (1978) carefully measured technology and crop outputs (but not labor inputs) in Thailand. They report swidden yields of 1,665 and 1,540 l/ha for Lua' and Karen swiddens over 2 years (1978, p. 110, Table 6.6), which are within the range reported in this study. For sawah they report 4,061 and 2,746 l/ha (1978, p.110, Table 6.6). These are below the lowest figures in my Table 2, but well above the swidden range.

Several studies have reported much higher labor inputs than are presented here, including Buck (1937), Barker and Herdt (1985) and Bray (1986). There are two reasons for being extremely cautious before one accepts their results: (1) we are not told how labor input was measured and (2) most important, the technology in each case was not measured. Buck's (1937, p. 302) summary report of a massive survey of 16,786 farms reports labor days/crop/acre, but does not report how labor is measured. More important, there is no discussion of technology. The presence and absence of animal traction for preparing the soil makes an enormous difference in the number of person–days required for growing wet rice. It is not measured, and not reported, by any of these general studies. I therefore conclude that their results are not relevant to the question addressed in this paper.

On formal grounds there is very little external validity (Campbell and Stanley 1963). The case studies come from only two parts of the rice grown areas of Asia, Thailand, and Borneo. The sampling units were not the product of a random sample. And the sample size is small.

It is highly unlikely that more data sets will appear. New studies would likely find that pesticides, fertilizers, and high-yield varieties are now ubiquitous. The major hope for more cases would come from data sets still unpublished. It is anybody's guess how many of these there might be. A much larger sample of traditional rice agriculture in Asia is not likely to appear. In consequence it is likely that our generation has all the data we are likely to see.

Agricultural Development

The relationship among agricultural technology, intensification, and agricultural development is not as clear as it might be. I agree with Turner and Doolittle (1978) that agricultural intensification is most usefully defined as agricultural output per unit area per unit time. Changes in agricultural technology are the core of the process. There are changes in the ways that soil, vegetation, water, nutrients, large animals, small animals, and genetic stock are managed, which lead to increases in production per unit of land per unit of time.

I therefore conclude that there is good reason to define agricultural development as changes in technology which increase the output per unit of land per unit of time. It is probable, but not certain, that the amount of labor time will decrease as well. That is an empirical question which needs to be answered in particular cases. I have presented an answer to that question for traditional rice agriculture in Southeast Asia.

Division of Labor, Surplus, and Labor Productivity

In the introduction to this chapter, the puzzle that the decline in labor productivity view poses for social evolution was noted. If labor productivity declines or stays steady with changes in technology, and if the division of labor is developing so that a smaller percentage of the society is involved in the food quest, where does the extra food come from? While surplus in general has a contested history (*see* Pearson 1957; Harris 1959; Dalton 1960; Orans 1966), there can be no doubt that as societies evolve and get more complex, the agricultural sector must develop a surplus to feed the rest of the society.

When the proportion of active workers in the agricultural sector falls, the most attractive way to increase output per worker is to increase worker productivity. Of course some increase can be found in increasing the number of hours. But it is not credible that all the increase can come from an increase in the hours worked. In the industrial era productivity in agriculture has risen enormously due to technology. The question remaining is how the increase was accomplished in preindustrial contexts.

I believe that the answer is the same: technology changed, with increases in the productivity of both labor and land. And this probably goes back to the beginning of cities and the state. There is a plausible argument to be made that some of that technological improvement was probably found in genetic seed material, some in using beasts of burden, some in the plow, some in metal tools, and some in irrigation systems. Improvements in the genetic seed material will lead to increases in the mean yield per hectare. The assumption that little or no extra labor is required to grow the new variety is a reasonable one, with the exception of labor needed for harvest. The yield per day of work will rise as well.

Beasts of burden will reduce labor in transport of the output, and for threshing. When combined with the plow (and other cultivating implements, such as harrows) they vastly increase the amount of land a household can cultivate in a given unit of time. One effect of plowing is deeper and more thorough preparation of the land, allowing for more vigorous plant growth. Another effect of plowing is the reduction of competing vegetation. A thorough plowing will uproot these weeds, and if they are removed by hand there is a reduction in the amount of weed seed and root in the field.

The effects of this are reduced competition for the crop, higher yields, and reduced labor per hectare. The combined effects increase the productivity of labor.

Another technological innovation is the use of metal tools. There would seem to be a major gain in effectiveness in the switch from stone to metal tools for cutting down large trees.[8] There might well be a large gain in effectiveness in metal harvesting tools as well. It looks as though the sickle is much more productive than the finger-knife in harvesting rice in Southeast Asia, for example.

An irrigation system ameliorates the constraint of water on crop growth. Irrigation systems do require work, both for construction and for operation and maintenance. The largest labor cost for irrigation work in our sample is on the order of 20% of total in-field labor. The construction work should be amortized over the life of the feature, but the operation and maintenance work is a yearly charge. The question, then, is whether the addition to output is greater than the extra labor input.

In the case of sawah, irrigation is a very important part of the package. Where there are significant dry seasons the seedbed must be prepared first, and the only way to soften it enough for plowing, is to irrigate it. If the rains are not sufficient for plowing, harrowing, and puddling the sawah fields themselves, irrigation water is then introduced for the purpose of making the soil workable. Irrigation has a counter effect, for it encourages the growth of competitors (plants and animals). In the case of sawah rice the irrigation water inhibits the growth of dry-foot weeds, thereby increasing yield, and thereby increasing the productivity of labor. My best guess is that the yearly labor charge for irrigation is smaller than the labor benefits, and that labor productivity rises with irrigation.

Conclusions

This study supports the idea that labor productivity is higher with more complex technologies (and shorter fallow) than with simpler technologies (and longer fallow). The increase of output per unit of land per unit of time is the core of the evolutionary process and seems best called agricultural development. It is composed of changes in technology. Intensification as a technical term is problematic and, perhaps, should be avoided.

A puzzle about the evolution of cities and the state has been resolved. Higher labor productivity in agriculture, due to technological innovation, makes the growth of the necessary agricultural surplus possible.

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[8]Under conditions of stone-age technology it is likely that the difference between swidden and sawah labor productivities would be even larger. We have only a tiny handful of studies of the productivity of stone tools used for cutting woody vegetation (Salisbury 1962; Carneiro 1976; Toth et al. 1992). They are not very persuasive, being crude estimates at best. It is easy to imagine that iron (and steel), are much more effective than stone when it comes to felling a large tropical hardwood tree, but that may be no more than an iron-age bias.

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Following Netting: The Cultural Ecology of Viliui Sakha Households in Post-Soviet Siberia

Susan Crate

Introduction

The transition from a communist infrastructure to a market economy presents a great challenge to indigenous agropastoralists of the former Soviet Union. Sakha (Yakut) are a Turkic-speaking people, today numbering approximately 360,000, who inhabit the Sakha Republic of northeastern Siberia, Russia. Rural Sakha practice horse and cattle breeding, a subsistence strategy brought to the northern latitudes by their southern Turkic ancestors in the fifteenth century (Ksenofontov 1992; Gogolov 1980, 1993; Forsyth 1992). Tungus, most notably Evenk, and nonagropastoralist Sakha were the reindeer-herding inhabitants of the Viliui Regions prior to colonization by Sakha agropastoralists. Today rural Evenk, Even, Yukagir, and Dolgan ethnic groups also inhabit the Sakha Republic, where they herd reindeer, hunt, fish, and forage. Viliui Sakha are located in the Viliui River watershed areas of the western Sakha Republic. Along with Sakha of the central regions, they make up the two ethnic enclaves of horse and cattle breeding Sakha, the highest latitude practicing agropastoralists in the world today. Sakha constitute the majority in the Viliui watershed, where one-third of the total Sakha population lives.

Prior to the seventeenth century, Sakha practiced subsistence horse and cattle husbandry in relative isolation from the outside world. The centuries that followed saw increasing infringement by Russian colonists on Sakha lands and resources. With the twentieth century Soviet collectivization process, Sakha were forced to give up their traditional subsistence lifestyle, including their private holdings, and live in compact villages to work in the Soviet agro-industrial farming system. The early 1990s demise of Soviet power and the concomitant loss of the agrarian

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The original article *Viliui Sakha Post-Soviet Adaptation: A Subarctic Test of Netting's Smallholder, Householder Theory* appeared in *Human Ecology* vol. 31, No. 4, December 2003.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*, 213
DOI 10.1007/978-1-4419-5701-6_14, © Springer Science+Business Media, LLC 2010

infrastructures presented Sakha with a variety of problems related to adopting new subsistence strategies in the post-socialist context.

For rural Viliui Sakha, subsistence survival in the twenty-first century is based on household-level cultural ecology centered on keeping cows and exchanging labor and products with kin (Crate 2001). Netting (1993) argued that in times of change the household system is the most resilient unit for subsistence production, having both integrity and longevity through ethnic, political, and geographic changes due to its specific qualities. First, the household is a repository of ecological knowledge with which its members are able to make the most effective use of resources, based on their intimate understanding of the specific microenvironments of their smallholding. Second, the household is a joint enterprise based on implicit labor contracts. Third, the bonds of kinship, family, and household enact strong work ethics and specialization of work by gender to dependably fulfill the labor load of daily chores and seasonally specific bottleneck demands. Lastly, these contracts bind members in an innate social security system, providing for children and elders as the generations move through a cycle of either the cared for (children and elders) or the caretakers (youths and adults).

Netting describes parallels between the household and a corporate entity in that both maintain their own labor force, manage their own productive resources, and organize consumption for the household unit. The household generally also produces for subsistence and for the market, with at least one of its members involved in outside employment. The household has ownership or usufruct rights over its land base to maintain production.

How well does Netting's householder theory hold for subarctic agropastoralists? The Viliui Sakha case is fertile ground for testing Netting's theories for several reasons. Netting provided an overview of various householder systems throughout the world and conducted comparative research on householder systems in the Swiss Alps to "see a system that had persisted for centuries in an easily damaged environment of steep slopes, short growing seasons, and low rainfall" (Netting 1981, 1993, p. 8). The Viliui Sakha also live in an easily damaged environment - in this case a subarctic ecosystem with extreme temperatures a short growing season. Much recent research in the circumpolar north analyzing how groups have adapted to recent historical changes also emphasizes the importance of household-level production. This study extends Netting's model for intensive agriculturalists to include pastoralist societies. Lastly, the demise of the Soviet era, along with its imposed economic and subsistence infrastructures, presents a unique opportunity to understand what form households took in the precollective and collective era and what form they take today. This study is the first case of applying Netting's theories in a post-Soviet context.

I begin by discussing the demands of keeping cows in a subarctic environment – in effect, the cultural ecology problem faced by Sakha. Next I explain the research methods and analysis that lead to my central finding of the cows-and-kin system. Following this I describe the six most prevalent cows-and-kin household patterns. I then analyze the Viliui Sakha case in the context of Netting's householder theory. In conclusion, I discuss the future prospects of Viliui Sakha contemporary cows-and-kin adaptation.

Having What it Takes: The Demands of Keeping Cows in the Subarctic

In Viliui Sakha villages cows are not only *everywhere*, they are *everything* to survival. Meat and milk products are the staple foods of Sakha diet traditionally and today. If you keep cows, meat is in constant supply for daily soup and main dishes. Similarly, you have milk for tea, considered the only way to drink tea. With a supply of milk, you are able to produce all the Sakha milk foods. You also have a ready supply for any young children in your own or neighboring households.

But keeping cows is labor and time-intensive. Of the household members most typically involved in cow care, male elders spend one-fifth of their waking hours in cow care, female elders spend one-sixth, and male and female adults spend one-tenth. A division of labor with elders acting as primary cow caregivers would make sense in a society where male and female adult household members tend to have salaried positions and little time for domestic responsibilities. However, in the post-Soviet context there are many examples of Viliui Sakha households in which one or more adults are unemployed. Nevertheless, elders tend to perform major cow care until they are physically unable to, at which point other older adults take over. Contemporary elders involved in daily cow care explained to me that they held the major responsibility for household cow care because they have done it all their lives, it gives them a purpose, and they are more knowledgeable. Non-cow-keeping households contribute labor to cow-keeping kin households especially during the summer hay season. Additionally, on an annual basis adult and elder females of non-cow-keeping households spend one-half of 1% of their time in daily cow care duties for cow-keeping kin households.

Cow care has high seasonal variance. Summer is most labor intensive due to the need to harvest sufficient hay from natural meadows to over winter herds. Each cow with a new calf needs 2 tons of hay to fodder them over the 9-month winter. For this the household needs the land, tools, labor, and machinery to harvest and transport the hay. Adult and elder males spend the most time haying, 8% and 6% respectively for cow-keeping households, 3% and 3% respectively for non-cow households. However, haying is a crucial activity and a major labor bottleneck so all household members are regularly called to help regardless of age or sex.

Although summer is a bottleneck for haying, daily cow-keeping chores are at their least labor intensive. In the temperate months from the end of May through early September, cows go to pasture each morning after milking, to return in the late evening for a second milking. Of the diary-keeping households,[1] summer cow care took from 2 to 4 h per day, depending on whether the cow tenders were young or elderly. Half of that time is spent in the processing and preparation of various Sakha milk foods.

[1]This refers to the 11 households that kept economic diaries for me over the course of the research year. See "Research Methods" below.

In winter, cows spend most of their time in a *khoton* (cow barn). Daily chores involve morning feeding, milking, and the cleaning and hauling of manure, midday feeding, and evening milking, feeding, and manure cleaning and hauling. This daily cycle took diary households anywhere from 3 to 7 h of per capita labor. Most of the cold season cow care is taken up by manure management. Households make *balbaakh* by forming the fresh manure into compact symmetrical shapes, which freeze and are easy to transport, either in single blocks or in large columns. *Balbaakh* piles continue to grow through the winter. Some of the annual accumulation of *balbaakh* is used as fertilizer in household gardens, but in late March, households arrange to have the bulk of their *balbaakh* hauled away, either to a village dump or a random location in the woods adjoining the village. In the winter months there are also bottlenecks, especially when cows calve, increasing daily cow care time to a total of 5–7 h.

Subarctic cows also need good housing. Sakha *khotons* (cow barns) vary in size depending on herd size to both maintain heat in the −50°C winter and prevent crowding. If a barn is too big, cows may freeze and if it is too small, calves get trampled. Some kin households will pool their cows to create a barn temperature suitable for all. Adapting *khoton* size to the current number of cows can be an annual event and the majority of cow-keeping households spend some part of their summer rebuilding to suit their herd's needs. *Khotons* also require annual sealing with fresh manure to insulate them through the winter. Sakha reported that a proper sealing requires at least three layers, beginning with a 2-in. thick "primer" followed by a 1-in. second coat and a ¾ in. final coat. This seasonal activity takes several hours a day for about a week to complete.

The daily care cows require ties a household to their *khoton*. However, this is not considered an inconvenience since meat and milk remain central to survival and household-level production is, for most, the only way in the post-Soviet context to access cow products. Both the number of cow-keeping households and household herd size have increased in the post-Soviet era. In 1992, ten percent of all surveyed households kept cows with only one milk cow, whereas in 2000, fifty-five percent of all households kept cows, with an average of three milk cows.[2] Most households keep cows in order to have fresh meat and milk products, which they cannot afford to buy otherwise and are anyway no longer available for sale in village stores.

There is some local level cultural antagonism between cow-keeping and non-cow-keeping households. Cow-keeping households consider themselves the hard-working "real" Sakha and they perceive non-cow-keeping households as lazy and transient. In contrast, many non-cow-keeping households explain that they presently do not keep cows precisely because they had not been raised in a cow-keeping household and are used to a non-cow household regime and diet. Most of them drink black tea and depend on wild game meats, including duck, rabbit, squirrel, reindeer, bear, moose, and water and wood fowl, as their protein sources.

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[2]To a large extent the low herd numbers prior to the 1991 Soviet break-up was a carryover from policies of the Khrushchev era that limited households to keeping only one cow and calf.

Many of these non-cow-keeping households are however playing an active role in cow-keeping via their interdependency with a kin cow-keeping household. They supply much-needed labor during the summer hay harvest in exchange for a significant supply of bovine products from kin households.

In the broader context, contemporary Viliui Sakha cow-keepers are on the one hand locally revered as true Sakha maintaining ties to the land to harvest hay and pasture their herds and not fleeing the village for the "better life" in the regional center or capital. On the other hand, in the wake of the "new market economy" and overall economic restructuring, cow-keeping is considered by many a dead end occupation with no future prospect, despite its overwhelming centrality to contemporary survival. Nevertheless, the social status of being decidedly more Sakha is a positive attribute and a response to increased ethnic awareness in the post-Soviet setting.

Research Methods

I collected the data for this study in Elgeeii and Kutana villages of the Suntar region, Sakha, between July 20, 1999 and June 16, 2000, eight years after the fall of the USSR. I used both qualitative and quantitative research methodologies including household surveys, time allocation observations, household economic diaries, sequential elder life history interviews, archival research necessary to fill out the local historical record, and semiformal interviews with local, regional, and state specialists concerning issues of demography, history, ecology, politics, environmental degradation, and ethnology. I annotated all my quantitative data, drawing on my qualitative habits and an inexhaustible thirst for details. For the purposes of analysis, I will detail the methodologies relevant to the research described in this paper.

I administered a survey to a random sample of 30% of all households in both villages ($n=289$) for economic, demographic, genealogical, historical, agricultural, and environmental data. This provided the source data used to test my original hypothesis and to develop a supplementary survey to further test the cows-and-kin theory. To both complement and give the survey data depth and breadth, I recorded time allocation observations of all household members in the random sample and kept economic diaries with a representative sample of 11 sample households. I located my observations in the households themselves mainly because household members could be found at home or nearby most of the year, due to the subarctic environment. I made observations every sixth day to maintain an even representation of the 7 days of the week over the course of the year, each day making rounds within one of the seven blocks of 30 households within the 30% random sample in Elgeeii ($n=210$).

For the economic diaries I chose households representing different levels of home food production and a diversity of household composition. A head of each household kept a daily record of production, consumption, expenditures, informal exchanges, kin interaction, and menus. I met with each diary-keeper every 2 weeks to review progress and record changes and new developments.

I had the great advantage of working in my base village for the 8 years prior to my dissertation research and so was known to most inhabitants and was familiar with the rhythms of daily village life. I also knew both the native Sakha and Russian languages.

On the basis of my data from the original 289 surveys I determined that the common predictor of high household food production was cows. That raised the question of how households without cows access their cow products. By-and-large my data suggested that this happened via *kin* networks. Based on this I administered a one-page supplementary questionnaire addressing specifically the cow and kin characteristics of households.

Results: Interhousehold Cows-and-Kin Dependencies

Using data from both surveys, I determined how each household maintained a supply of cow products. I classified households as having "reciprocal," "one-way" or "non-kin" dependence. *Reciprocal dependence* is based on either keeping cows and providing meat and milk products in exchange for labor in the haying season or supplying labor in the haying season in exchange for year-round products. *One-way dependence* means that they either received cow products from kin with no return of labor or gave products to kin expecting no labor in return. If neither a reciprocal nor a one-way dependence was operating, the household either kept cows and was internally independent by having both cow tenders and hay laborers "in house," or had no cows and either went without or purchased what they needed from non-kin sources.

The results showed that two-thirds (63%) of all households are supplied with milk and meat products from their own cows. However, if household supply includes both household production and interhousehold distribution, 90% of all households are supplied. When type of dependency is broken down, I found 29% of all these households depend on receiving kin labor in exchange for products, 20% depend on receiving cow products from kin in exchange for labor, and 4% have cows and exchange both labor and products. On average, in both villages, 15% of all households surveyed had one-way dependence, with 50% of those at the receiving end, 25% at the giving end, and the remainder both receiving and giving with no expected reciprocation. Households with no reciprocal or one-way dependence are either internally independent or have no interhousehold interaction, the latter due to having no kin in the immediate village or to being on non-sociable terms with the kin they have. Across the two villages, of the households with no reciprocal or one-way dependencies, 2% go without meat and milk products and 8% purchase and barter. Twenty-two percent of all households in both villages are "independent," meaning they are self-sufficient in producing meat and milk by using ample labor force in-house for haying and cow-tending. "Besides these village-level interhousehold relations, 25% of all households surveyed sent products out of the village, most often to kin without cows either in the regional center, Suntar, or the capital, Yakutsk.

The Centrality of Kin

For the majority of contemporary Viliui Sakha households, kin, like cows, play a major role in subsistence. Almost all of the households surveyed said they have close kin in their immediate village. Over half of these are sibling or parental relationships. When asked how it would be to live without their kin, 57% said their lives would be difficult or significantly changed without their kin. The rest were either independent or relied on friends or monetary income.

Traditional Sakha proverbs which emphasize the long-standing reliance on kin, such as *Aimaakhtaakh siljar ere kihi buoluo*, meaning literally, "Only the person who has kin can call himself a person," are still standard fare in contemporary conversation. What is interesting and compelling about Viliui Sakha kin relations is the extent to which kin networks have had a central function over time *and* the extent that kin networks are being utilized anew after a long period of political oppression of such social relations. The Soviet period was marked by a deliberate policy to break down "clan survivals" (*rodovyye perezhitki*) by separating kin households within and across villages (Humphrey 1995, p. 283).

However, since the fall of the USSR, despite the apparent utility of kin for most contemporary Viliui Sakha, some kin relations are strained by the growing gap between "haves" (those with all or any combination of cows, resources, salaried jobs, and high home food production) and "have-nots" (those without such resources) and the unprecedented rise of alcoholism and crime. Of the households surveyed, the "haves" complain that they are seeing too much of their "have not" kin. "Have nots" complain that their "haves" kin are cutting them off. For the most part these antagonistic relationships exist between "haves" and "have-nots" outside the context of exchange within the cows-and-kin system.

Fifty percent of all inhabitants asked how they perceive the reemergence of kin relations since the Soviet break-up said there has been no change and that they interact with kin to the same degree they did in Soviet times. Almost 33% said they interacted with kin more, especially as the division of "haves" and "have-nots"grows. The remaining 10% said there was more kin interaction in the Soviet period when everything was inexpensive and all could afford to house and feed each other. Nevertheless, 33% of households keeping pigs and chickens share products with their kin; a little over 50% of those with gardens share their produce with kin; 85% of households which forage for berries share their crop with kin; over 50% of all duck hunting households share a substantial portion with non-hunting kin households; and over 75% of *sobo*-fishing households share their catch with kin.

Sharing among kin households is not limited to food products. Survey results and household economic diaries indicated that monetary resources are also shared, most often in the form of elders' pensions redistributed to young kin households. Money is in short supply in the villages, with paychecks and other subsidies arriving several months late. Pensions, so far, are received on time and are regularly reallocated among most cows-and-kin networks.

There is a lot of variation within cows-and-kin exchanges largely due to differences in household make-up, access to resources, and kin relations. I identified six main patterns. (1) Household type A is a young to middle-aged family, with one or both sets of individual parents also resident in the immediate village. The parents perform the daily tasks of cow keeping, supply the children's household with meat and milk in exchange for all or part of the labor required to cut, stack, and haul the hay to overwinter those cows. (2) Household type B is a young to middle-aged family whose parents may be present in the village but are too old or unable for health reasons to tend cows. The children keep cows and provide the parents with all their meat and milk. (3) Household type C is a young to middle-aged family with one elder parent living with them who performs all or most of the cow care on a daily basis and the children perform all the heavy work of haying. (4) Household type D is a group of siblings who never married and whose parents are deceased. Their oldest female siblings, who were taught cow care and were responsible for taking over the cow care in the household they all were brought up in, live in the village with their own families and tend cows. The sibling households get all their meat and milk from the cow-keeping households in exchange for performing most of the heavy labor involved in haying. (5) Household type E is a young to middle-aged couple who both work and whose parents live in nearby villages where they were brought up. They get all their meat and milk from their parents and spend the summers commuting to their homelands to cut all the hay for their parents. (6) Household type F is a young couple with cows and a parental household(s) in the village also with cows. Despite their ability to produce independently (having their own cows and labor "in-house), they interact with the elderly households to supply labor in the summer and receive extra resources to make ends meet.

Cows-and-Kin and Netting

Viliui Sakha households possess salient cultural ecological features detailed by Netting. First, Viliui Sakha households are a repository of ecological knowledge, allowing members to make effective use of resources based on intimate understanding of the local microenvironments. Since the end of the Soviet period, the focus of Viliui Sakha survival has gone from dependence on the socialist infrastructure for employment and consumer goods to dependence on household-level cows-and-kin production. In the context of Netting's householder theory the cases show how Viliui Sakha households are analogous to corporate entities because they maintain their own labor forces, manage their own productive resources, and organize consumption for their household units, both internally and with dependencies among kin households. Viliui Sakha households produce first and foremost for subsistence, with some involved in nascent entrepreneurial activities for the market, and the majority of households have at least one member involved in outside employment. Households have usufruct rights over their land base (hay meadows, garden sites) to maintain home food production, although most are restricted to a ration of hay land as well as being limited to their immediate household yard for their gardens. The households who raise animals and grow produce as a sole means of income are able to do so because of special allotments of land given to certain individuals when the Soviet regime fell. This makes a difference because if more households move into market production, they will need access to more land, specifically to harvest more hay and plant more gardens.

Another aspect of the household-as-joint-enterprise is the implicit contracts that bind the household members. Viliui Sakha households and their kin networks function efficiently on a daily basis, caring for their herds, engaging in food production tasks, seasonal harvesting of hay and other consumption resources, foraging for wild foods, and slaughtering. Because of renewed kin interdependence, 35% of all households – those that have no cattle – are supplied with cow products. With exchange, a total of 90% of all households are self-sufficient for their milk and meat needs. The remaining 10% make enough money to buy their cow products. This cows-and-kin adaptive pattern also is the key to survival in nearby Kutana village, a former sector of the Elgeeii state farm. On average, a household of four needs an average of two milk cows or a herd of five or six head total to supply its daily needs of meat and milk. However, to keep a herd over the 9-month subarctic winter, each household must harvest an average of 2 tons of hay per cow and new calf. The majority of households depend on kin labor to realize the production.

To a large degree, the efficiency of the household is credited with specialization by gender. This tendency is best exemplified in Viliui Sakha labor specialization during the intensive summer period when males spend their waking hours cutting and stacking hay while females are busy foraging for wild berries and plants, tending the home gardens and greenhouses, and managing the herds when they return from daily pasture late at night.

Netting states that households do not live in isolation from important external markets. This is also the case for about 10% of all Viliui Sakha households which generate substantial income through entrepreneurial efforts, marketing garden and greenhouse produce, meat and dairy products, and traditional crafts. In one sense the contemporary trend of cows-and-kin survival strategies is a return to the pre-Soviet reliance on animal husbandry, haying, foraging, garden production, and interhousehold clan dependence.

The cows-and-kin system is based on implicit contracts among kin groupings within a home village, less frequently among adjacent villages. Most typically this involves a parental household, which performs the daily tasks of cow care, and one or more children's households, which provide the intensive bottleneck labor of the summer hay harvest. In all cases, task specialization is determined by gender and age. Work is performed as it needs to be done by those most able or most available. Although in the Elgeeii village there are many single-parent and nuclear family households, the households most involved in food production are either internally multigenerational or function this way on an interhousehold basis.

Household production is a matter of balancing labor and need. In most of the cases where these are imbalanced (less labor and greater need or more labor and less need), kin often provide the compensating factor, supplying labor and resources or receiving surplus products. In several cases in which households are producing above and beyond their household needs, they sell the surplus for a profit. Even here the household member labor force is used to its maximum as well as the available kin labor force. These cows-and-kin systems epitomize Netting's points regarding the social safety net provided by household systems.

Because Netting's theory fits well in Viliui Sakha contemporary context, I argue that it can be extended beyond "intensive agriculturalist" household systems on which he focuses to include intensive pastoralists. Viliui Sakha are agropastoralists who rely on the harvesting of substantial fodder in the brief summer periods to over-winter their cattle in barns for the 9-month winter. Although they are thus not technically intensive agriculturalists, they nonetheless embody Netting's key qualities of householder survival strategies.

Conclusion

Most Viliui Sakha have made the transition from dependence on centralized industrialized agriculture to decentralized household-level production, using what I have termed the cows-and-kin system. Their case provides an example of Robert Netting's householder theory at work. The future of these contemporary adaptations in the face of the external pressures of economic forces and globalization is unclear. As noted above, cow-keeping in the villages is considered by many to be a dead end livelihood and an impediment to modernity. Most crucial is whether contemporary youth, most of whose parents are presently fulfilling their household's cows-and-kin duties, will take up those duties once their parents are unable to do so.

These questions are of significant concern to Sakha themselves. They are also part of a larger dialogue concerning the future of rural Sakha villages, which in turn has sparked efforts to bring modernity to the rural areas. These include regional internet centers for access throughout the village school system and regional branches of the state university. How these initiatives will pan out is not known. What is clear is that in the present context, the cows-and-kin system represents a unique adaptation which offers, in the wake of Soviet infrastructure collapse, a sound strategy of household-level food production for contemporary rural Viliui Sakha.

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Adaptive Responses to Environmental and Sociopolitical Change in Southern Zambia

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Introduction

The Gwembe Tonga live in Zambia's Southern Province, a region of climatic extremes including severe multiyear droughts over the past century, coupled with periods of flooding and pest infestation. This, together with political fluctuations over the last 50 years, has significantly influenced their livelihood choices and ecological impacts, and they have learned to anticipate difficulties beyond local control. The building of the Kariba Dam on the Middle Zambezi River in the late 1950s, initiated by the colonial government in conjunction with the World Bank, resulted in the forced and very unwelcome relocation of the Gwembe Tonga. Almost 50 years after this forced resettlement, which virtually overnight undermined the local livelihood system and resource base, and drastically altered their social world, we find the Gwembe Tonga voluntarily colonizing "frontier" regions in different ecosystems on the plateau above their original Valley home. It is thus possible to examine a long trajectory of adaptation to new ecosystems and look for patterns over time.

This article presents ethnographic data collected since 1958 through the Gwembe Tonga Research Project in Southern Zambia. By joining our understanding of Gwembe life in the Valley together with what we are learning of how they have settled in the migrant frontier on the Plateau, we illustrate how they have "domesticated" two different environments and highlight recurrent processes.

The original article *Chronic Uncertainty and Momentary Opportunity: A half century of adaptation among Zambia's Gwembe Tonga* appeared in *Human Ecology* Vol. 35, No. 1, February 2007.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_15,

Background to Study Site

The Gwembe region (Fig. 1) and the Tonga people of Southern Zambia are best known through the works of Elizabeth Colson and Thayer Scudder, who have documented the transformation of a small-scale society through a macro-level development project. The "before and after" study of Gwembe Tonga life in conjunction with the building of the Kariba Dam in 1958 quickly became a unique longitudinal study of continuity and change when Colson and Scudder realized that their baseline data offered a unique foundation for examining a range of social issues as Zambia gained independence from Britain. They examined how resettlement and "development" impacted religious and kinship systems and also documented in rich detail the livelihood changes and continuities among the Gwembe Tonga.

In the mid-1990s, Samuel Clark, Lisa Cliggett, and Rhonda Gillett-Netting joined the project with the goal of carrying on the longitudinal research program into the twenty-first century. Since then, Cliggett has carried out anthropological research in the Gwembe Valley and the migration destinations of the Gwembe that most recently has focused on livelihood and food security in the context of migration, with attention to access rights to productive resources, such as land, farming inputs, and labor.

Map produced by Center for Urban Environmental Research, California State University, Dominguez Hills. Cartographer: Michael Ferris

Fig. 1 Southern Province, Zambia. Case study field sites are the Gwembe Valley, along the Northwest shore of Lake Kariba, and Chikanta, bordering the Southwest side of Kafue National Park

In 2001 Cliggett collaborated with two geographers, Unruh and Hay, examining links between migration and environmental change in one of the primary migration destinations for the Gwembe generally known as Chikanta, which borders Kafue National Park, one of Africa's largest national parks. In 1979, the Zambian government announced on the radio that six "previously uninhabited" regions designated as wildlife management areas were now open for settlement (in fact some areas had been inhabited until the early 1950s when attempts to control human trypanosomiasis – "sleeping sickness" – led to relocation of villages outside of what became Game Management Areas). Any Zambian wanting more land was free to settle in any of those areas. Many farmers from the Gwembe Valley saw this as an opportunity to improve their living conditions and escape environmental and social constraints in the Valley (Cliggett 2000). Since 1980, increasing numbers of Gwembe migrants have settled in Chikanta.

Upon settling in a new area, migrants first clear a portion of the forest, and then, using cattle drawn plows – and increasingly, tractors – and family labor, they cultivate their fields to grow maize, which they sell within the national market. It is these "emergent farmers" who provide the majority of Zambia's maize, the nation's food staple, for national consumption. The signs of this increasing rate of in-migration to Chikanta show up in decreasing forest cover and expanding agricultural land, as seen from the ground and on satellite images and aerial photographs. Using this satellite imagery, the team links remotely sensed data with ethnographic and survey data collected through extensive periods of fieldwork (2004–2006) in order to examine both the processes and motives for land cover change.

Methods

A time series (1986, 2000) of satellite imagery provided the visual and spatial foundation for examining the sociopolitical world of those living in the study area. Following 5 months of ethnographic data collection in 2004, the team used a survey to record basic demographic characteristics, livelihood activities, and land access and tenure. The survey was administered to 650 households (defined as a male or female headed co-resident group engaged in agricultural activities on the same parcels of land) over 4 months in 2005. The survey included information on each household's primary agricultural resources, and a history on relations among neighbors, conflicts, and movements of household members. We refer to this questionnaire-based data as "cognitive maps." During data entry of the survey into MS Access, the maps were photographed digitally for incorporation into both the data base and the spatial imagery created with ArcGIS to make the individual characteristics visible while scanning the landscape of the study area. Combined with the longitudinal data collected by Colson and Scudder, which includes socioeconomic and demographic data and extensive qualitative data collected through interviews and observations, the outcome of the combined research projects is "deep knowledge" over a substantial time period for a broad swath of Southern Zambia.

The Socioecological Context of Gwembe Life

Since Gwembe villagers were resettled in 1958, they have lived under conditions of increasing uncertainty that militate against conservation of resources and promote environmental degradation. Four major factors influence the villagers opportunistic responses to their environment over the past 50 years: two of them are related to climatic factors, while the third and fourth, and most important, arise from the rapidity with which Zambia's changing political economy affects agriculture, rural services, and the job market, and the uncertainties brought about by the short attention span of international donor agencies.

Climatic Factors

Throughout the past century, the Gwembe has suffered frequent hunger years because of drought, which has increased in number since the 1970s. Some droughts have persisted for several years, and there have also been shifts in the timing of rainfall, so agricultural decision making has become increasingly problematic. Thus every year is a gamble in which the odds may seem too high for people very much aware that they may lose their investment in the purchase of seed and other inputs such as fertilizer.

During the 1980s and early 1990s, droughts led to massive reduction in the size of the lake above the Kariba Dam. As a result, a number of irrigation schemes developed during the years when the lake was at its maximum (around 1963) failed, as pumping water from the lake became uneconomic. On the other hand, shrinkage of the lake provided those living nearby with an unexpected bonus of new land to farm during and after the rains. This allowed them to fallow fields cleared after the 1958 resettlement whose fertility had begun to fall, or to hand these on to relatives while they cultivated the new land gained from the lake. The lake margins also provided excellent pasturage for the growing herds of cattle that are perhaps the Valley's most important legal source of cash (Colson and Scudder 1988; Scudder and Habarad 1991).

In the late 1990s and early 2000s, heavy rainfall in the Zambezi catchment area upstream brought the lake back in flood. The waters rose rapidly over lakeside fields, taking standing crops and sometimes equipment, causing loss of substantial agricultural acreage and pasture. The unpredictability of the lake margins greatly increases the uncertainties of the agricultural livelihoods of many living in Gwembe South, Gwembe Central, and Gwembe North near the lake. Others in Gwembe North who are settled along the Zambezi River have had their fields inundated when the dam gates have been opened either at short or no notice to relieve pressure on the dam during high water periods in the lake. These uncertainties negatively affect people's evaluation of the desirability of conservation or restoration measures.

The Unpredictability of Zambia's Political Economy

In addition to climatic factors, farmers are also forced to plan in an environment where government and international donors' policy decisions are unpredictable and not responsive to local conditions. Agricultural development schemes over the last 40 years have encouraged Gwembe farmers to engage in cash cropping variously cotton, sunflower, maize, or brewing sorghum or some other favored product. However, since the late 1980s the marketing mechanisms for agricultural inputs and products other than cotton have been chaotic. Gwembe Tonga farmers cannot count on the delivery of agricultural supplies or the availability of markets. Even if they can find a buyer, they have no assurance that they will receive their money before inflation wipes out any profit. Payments sometimes lag 6 months or more after the crop has been delivered. Payment for last year's crop may not pay for this year's inputs.

The inconsistency and changeability of national policies related to rural areas have further contributed to farmers' difficulties. In the 1950s and 1960s the Gwembe Valley was linked to the Zambian economy by a network of newly built roads that made it possible for people and produce to move freely within the Valley and from the Valley to the towns and markets on the Plateau. After Zambian independence in 1964, credit facilities became available for seeds, fertilizers, and agricultural equipment; transport was available for the movement of crops to market; and local shops were well stocked with consumer goods. This encouraged some to shift from labor migration to cash crops. Indeed this period appeared to be a boom in the local economy, and people hoped for improved living standards.

However, with the downturn of the Zambian economy in the mid-1970s, the rural economy suffered. The Gwembe farmers experienced further damages during the Rhodesian war when the Valley was seeded with landmines. The impact of structural adjustment programs imposed in the 1980s and 1990s by international donors, particularly the IMF, exacerbated local economic uncertainty yet further. Roads deteriorated and in some cases vanished. Agricultural inputs were delivered late if at all, and in many areas it became uneconomical for merchants to buy crops because of the bad roads. Prices of food crops were volatile, especially for local producers who had to compete with grain imported from the south or as relief food from overseas. With the exception of cotton, which continued to be handled by a separate government organization until sold in 1994 during Zambia's privatization program, government schemes for credit along with organization of crop marketing disappeared (Scudder and Colson 1997, 2002).

These volatile conditions have favored the growing of marijuana – a crop which is of high value, easily transportable, and requires few inputs, and also has the advantage of being drought resistant. There is good reason to believe that Gwembe production of marijuana has increased dramatically over the last 30 years even though the crop is illegal under Zambian law. Returns are high enough to justify the risk. Recent research documents the ways some Gwembe producers have marketed the high value crop via the Kapenta fishing industry on Lake Kariba (Malasha 2003).

Another response to production and marketing uncertainties has been to concentrate on subsistence agriculture with minimum of investment. Continued high birth rates among the Gwembe Tonga facilitate this return to subsistence farming by providing cheap labor. Villagers have also invested in livestock, especially cattle, which are used as draft animals, which produce milk, and serve as a store of value since they can be sold when the need arises and driven to market when necessary.

Uncertainties in the Relationship to Land

Given uncertainties in both climate and markets, investment in maintenance of soil fertility or other forms of intensification is not seen as likely to be profitable option. At the same time, in many areas of the Gwembe region farmers complain of a shortage of arable land. The birth rate is high, and movement to the towns is not attractive given the stagnation of the Zambian economy since the mid-1970s and the increasing numbers of unemployed. Uncleared arable land is no longer available locally. Shifting cultivation is also not an option in most areas because either potential fields have been claimed and are in use, or the land is abandoned as it is no longer sufficiently fertile for farming.

In the 1970s and 1980s, resettled villagers had already cleared land in the nearby hills, wherever soil and water were available. This led to the dispersal of homesteads and villages, complicating programs for the provision of schools or extension services, and adding to the difficulties of road maintenance and crop collection. In Gwembe Central, for instance, the area between the Chezia and Chiabi Rivers that was bush country full of game in the 1960s is now occupied by small settlements. In Gwembe South, the villages of Siameja neighborhood have also fragmented, with people moving either to the lakeshore or into the hills where they cultivate fields for a year or two before moving on, leaving an eroding slope behind them. Whatever the rainfall the people of Siameja cannot grow enough grain to feed themselves throughout the year. Each year, grain must be imported either through private purchase or with NGO and government assistance. In officially recognized hunger years, grain is distributed through various programs including food-for-work projects. The Siameja economy is highly dependent on employment in the nearby amethyst mines or in small-scale gemstone-mining, which is technically illegal. Residents also rely on the sale of cattle, and during the period from the 1970s to the early 2000s, some Gwembe South villagers produced handicrafts (especially wooden stools and drums, and baskets) for the tourist market. This resulted in its own environmental impacts. Trees suitable for carving became increasingly in short supply and by the 1990s basket-makers were importing some of their materials from the Plateau due to over exploitation in the Valley. Then markets dried up. As of 2004, the handicraft purchasers from the Plateau found that transportation costs into the Valley were too high and consequently there is currently no outlet for Valley producers.

We do not know to what extent the amethyst miners of Gwembe South are also contributing to deforestation by cutting trees for mining props. Some deforestation here as in Gwembe Central and Gwembe North is due to tree cutting for drying racks and firewood for the Kapenta fishery. The charcoal trade is increasingly taking its toll on wooded areas throughout the region and especially in Gwembe North, which has good road access.

Land resources may be thought of as finite. Allocation of land is subject to political decisions that can deprive the local population of access to desirable land. From many points of view, Gwembe land is desirable, especially in Gwembe North where the road system is in better shape. Water is available from the Zambezi River and Kariba Lake. There are some good soils locally under cultivation. There is now the promise of electricity. In recent years, land near the Zambezi River in Gwembe North and along the lake in Gwembe Central and South have been handed over to Europeans and members of the Zambian (especially non-Tonga) elite, for plantations, crocodile farms, game ranches, and other tourist activities. Much of the lucrative Kapenta fishery, which includes valuable lake shore property, is in the hands of expatriates and non-locals.

Aerial photographs from different periods document the creation and decline of the Gwembe infrastructure: roads, small dams, buildings, etc; the extent of erosion; and village fragmentation and dispersal through the hills. What they cannot show is how people have responded at a number of different levels. Responses depend upon the factors people take into consideration as they plan their crops, decide to emigrate, or turn to exploiting other existing resources within the Valley. They are also affected by the political impact of village fragmentation on the authority structure, the ability to mobilize people for public works, and the feasibility of enforcing such regulations as exist with respect to conservation or reforestation, or controls on the Kariba Lake fisheries. Through the 1990s and at the beginning of the twenty-first century, outlying settlements have been demanding recognition as legal villages under their own headmen. There is some evidence that this reflects the economy of drought years, when people rely upon food-for-work and other relief programs for grain, which are distributed by village, without taking population into consideration. But village fragmentation is also taking place within a political environment in which power over local affairs has been handed back to chiefs and headmen throughout Zambia, beginning in 1991.

Recurring Patterns

Gwembe Tonga strategies for settling in the migrant frontier provide other evidence of how they engage with natural and social environments. Mobility has been a primary strategy for dealing with variable ecological, social, and political economy circumstances. When shifting to areas closer to central villages no longer offered the kinds of options they wanted, some ambitious farming households moved to the

Plateau frontiers. Their reasons for moving usually center on issues of resource access – both environmental changes impacting farming in the Valley and conflicts over control of key resources (Cliggett 2000). Additionally, many of the settlers have relocated from urban regions, either following urban retirement or because of the expense of urban life and the difficulty of earning a living wage. Rather than return to "home" villages that offer no prospects for successful farming, they choose to pioneer a new region that has great potential for profitable farming.

Resource Exploitation

Migration, mobility, and resettlement (whether voluntary or forced) constitute the most important forms of livelihood diversification for the Gwembe over multiple decades. Settlement in a frontier region requires particular techniques of resource exploitation – especially in terms of land clearing and forest management. Gwembe people who lived through the 1958 resettlement and those who subsequently shifted into the uplands surrounding the resettled villages engaged in extensive forest clearing. However, the new migrants and the earliest pioneers have conflicting approaches to land tenure that have triggered different strategies to ensure land access and livelihood security. The new generation of migrants on the Plateau has moved into areas towards the national park border where they are rapidly felling woodlands in an attempt to clearly demarcate and "protect" their claim to land, most likely resurrecting clearing practices they learned from their parents. The extent of this clearing is particularly evident on a composite of satellite imagery combining an image from 1986 with one from 2000. The more established migrants, on the other hand, have recognized rights enabling them to keep portions of their land in primary forest cover.

Increasing population densities resulting from expansion into the bush in both the Valley and Plateau settlement areas have led to very similar patterns of diversification, resource use, and response to opportunities. Following relocation in 1958 there was a boom in the local economy triggered in particular by the new fishing industry on the lake, as well as agricultural expansion into previously unfarmed areas on the uplands. In the migrant frontier there is currently a similar economic boom. Clearing in new woodlands offers vast fertile lands for farming. The borders of a national park offer plentiful game for hunting, despite occasional enforcement of laws against poaching. In both the Gwembe Valley of the 1960s and the Chikanta region of the 1990s and 2000s vibrant local markets developed. Tea houses and shops increased in the Valley towns after resettlement in 1958, and similarly, from the 1990s in Chikanta the thriving local markets trade in second-hand clothing, cooking utensils, and other town produced goods for maize, and - although not well-documented - bush meat. Recent NGO and government efforts to stop poaching have led to a decline in local bush meat markets, but residents predicted that if the NGOs and government groups withdraw from the area trade in bush meat will increase again to the levels of the late 1990s.

Class Differentiation and Social Change

Individuals, families, households, and different social networks diversify their livelihoods by combining self-provisioning with cash cropping agriculture; engaging in resource extraction for sale through multiple markets (thatching grass, forest products, fish, game meat, etc); combining animal husbandry with agriculture and cottage industries. In the migrant frontier some families embrace new crops such as cow peas and sunflower, as well as opportunities to produce crafts for the anticipated growth in tourism. These activities have all appeared in conjunction with different externally driven development efforts in the region.

Those who lack access to NGOs promoting new livelihood options diversify their livelihood repertoire with activities that depend on local markets, such as fishing, growing vegetables for sale, carpentry, brick laying, and other construction skills, self-provisioning with maize, and for some, acquiring skills for healing and local medical treatments. The range of diversification choices thus varies among individuals and groups depending upon the social networks to which they have access.

Increasingly in the areas bordering the Kafue Park government and development agencies are injecting resources directed to "natural resource management," "food security," and "sustainable livelihoods." While the professed goal of these activities is to benefit the entire population of the region, the actual dispersal of resources and rewards is uneven. Consequently, local populations here, just as in the Gwembe Valley, vary in their access to benefits from government and NGOs.

The uneven inputs of assistance and development investment result in quite different approaches to livelihood diversification among populations living in the park border zones. What might be considered the local elite – a mixture of wealthier host population and wealthier longer resident migrants from the Gwembe Valley – tap into both employment opportunities and development endeavors, which include distribution of new seed varieties, new breeds of cattle for studding to improve livestock in the region, and medicines for animals and people. For those outside the network of local power holders, access to these benefits is not guaranteed. For the less privileged, exploiting natural resources such as game and forest products offers valuable additions to their primary dependence on maize and cotton farming.

Conclusion

The Gwembe Tonga face both chronic uncertainty in the form of climatic extremes of droughts and floods, and fluctuations in local, regional, and national political economies, as well as what might be termed intermittent collapse – periodic opportunities and challenges presented by changing ecological resources combined with external interventions. Examples of this pattern in the Gwembe Valley include the fishing industry following initial relocation in the late 1950s, and the repercussions for the Valley people of the strong national economy in the early 1970s. However, by the mid-1970s, economic stagnation had set in and persists today. More recently the Valley farmers have suffered from significant loss of soil fertility. In contrast, on the Plateau frontier, the current availability of previously unfarmed land and periods of poorly enforced hunting regulations offer opportunities for economic benefit.

The range of adaptations to environmental, political, economic, and social change that the Gwembe Tonga have adopted over the past half century vividly demonstrates their creative ability to respond to opportunities and adversities as they arise. Given the macro structures of global climate change, national political maneuvering, and an increasingly globalized economy, they have developed highly resilient adaptive strategies in the face of great uncertainty. Most important in their adaptive repertoire are migration and mobility, economic diversification, and natural resource exploitation.

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Social and Environmental Impacts of the Rise and Fall of Flue-Cured Tobacco Production in the Copán Valley

William M. Loker

Introduction

The Copán Valley, located in western Honduras adjacent to the Guatemalan border, is famous as the site of the ancient Maya city of Copán, which attracts thousands of tourists to the Valley every year. Visitors to the archeological site find a beautiful Valley with an appealing agricultural landscape of crops, pastures, and tobacco barns scattered along the bottomlands of the Copán River, which lies at about 600 m above sea level (masl) and flows westward into Guatemala. The surrounding hills and mountains, extending up to about 1,500 masl, are a patchwork of land cleared for crops and pastures, secondary forest, coffee groves, and pine-oak forests.

While the current residents of the Valley increasingly identify with the archeological site as it becomes a source of tourism revenue, until recently, the *patrimonio cultural* (cultural patrimony) of the Copán Valley has been the cultivation of tobacco, which has a long history, and perhaps prehistory, there. This article examines the reasons for the rise and decline of flue-cured tobacco production in the Copán Valley in the second half of the twentieth century and describes and analyzes the social and environmental changes wrought by the crop. Recounting this process requires excursions into the international tobacco trade, the history of land use change in the Valley, and the agroecology of the Copán Valley and the tobacco production process. Data for this study were gathered during field research extending over three years (2000, 2001, and 2003) for a total of about eight months in the field.

Bennett (1993, p. 15) characterized the description and analysis of human-environmental interactions as one of the most difficult and complex intellectual endeavors. While this process has been aided by recent technological, conceptual, and

The original article *The rise and fall of flue-cured tobacco in the Copán Valley and its environmental and social consequences* appeared in *Human Ecology* Vol. 33, No. 3, June 2005.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_16,

methodological innovations, the task remains difficult for several reasons. For example, computer-assisted GIS analysis, while a powerful tool, has not overcome some potent methodological obstacles in the accurate characterization of social and natural systems, which are often exceedingly complex and variable in both space and time. Also, environmental data tend to be continuous in nature, while social data tend to be point data (from individuals, households, villages, or other administrative units) making their linkage difficult (Fox et al. 2003).

Our conceptual models for understanding environmental change are also still very much in the process of development and refinement. The political ecology framework that has emerged over the last 20 years has succeeded in directing our attention to the complexity of the multiple forces shaping human decision-making regarding a variety of uses of natural resources. Yet there is little consensus regarding general principles of inquiry in the political ecology program, or even agreement on whether general principles are possible or desirable. This is due in large measure to the site specificity and the multiple levels of analysis required in the political ecology framework, as well as the requirement that research projects focus on particular events in particular places (case studies). The ability to build general theory from a multitude of case studies has so far proved elusive. Another factor contributing to the difficulty of characterizing and understanding environmental change is that the object of our understanding is a moving target. That is, the nature of environmental change is, itself, changing. As the forces of globalization unfold in novel ways in new (and used) corners of the world, the forces and responses to environmental change shift and change.

Political ecology as a theoretical framework has been around long enough now that it has been applied to a variety of case studies, generated insights, revealed its limitations, been the subject of criticism, evolved, branched off, formed schools and subschools of thought and practice until one scarcely knows what one will find when encountering a political ecological study. What has endured in the political ecology framework is the notion that understanding environmental change requires close attention to the broader political economic framework in which human decision-making takes place, an explicit concern with signals and forces emanating from the international and national economy and an appreciation for the creativity, constraints, and capabilities demonstrated by social actors in their interactions with each other and the environment. There is no agreement on what political and economic forces should be prioritized in specific cases (Vayda and Walters 1999), in how to measure environmental change, in dealing with variation and contingency (Vayda 1994), agency (Nygeres 1997), particular histories (Balée 1998) and a variety of vantage points (Batterbury et al. 1997; Bebbington and Batterbury 2001) in understanding environmental change.

While recognizing these challenges and difficulties, the present study does not attempt a grand theoretical synthesis. Instead the article develops a detailed case study that illustrates the power of a political ecology framework (recognizing the vagueness of that appellation), involving as it does the decided intervention of international actors in a limited geographic space with clear repercussions and responses for the local environment and society.

Case Study: Flue-Cured Tobaccoo in the Copán Valley

Tobacco was a crop widely used in prehistoric Mesoamerica, including the Maya region, though we have no direct evidence of its cultivation in the Copán Valley prior to Spanish contact (Lentz 1991). However, tobacco cultivation has been, without doubt, the most important commercial crop in the Valley over the last 200 years. The Copán Valley was a center for tobacco production as early as 1764 and when John Lloyd Stephens, visited in 1839 (a few years after Central America's independence) he observed tobacco under cultivation and remarked on the renown of Copán's tobacco (Stephens 1969, orig. 1841, p. 132). The tobacco grown in the nineteenth and early twentieth centuries is known by the generic name "criollo," though interviews with older residents during fieldwork in 2001 revealed names for a number of local varieties which are now apparently lost due to their susceptibility to introduced diseases and the lack of a market for them.

Tobacco cultivation in the Copán Valley took a dramatic turn in the second half of the twentieth century. In the mid-1950s, British American Tobacco Company (BAT) became active in the Copán Valley, introducing flue-cured tobacco in order to supply leaf for the manufacture of cigarettes in its Honduran factory. BAT was formed in 1902 as part of an agreement between the American Tobacco Company (ATC), founded by James B. Duke in 1890, and Imperial Tobacco Company of Britain. Both ATC and Imperial were formed by consolidating preexisting cigarette manufacturers during the explosive growth of cigarette manufacture and consumption immediately after the invention of a cigarette rolling machine, patented in 1881. The so-called Bonsack machine produced huge gains in productivity over hand rolling, dramatically lowering the price of cigarettes, which together with mass-marketing, led directly to the rise of the cigarette as the preferred means of tobacco consumption, displacing chewing, snuff, and pipe and cigar smoking. The rise of the cigarette set off a tremendous surge in tobacco consumption, competition for markets, and subsequent consolidation in the industry. When ATC's James B. Duke arrived in London in 1902 with an eye to further acquisitions to compete in the lucrative British market, previous rival manufacturers there united as Imperial Tobacco to fend him off and invade the U.S. market. After 12 months of fierce competition, ATC and Imperial declared a truce and rather than slug it out in competing markets, carved out exclusive spheres of influence in the U.S. and Britain, respectively, and formed BAT as a joint venture to take the cigarette business global. Initially, ownership of BAT was two-thirds American and one-third British, with headquarters in London. In 1911, the US Supreme Court ordered dissolution of the "tobacco trust" of ATC into a number of competing elements, as well as the disposal of ATC's institutional holdings in BAT, which shifted the balance of ownership toward Britain. Four main successors were formed from ATC: Ligget & Meyers, R.J. Reynolds, Lorillard, and a reformed ATC. These successor companies focused on battling for the domestic US market, leaving the international terrain virtually uncontested to BAT (Cox 2000).

Thus BAT represents an early prototype of the multinational corporations that have come to dominate international commerce in the last 100 years. Due to its somewhat unusual genesis as a mechanism to avoid competition between two tobacco powerhouses, BAT quickly gained a dominant position in the global tobacco industry by following the early strategy pioneered by James Duke of gaining market share and eliminating competition through acquisition of rival firms. This strategy was driven in part by its formulaic success and secondarily as a means to avoid tariffs and domestic content legislation which quickly appeared in country after country as governments sought, unsuccessfully, to protect domestic tobacco industries (Cox 2000, p. 5). Another reason for local acquisitions was to diversify sources of flue-cured tobacco and reduce dependence on US growers. For example, in 1919 BAT and Imperial purchased 47% of the southern US Bright leaf crop and were accused by the Federal Trade Commission of monopsonistic buying practices (Cox 2000, p. 9); foreign cultivation of tobacco under local subsidiaries solved this problem. Through these tactics BAT became, and remains, the dominant corporation in the international tobacco market (BAT 2002).

BAT followed a strategy in Honduras and the Copán Valley whereby the company did not purchase land, choosing instead to introduce the desired tobacco varieties and technologies to local farmers who bore the risks of production but in exchange gained access to agricultural technologies (varieties, machinery, and agrochemicals), new production practices, credit, and an assured market for the product. A similar procedure has been widely replicated in a variety of agricultural commodities and is known as "contract farming" (see Glover and Kusterer 1990 for a discussion of contract farming globally). Contract farming of flue-cured tobacco persisted in the Copán Valley until the mid-1990s when BAT pulled out of tobacco cultivation.

Flue-Cured Tobacco

The predominant type of tobacco used in the manufacture of most cigarettes over the last 100 years is variously known as Bright leaf, Virginia, or flue-cured tobacco. In the Copán Valley, producers consistently use the term "*tabaco virginia*," to refer to the tobacco they produced for BAT. The term "Bright leaf" comes from the bright yellow color that characterizes this tobacco after curing. Bright leaf tobacco is produced by a combination of specially bred varieties, soil and weather conditions, and cultivation practices, especially post-harvest handling, including flue-curing, which entails curing the tobacco in tobacco ovens at temperatures of around 100–130°F over 5–10 days, depending on ambient conditions. Legend has it that the flue curing process was initially discovered by accident on a North Carolina tobacco plantation in 1839 by a slave who fell asleep while fire-curing tobacco (yet another curing technique) and hastily added charcoal to a dying fire. The increased heat and absence of smoke turned the leaf a bright yellow. The mild flavor of the resulting product fetched a high price at the local tobacco auction, and Bright leaf tobacco was born.

BAT imported US "technical experts" – in fact North Carolina tobacco farmers – to transfer the technique of producing flue-cured tobacco to local Copán farmers.

These Carolina farmers, most of whom lacked university educations and whose expertise was born of hard experience, trained the first cadre of contract farmers for BAT. Later, in the 1960s, BAT brought university-educated Americans to the Copán Valley as well as sponsoring the training of Honduran technicians at the Pan American Agriculture School in Zamarano, Honduras, and in the United States. Many former tobacco growers recall with great happiness this "golden age" when American tobacco farmers (and later technicians) were living in Copán, and *Copanecos* often traveled to the United States for business and pleasure at company expense.

Several factors contribute to flue-cured tobacco's high labor intensity: (1) tobacco is initially germinated in specially prepared seed beds and then hand-transplanted into the field about 45–60 days after germination; (2) the crop is susceptible to a number of pests and diseases which require close monitoring for their control; (3) plants must be topped and suckers removed to ensure quality crop – operations until very recently performed entirely by hand; (4) tobacco leaves are easily bruised in the field, lowering their quality and price, hence it is difficult to introduce machinery into the fields once the crop has reached a certain height; (5) harvest occurs over a protracted period as, on average, only three to four leaves per plant are "ripe" and thus harvested at any one time, requiring multiple passes through the fields over a 5–7 week period (Hawks 1970, p. 185); (6) the flue-curing process itself is labor intensive and requires near-continual supervision; and (7) cured tobacco must be hand sorted into various grades prior to sale.

In the US South, slavery and later share cropping and wage labor took care of the labor requirements of tobacco production. In the Copán Valley, the demand for labor was met by a resident, landless population of agricultural laborers living in virtual serfdom on the lands of prosperous tobacco growers. Labor was controlled and disciplined by denying access to land ownership, making households dependent on the local owner, or *patrón*, for wages and access to land. Tobacco in Copán is cultivated in the dry season (October–May) under irrigation. Once the crop is out of the field, tobacco growers formerly made the land available to loyal workers at low or no cost for the cultivation of maize and beans in the rainy season for household subsistence. The provision of land was part of the "compensation package" received by landless laborers, who generally earned very low wages. Many of these laborers were descendents of the Chortí Maya whose traditional territory extends from the Copán Valley into Eastern Guatemala (Wisdom 1940). These impoverished workers later formed the bases for the successful ethnopolitical movement discussed below.

Besides the labor problem, flue-curing requires considerable heat to maintain the interior of the oven at a temperature over 100°F day and night for up to a week. In the Copan Valley, firewood from the surrounding hills was the predominant fuel used for the ovens. It is difficult to quantify the amount of firewood used in the curing of tobacco. Local measures of firewood are not standardized. Growers and technicians spoke of "*tareas*" of firewood, with each tarea equal to 8–10 "*cargas*" (the amount a mule can haul, generally around 200 pounds) with each carga composed of about 500 pieces of firewood. Also, "*una horneada*" – one oven's worth of tobacco—is not a fixed measure. The size of ovens, the heating system, construction material, and other features influence the amount of wood necessary. Also, ambient conditions at the time of curing: temperature and humidity, and the moisture content of the leaf itself affect the amount of wood needed. Given all these factors, there was a surprising consensus among growers regarding the amount of firewood needed for each curing: three to four tareas of firewood, equal to approximately three cubic meters of wood, or the caloric equivalent of 150–200 gallons of kerosene. Each hectare of tobacco required approximately five horneadas. Clearly, flue-curing tobacco required considerable firewood with the potential to cause extensive deforestation in the study area, a topic considered in detail below.

Golden Years: The Boom in Flue Cured Tobacco, 1955–1985

BAT found in the Copán Valley nearly ideal agroecological and social conditions for the cultivation of tobacco. Agroecologically, the Valley has flat, deep, well-drained alluvial soils of moderate fertility bordering the river (Wingard 1992), ideal for tobacco (Hawks 1970, p. 39–43). The climate is tropical with nearly uniform temperatures year-round. Flue-cured tobacco requires at least 120 frost free days, and performs best where daytime temperatures range from 85° to 90°F and nighttime temperatures do not fall below 65°F (Hawks 1970, p. 34). Rainfall in the Copán Valley is seasonal (80% falling between May and November) and tobacco could be grown in the dry season using irrigation water easily drawn from the Copán River by small gasoline-powered pumps and distributed via overhead sprinkler systems. Growing tobacco in the dry season under irrigation allowed for greater control of growing conditions and reduced disease pressures. The Valley was already a proven tobacco growing region. Local farmers had experience in the culture of tobacco; several aspects of the cultivation of Virginia tobacco, such as the use of seed beds and hand transplanting, were also required in growing the local criollo varieties. All that was necessary was to introduce some revisions into the existing system: new varieties, agrochemicals, limited mechanization, and a novel curing process. This also required the provision of physical and institutional infrastructure to make it work: technicians, the provision of credit (initially provided through low or no-interest loans), importation of machinery and agrochemicals, and establishment of marketing mechanisms. In the early 1950s, Copán was only marginally connected by road to the major marketing center of San Pedro Sula, with the trip taking several days by mule. Vehicles were rare or absent. The first tractor was brought to Copán under BAT auspices in the 1950s by airplane and initially fuel was flown in and tobacco flown out of the Valley until road infrastructure was improved. In addition, the Valley had a population of dispossessed peasants to form the basis of a cheap and willing labor force. Production of Virginia tobacco took off in the Copán Valley.

During the "golden age" of Virginia tobacco production, the extent of production in the study area ranged from 210 to 420 ha from the Guatemalan border to the Hacienda El Jaral, 9 km east of Santa Rita. Virtually all of the flat land in the Valley was devoted to flue-cured tobacco in the dry season, with anywhere from 20 to 25 growers participating. Growers recall an agricultural landscape of a sea of green tobacco growing in the river bottoms and adjacent hills: anywhere that could be cultivated by a tractor and reached by irrigation water. Interspersed among the fields were tobacco barns where the crop was cured, most made of adobe, some of stone looted from the archeological site. Scattered in the hills and valley were the hamlets and villages of the laborers, in what locals call *casas de basura* (houses of trash), made of straw and thatch, or sometimes *bajareque* (wattle and daub) with thatch, or later, tin roofs. According to growers, labor was abundant, willing and skilled. According to laborers, working conditions were difficult, with routine exposure to toxic chemicals, low wages, and subject to the whim of landowners, who varied considerably in their treatment of workers and provision of land for subsistence production.

Growers describe initial relations with the company as extremely positive and friendly. *La companía* (the local term for BAT) provided seed, inputs and capital for long-term improvements (irrigation equipment for example), and cash for meeting the payroll at no interest throughout the 1950s and 1960s. Costs were discounted from tobacco sales at the time of purchase and profit margins were ample for good growers: those who followed BAT recommendations and produced high quality leaf. The relationship, as described by both growers and company representatives, was "paternalistic." Clearly the company held the power in the relationship through its monopsonistic buying practices and control of capital, but at least initially, both the company and most growers seem to have benefited. Tobacco representatives claim that the company advanced around $5 million to 23 growers at the height of the boom. The production of Virginia tobacco on 210–420 ha in the Valley at this time, using about 2,000 person hours per hectare (about 250 person days per hectare), required a total of 52,500–105,000 person days per growing season. This meant that on average, about 250–500 people would be working in the fields and barns every day over the 7 month season from planting to marketing.

Human Ecology of Tobacco: Environmental and Social Effects

Deforestation

Flue-cured tobacco was introduced in the Copan Valley in 1952 and the last crop was bought by BAT in 1995, according to local growers. Allowing a few years for practices to be established and a period of gradual decline, we can estimate that the boom in flue-cured tobacco lasted from about 1960 to 1985. Throughout this period, the area under tobacco cultivation ranged from 210 to 420 ha per year, according to local growers. We can estimate the amount of firewood used per year in curing tobacco from the following formula:

$$C = F * H * M$$

where: C = quantity of firewood used in cubic meters, per year; F = quantity of firewood per horneada (3 m^3); H = number of horneadas per hectare of tobacco cultivated (6); and M = total number of hectares of tobacco cultivated (210–420).

This formula produces an estimate of 3,780–7,560 m^3 of firewood used per year. These results agree with the estimate provided to the author by the representative of COHDEFOR (the national forestry service) who independently estimated that the curing of tobacco used about 6,000 m^3 of wood per year. According to COHDEFOR data taken from direct measures, contemporary local pine forests have 85–120 m^3 of pine per hectare. This estimate does not include the amount of wood found in other species frequently associated with the dominant pines, such as oaks. Tobacco growers would use virtually any kind of wood available in their ovens. If we take a round number of 100 m^3 per hectare as an approximation of the pine wood available in local forests, and we further assume that pine represents about two-thirds of the total volume of wood per hectare, this means that the average hectare of forest has about 150 m^3 of wood total. Thus, we can estimate that the curing of tobacco required deforestation of about 25–50 ha of forest annually. For perhaps five of the 25 years of the tobacco boom kerosene was the dominant fuel. Therefore, during this 25 year period, tobacco cultivation deforested about 500–1,000 ha. In comparison, the two sawmills that operated in the area during this time used "only" 1,000 m^3 of pine wood per year each (2,000 m^3 total per year) resulting in the deforestation of approximately 20 ha per year.

Wood is a renewable resource, but very little forest regenerated, even partially, during these years. Many of the tobacco growers were owners of extensive amounts of land and cattle, and they burned deforested areas to plant pastures for their cattle. It was, and still is, the usual practice of cattlemen to burn their pastures periodically to keep them free of weeds and shrubs, interrupting the process of forest regeneration.

Tobacco growers also used the waste wood from local sawmill operations as a source of fuel and used downed and dead wood whenever possible. Both these practices eased pressure on local forests. Contracts with BAT from the mid-1980s on also specified that growers should reforest using company-supplied seedlings, mostly leucaena and eucalyptus. But the reforestation programs had little impact due to the voracious demand for firewood. Several tobacco growers volunteered that extraction of firewood for curing tobacco was a major agent of deforestation during this time and several cited the increasing scarcity and consequent rise in cost of firewood as contributing to the decline in flue-cured tobacco growing in the late 1980s and 1990s.

Figures 1–4 present pie charts and summary aerial photo data of the area in various vegetation classes in the Valley at the time the photos were taken.[1] Figure 1 is a pie chart of land cover derived from the 1955/1960 aerial photographs, while Fig. 2 shows the same information for the area of overlap between these two sets of photos for 1978. Note that the area in forest diminished significantly from 1955/1960 to 1978, the period covered by the rise of flue-cured tobacco, from about

[1]There are a number of methodological issues associated with the interpretation of land cover in tropical areas under active cultivation like the Copán Valley that are not explored here, due to lack of space. For detailed discussion of these issues seen in another area of Honduras see Loker 2004.

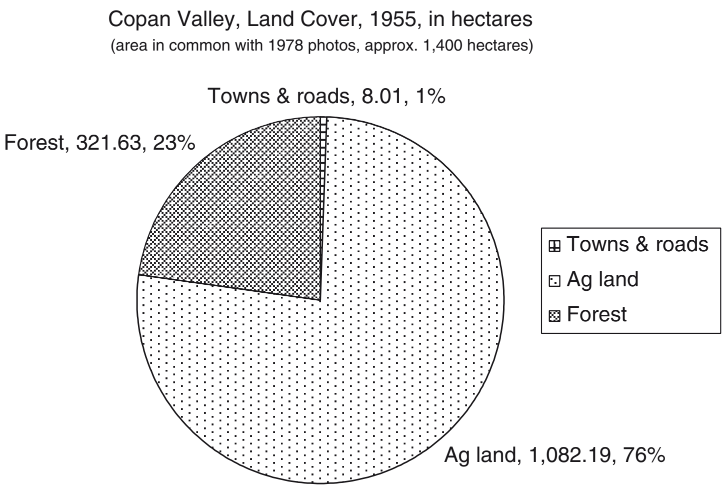

Fig. 1 Pie chart of area in various land cover classes in the Copán Valley in 1955

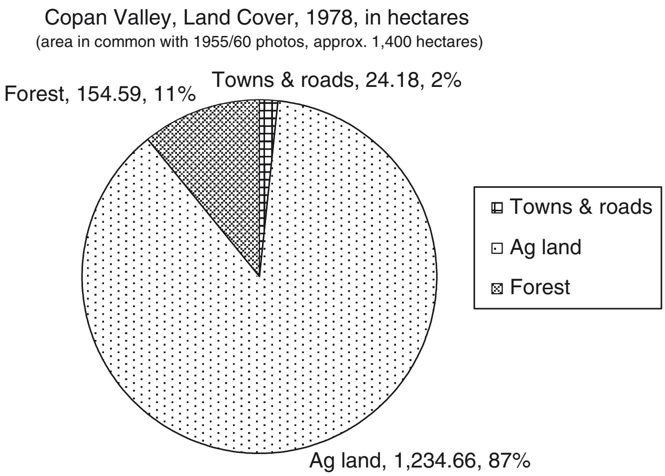

Fig. 2 Pie chart of area in various land cover classes in the Copán Valley in 1978

23% to about 11% of the total area, a decline of about 170 ha. While not all forest loss can be attributed to flue-curing tobacco, given these data and interviews with producers, it seems clear that flue-curing contributed significantly to this loss.

Figure 3 presents the same data for 1978 for the approximately 75 km^2 covered by the 1978 and 1999 photos. (This is about half the area covered in common by the 1955/1960–1978 photos and includes even less of the surrounding hills.) The data from 1999 (Fig. 4) represent four years after the last tobacco contracts were issued

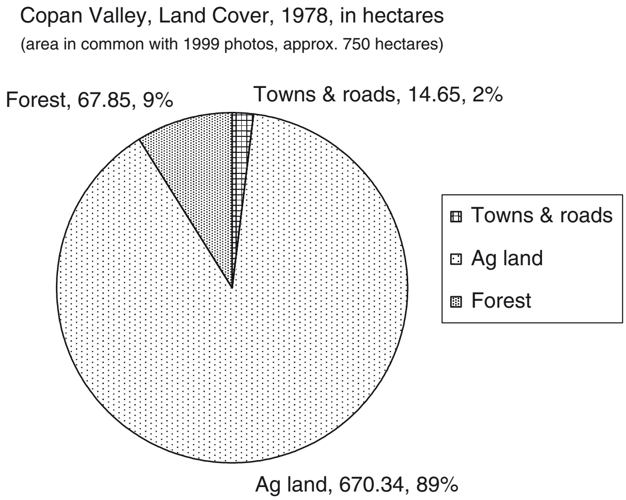

Fig. 3 Pie chart of area in various land cover classes in the Copán Valley in 1978

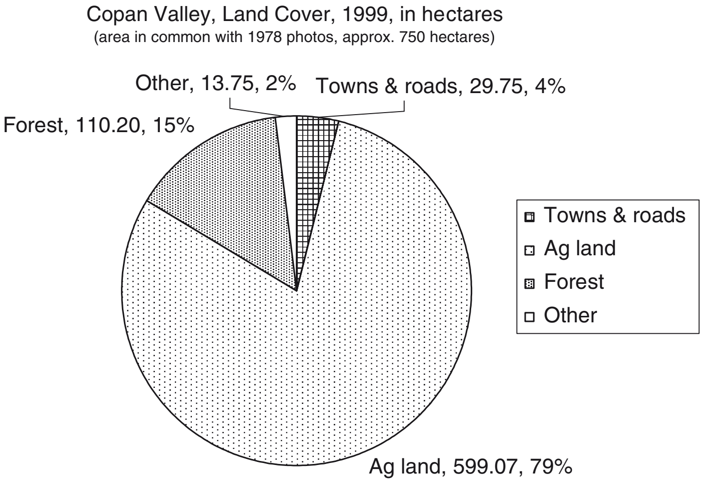

Fig. 4 Pie chart of area in various land cover classes in the Copán Valley in 1999

by BAT in the Copán Valley, and about 10 years of gradual decline in flue-cured tobacco production. Interestingly, the forested area between 1978 and 1999 *increased* from about 9 to 15% of the area covered by the two photos. Thus the decline of flue-cured production is associated with a process of gradual reforestation. Again, while correlation does not prove causality, the noted trends of deforestation during the rise and boom of flue-cured tobacco production and reforestation after its demise, strongly suggest that flue-cured tobacco caused significant deforestation.

Agrochemical Use

Another aspect of tobacco cultivation with significant environmental effects is the use of agrochemicals; tobacco is a crop that, in general, is a heavy user of various pesticides and fertilizers. The cultivation techniques introduced by BAT in the 1950s brought the first fertilizers, pesticides, and agricultural machinery into the Valley. The types and quantities of agrochemicals used in flue-cured tobacco production varied over time as new products became available and as pest and disease pressures in the tobacco mounted. For example, in 1981, the deadly tobacco disease "Blue Mold" was introduced into Honduras. Blue Mold is a fungus (*Peronospora tabacina*) transmitted by airborne spores that can wipe out a tobacco crop within 24 hours. Control required the use of a changing set of expensive fungicides as the disease developed resistance. (It was Blue Mold that ended the cultivation of local varieties, eliminating a fairly important cash crop for growers outside the flue-cured nexus.) All growers interviewed agreed that pesticides of various types were a part of the technical package from the beginning of flue-cured production in the Valley.

One agronomist with long experience in the area indicated that the first products used were highly toxic and persistent insecticides. In general protective clothing was not used and pesticides were carelessly handled. Chemicals were generally applied by hand or using back-pack sprayers both of which, when combined with the lack of protective gear, lead to heightened exposure of concentrated doses of pesticides. Several former tobacco workers mentioned frequent bouts of pesticide poisoning varying in severity from spells of headache and dizziness, to loss of consciousness and emergency trips to physicians for cases of acute poisoning. In addition, practices such as cleaning out spraying equipment and disposal of pesticide containers in local creeks and rivers were also mentioned, with probable negative effects on fish and bird life. These practices resulted in unnecessarily high exposure of people and the environment to highly toxic pesticides.

While I gathered no specific data on the presence of pesticides in workers' bodies or in the environment, Díaz Romo and Salinas Álvarez carried out research on pesticide exposure among tobacco workers under similar conditions in Nayarit, Mexico. Many of these laborers worked for contract growers for Cigarrera La Moderna, a BAT subsidiary, and cultivation practices, including the types of pesticides used, were similar to those in Copán. Blood samples drawn from tobacco workers and those living near tobacco fields indicated inhibition of erythorocytic acetylcholinesterase (EC, an enzyme critical for neurotransmission) levels symptomatic of prolonged exposure to carbamate and organophosphorous pesticides (Diaz Romo and Salinas Alvarez 2002: xiv). Given the similar environments and production techniques in the two areas, similar neurotoxicological effects are to be expected in the Copán Valley. As in Copán, workers in Nayarit reported symptoms such as headaches, dizziness, and nausea during and after pesticide applications.

Social Effects

The rise of flue-cured tobacco cultivation was predicated on a cheap, abundant supply of labor. In the Copán Valley this was provided by the dispossessed peasantry living in and around the Valley. BAT-sponsored tobacco production reinforced significant social and economic inequalities in the Valley and tied it more tightly to national and international markets, quickening the pace of exploitation. Growers look back on this period with nostalgia for the good old days, but most former workers express little regret at the passing of tobacco.

As indicated above, tobacco production was a massive source of employment, without doubt the most important in the Valley for three decades. Given the labor demands estimated for production of Virginia tobacco (52,500–105,000 person days per growing season), tobacco provided anywhere from about $100,000 to $200,000 per year in direct wages to local workers (assuming a wage of about $2.00 per day, in line with recent agricultural wage rates in the country). If we assume that about 200 households shared in these wages, this represents earnings of $500–$1,000 per household per season. In addition, at least some workers received access to land, rent-free, for the cultivation of maize in the off-season. While $2.00 per day is not a handsome wage and the work performed was arduous and dangerous (due to exposure to toxic chemicals), on a household and aggregate basis, the economic contribution of tobacco was considerable.

The economic importance of the crop makes the lack of regret expressed by former workers all the more surprising. The reason is largely due to the exploitative *patrón-peón* relationship that prevailed in tobacco production. Former workers spoke of feelings of extreme dependency, if not servitude, in their relationship with the growers and landowners. The fact that, in many cases, people did not even own their house lots left them open to abusive practices, such as having their yards and even houses invaded by the owner's livestock. Their precarious position made it difficult to obtain access to basic social services such as education and health clinics. Their vulnerability also made it difficult to advocate for better wages or working conditions; to alienate the patrón ran the risk of cutting off access to employment, land for maize, and even risk eviction from the house lot. Add to this the not-infrequent bouts of headache, dizziness, and more serious symptoms of pesticide poisoning, as well as the success of many of these formerly landless households in acquiring land through the ethnopolitical movement discussed below, and it is clear why tobacco's demise is viewed with little regret, despite its economic importance. Growers, on the other hand, find themselves in desperate straits with the collapse of flue-cured tobacco production.

The Boom Goes Bust: The Decline of Flue-Cured Tobacco, 1985–1995

A number of factors operating at the international, national, and local levels all contributed to the decline of flue-cured tobacco in Copán. The 1980s and early 1990s were a time of great uncertainty and upheaval in the tobacco industry in general. Increasingly strident anti-smoking public health campaigns, together with the gathering cloud of health-related law suits against tobacco companies caused great uncertainty in the industry. The turmoil of the 1980s and 1990s forced BAT to pay closer attention to its business model and the performance of its local subsidiaries. And this meant an end to the heyday of easy credit and friendly, patronizing relationships with Copán Valley growers since BAT was no longer willing to provide cheap or no cost credit and now insisted that growers get commercial credit from local banks. Contracts became less favorable to the growers and quality standards were more tightly enforced.

At the national level, Honduras in the early 1990s went through a process of structural adjustment including currency devaluation and trade liberalization, accompanied by high levels of inflation. All these affected the rationale and conditions for tobacco cultivation in Copán. Devaluation of the national currency dramatically increased the cost of imported inputs (pesticides and fertilizers) leading to rising costs of production. High rates of inflation led to increases in interest rates that made capital more expensive precisely at the time that BAT cut-off company-sponsored credit and forced growers to obtain credit through local banks. Trade liberalization meant that non-tariff barriers to the import of tobacco, such as government regulations requiring domestically grown tobacco in cigarettes manufactured in Honduras, were eliminated. BAT could now use imported tobacco to supply its Honduran manufacturing plant.

At the local level, growers were caught in a cost:price squeeze. New diseases, such as Blue Mold, demanded new, expensive pesticides. Levels of fertilizer use also increased to compensate for soil exhaustion brought on by over 25 years of continuous tobacco cultivation. Costs of credit and labor also increased. All this led to a decline in profit margins for growers. When growers turned to the company for relief, instead of the friendly patrón of old, they found a rigid attitude and an unwillingness to pay higher prices. In response to their deteriorating financial condition, in 1985 the growers formed PROTAVI (Productores de Tabaco Virginia), an organization aimed at negotiating better contract conditions with the company. Unlike the early days when contracts were signed on the hood of a pick-up truck, groups of growers negotiated contract conditions with company representatives in a businesslike, if not adversarial, atmosphere. Their chief demand was that the company pay them in US dollars instead of the continually devaluing national currency. On this, the company was inflexible. Those active in the producer's organization felt that their involvement was "punished" by BAT through downgrading the quality of their tobacco at the time of sale, thus reducing the price they received for their leaf.

The end came in 1995, when BAT cancelled all contracts with growers in the Copán Valley. Tobacco for the manufacture of cigarettes in Honduras is now imported from Brazil and Mexico, leading to what one grower termed the "maquilization" of tobacco in the country: cigarettes are fabricated using imported tobacco; only the labor is supplied by Hondurans.

The fall of flue-cured tobacco production was a disaster for local growers. Combined with the effects of Hurricane Mitch in 1998, which caused extensive flooding of prime bottomland, leaving a mess of rocks, mud, and fallen trees and destroying irrigation equipment, the loss of flue-cured production has caused a crisis in the local agricultural economy. Growers continue to search for an economic alternative to flue-cured tobacco: Burley tobacco, tomatoes, and peppers have all been tried with varying degrees of success. Many former tobacco fields are now being used for extensive grazing.

The collapse of flue-cured tobacco, while not regretted by many workers, did have profound social and economic impacts on the local rural poor. Because social structure and processes are affected by many forces emanating from a variety of levels, from the local to the global, it is impossible to attribute particular social changes exclusively to changes in the agricultural production system of the Valley. Still, flue-cured tobacco played a dominant role in the local economy and ecology over an extended period. As tobacco growers faced the increasingly difficult production environment they were forced to cut costs and rationalize production, mirroring, on a smaller scale, processes implemented by BAT. At the same time, the population of the indigenous villages of the Valley was growing, increasing the availability of labor as well as the demand for land to plant milpa. To reduce costs of production, growers were forced to cut labor and other costs. One of the measures they took was to restrict their workers' access to land. Even loyal workers received increasingly smaller plots of land for milpa production (according to interviews). Some growers took to cultivating maize for their own profit during the off-season for tobacco, as opposed to allowing workers to cultivate these fields, further violating the "social contract" between land owners and tobacco laborers. This led to a reduction in the already precarious living conditions of the *mozos colonos* until these became unsupportable.

The crisis for growers occasioned by the withdrawal of BAT from the Copán Valley created an opportunity for the rise of an ethnopolitical movement of the local Chortí for the recovery of ancestral lands. Emerging in the mid-1990s, this movement, known by its Spanish acronym, CONIMCHH (Consejo Nacional Indígena Maya-Chortí de Honduras), included many who lived on the lands of tobacco growers and labored in their fields. The increased "rationalization" of tobacco production and its eventual decline removed the principal source of wage labor for hundreds of families as well as curtailing access to land, providing a strong impetus to join the movement. Many former tobacco fields were turned over to pasture, and fields that were formerly provided at low or no rent to laborers were now grazed by cattle, cultivated in maize by owners or rented out at prevailing market rates, generally beyond the reach of poor, landless farmers. By the late 1990s, cash-strapped growers faced pressure to cede lands to local landless peasants at the same time that the government was willing to pay top dollar for land in order to resolve a potentially explosive social situation. Given this situation, many landowners opted to sell land, rather than fight. As of 2001, the Chortí ethnopolitical movement had received title to approximately 2,000 ha of land, with hundreds more hectares under negotiation and waiting for final payment and transfer to indigenous communities (CONIMCHH 2003). The decline of the tobacco economy has thus been instrumental in creating the (negative) social and economic conditions for the emergence of the land recovery movement, in creating the conditions under which landowners were willing to sell land, and providing new lands to work for the former landless and dependent tobacco workers.

Conclusions

This case study documents the links between the local, national and global political economy, the decisions made by local actors, and environmental change in the Copán Valley. The rise and fall of flue-cured tobacco provides a clearly defined starting and end point that enables us to trace the links between causal agents at varying levels of analysis and the local social and natural landscape. In this case, the local social and ecological landscape was transformed by the actions of relatively few, but powerful, local actors – tobacco growers – who linked up with a transnational corporation (BAT) to harness large numbers of laborers in the production of an international commodity, flue-cured tobacco. This production process had substantial ecological impacts in terms of deforestation and the use of a suite of highly toxic agrochemicals. The case draws our attention to the importance of preexisting social structural relationships, especially control over and access to resources, in shaping the nature of environmental change in particular localities. It also emphasizes the importance of local agroecological conditions in shaping environmental change. Rather than a static backdrop, the local agroecology is an active "actor" in this transformation; local agroecological conditions permitted the flourishing of BAT's flue-cured model in the Copán Valley. The fall of flue-cured tobacco, linked to changing macro-economic conditions associated with the pull-out of BAT, created a crisis of livelihood for both growers and laborers alike. As such, it was clearly a factor in the rise of the ethnopolitical movement aimed at recovering ancestral lands for the formerly landless laborers in order to provide an alternative livelihood to the now-vanished agricultural labor in the growers' fields. Growers are still casting about for alternative production strategies to replace flue-cured tobacco, which essentially ended with BAT's withdrawal from contract production in Copán.

This case study illustrates the importance of paying close attention to interactions among local agroecology, social conditions, the natural environment, and the impulses emanating from the broader political economy and how these resonate at the local level. While it is important to focus on "land managers," this case study demonstrates important interactions between national and international actors as well as the local social and natural landscapes that are the frequent objects of analysis of human ecologists. BAT chose to invest in the Copán Valley at least in part because local agroecological and social conditions were propitious for flue-cured production. At the same time, we can only understand the local social and natural landscape with reference to broader political economic forces that shaped non-local interventions in the region and the responses of local actors.

Thus, this case study presents examples of several trends in human ecology research: the progressive contextualization approach advocated by Vayda (1983) in which the investigator traces out whatever relationships are necessary to understand the given social and ecological questions under consideration (and ignores others). It is also an example of "classic" political ecology that links levels of analysis. It follows other successful examples of a "social life of commodities" approach, pioneered by Mintz (1985), in which a particular commodity or production process is used as the lens to examine social, economic, and ecological relationships. It also follows conceptual frameworks suggested by various "hybrid" political ecologies derived from theorists such as Nygeres (1997), Balée (1998), and Bebbington and Batterbury (2001), particularly in recognizing the importance of contingent, historical events that shape local agency. The study also incorporates remote sensing as a means of measuring environmental change and links this technique with ethnographic and historic research in creative ways, following methodologies pioneered by Moran and others (see Moran et al. 2003). While this article may represent "just another case study" (albeit an interesting one!), the methods pursued and the conclusions generated build on the insights generated by a number of threads of scholarship in human ecology and point the way toward a synthesis of theoretical frameworks and methodologies to guide human ecological inquiry in the future.

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Does Climate Change Affect War Frequency? The Case of Eastern China[1]

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Introduction

Past research using the paradigm of "historical particularism" has tended to reduce the fundamental causes of warfare to various economic, political, or ethnic sources. Webster (1975), using Darwin's concept of natural selection to examine a number of prehistoric and early historic societies, concludes that warfare is an "adaptive ecological choice" under circumstances of population growth and resource limitation. Recent studies also support the argument that resource scarcity and environmental degradation are both significant factors in generating armed conflicts throughout human history. However, none of these deal specifically with the probable contribution of climate change as a causal triggering factor. For example, historians of China speak of a war–peace cycle characterized by prosperity in the upswing when a new dynasty was established, and by increasing poverty in the downswing as the dynasty weakened. The fall of dynasties and the related social turmoil (i.e., internecine warfare and population collapse) were attributed to the degeneracy of the court (Zhao 1994). Although this generalization can account for instances of war–peace cycles, it cannot explain their timing or periodicity.

The Panel on Climate Variability on Decade-to-Century Scales of the National Research Council (1998) emphasizes that human societies, and especially agrarian societies, depend on or are controlled by climate. Temperature is probably the most important climatic variable influencing human societies. Temperature fluctuations directly impact agriculture and horticulture, exacerbate natural disasters, and can adversely affect plant, animal, and human rates of diseases. There is a long-standing scholarly tradition that in the historic past, organized armed conflicts and climate change are correlated. Some scholars (e.g., Huntington

[1] The original article *Climate Change and War Frequency in Eastern China over the Last Millennium* appeared in *Human Ecology* Vol. 35, No. 4, August 2007.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*, DOI 10.1007/978-1-4419-5701-6_17, © Springer Science+Business Media, LLC 2010

1907; Hinsch 1988; Hsu 1998; Atwell 2001, 2002) suggest that in the agrarian societies of preindustrial Europe and China cooling temperatures could hugely impact the availability of critical crops and herds. In situations of ecological stress, warfare could become the ultimate means of redistributing shrinking resources. Here we test this hypothesized relationship with quantitative data.

Study Area

In China there is voluminous archival documentation dating back to 880 BC recording major events of significance to different dynasties. This valuable and relatively comprehensive repository is the basis of our study. Eastern China, which includes the regions east of 105°E and within the latitude zones between 25 and 40°N, is the historic, political, economic, and cultural center of China. Since the establishment of Qin dynasty (221–206 BC), the first united Chinese empire, nearly 80–90% of the population lives in this area, and its agricultural production supports the majority of the Chinese population. The documentary records for this area are more complete than those of other regions, leading us to make it our primary study area.

According to the basic principles of physical regionalization we divided the study area into two macro regions: (1) the northern area, characterized by continental humid, semihumid, and semiarid temperate climate influenced by both the monsoons and the westerlies (i.e., prevailing winds from the west that occur in both hemispheres between latitudes of about 35° and 60°). Average annual temperatures range from 8 to 14°C and average annual precipitation ranges from 250 to 750 mm. Major agricultural products are wheat and maize, with some pasturage in the northwest. Frost days per annum exceed 100. (2) The southern area which is dominated by the monsoons, with average annual temperatures ranging from 14 to 18°C, and between 10 and 20 frost days. This region serves as China's major rice-growing area. In both regions, temperature and precipitation decrease from the southeast to the northwest.

Climate Change and Social Stability

We assume climate affected historic societies by altering agricultural productivity and consequently social stability. Warm but temperate climate may augment agricultural production, while significant cooling can directly impede production or even lead to crop failure. Temperature change influences agricultural production, especially at high and middle latitudes, by affecting the length of growing seasons, intensity of average summer warmth, and reliability of rainfall. In addition, a long period of cooling will lower the elevation at which crops can be grown, thus decreasing the amount of land available for cultivation and leading to a decline in total output or to more intensive cultivation but with lower yields. Lower yields may also result from the biological inability of certain grains to effectively withstand cooler temperatures and associated variability in short-term weather patterns.

According to Gong et al. (1996), agricultural yields in China from 1840 to 1890 (cold phase) were reduced by 10–25% in comparison with 1730–1770 (warm phase), despite the fact that the total arable area was at least 10% greater. Agricultural contraction caused by cooling is also evidenced in the history of rice cultivation in the middle and lower reaches of the Yangtze River (i.e., the southern portion of eastern China). Double cropping of rice started here in the Tang dynasty (618–906) and was further developed in the late fifteenth century during the Ming dynasty (1368–1643). However, between 1620 and 1720, the double cropping system collapsed because of cooler temperatures. Nevertheless, coinciding with the warmer phase that started around 1720, double cropping rice cultivation began to dominate the region again, although by the beginning of the nineteenth century (demarcated by a cold climate) it once more proved unsustainable despite government promotion. Today, double cropping rice cultivation is again functioning successfully. Nowadays, even in industrialized countries where technology is utilized to control as many environmental variables as possible, agricultural production is still limited by climate. Even though agricultural production may increase over time, its upward trend is tempered by climatic oscillations. We argue that such oscillations drove the historic war–peace cycles we examine here.

Chinese history has been shaped by nomadic invasions originating outside the Great Wall, which were also related to climate change. The territory outside the fortification that skirts around the heartland of Manchuria from the northeast, runs parallel with the present Great Wall in the middle, and curves southwestward to separate Kokonor and Tibet from China proper. It is estimated that a 2°C drop of air temperature can shorten the grass growing season there by 40 days. Cooling also changes the vegetative composition of the grasslands and the resulting forage shortage can cause the deaths of nearly 90% of domestic animals annually. It is not unreasonable to suppose that in the past cooling temperatures could lead to economic distress for the nomads in this area, triggering migration. Historically nomadic migrations moved in two directions: eastward movement of nomads in western China and the adjacent former Soviet territory; and southward movement of nomads in Manchuria and Inner Mongol Autonomous Regions of China and the south of the Mongolian People's Republic. These nomadic migrations threatened the Han Chinese who lived in the south. Occasional nomad raids to pillage Han farmers could escalate to large-scale invasions and reprisal attacks launched by the defenders.

Cold periods are often associated with great climatic variability, including extremes of drought, floods, and even occasional extreme summer heat, which further disturb agricultural practices already handicapped by a short growing season, potentially causing severe economic disruption and demographic stress. Agrarian distress also affects the tax basis for maintaining infrastructure and may well exacerbate the taxation or tribute burden on rural populations. During the "Little Ice Age" (1500–1900), many areas of the world experienced famine and some witnessed large-scale population migrations in search of food.

Methodology and .Data

Warfare Data

The *Tabulation of Wars in Ancient China* (Editorial Committee of China's Military History 1985) is a multi-volume compendium recording the wars that took place in China from 800 BC to 1911 AD. It includes an appendix detailing each war, including year of inception, type of participants, location, causes, and in most cases, the number of soldiers or combatants, casualties, progress, and results. The 899 wars in eastern China listed as occurring between 1000 and 1911 were used as the database for this study. To avoid bias associated with different sources of information, we used only those that included comparable data on inception year, type of participants, and location. Geographically, wars were categorized as either "north" or "south." We also categorized wars on the basis of types of participants, particularly the leaders, as either "rebellion" or "others" (state and tribal wars).

Temperature Data

Briffa and Osborn (2002) have analyzed the five most influential Northern Hemispheric climate series of the last millennium, including data on China, in order to resolve the differences among the results of various independent studies (Fig. 1a). Despite the diverse data sources, all five high-resolution climate series register a close matching of warm and cold phases, suggesting a high degree of accuracy with reference to both temperature and timing, and thus provide us with a reliable basis to investigate the relationships between climate changes and warfare. We adopted the records from 1000 to 1980 as the standard climate variations for this study. These records were reconstructed using multi-proxy data, including tree-ring, coral, ice-core, borehole, and historical document data. The data were recalibrated by Briffa and Osborn (2002) with linear regression against the 1881–1960 mean annual temperature observations averaged over the area north of 20°N, and the results were smoothed with a 50-year low-pass filter. We then averaged these recalibrated records to quantitatively define the boundaries of the cold and warm phases. A cold or warm phase would be determined if the average temperature change (bold black line Fig. 1a) has an amplitude exceeding 0.14°C, in order to get an equal aggregate duration of cold and warm periods. We identified six major cycles of "warm" and "cold" phases from 1000 to 1911 on the basis of the average reconstruction.

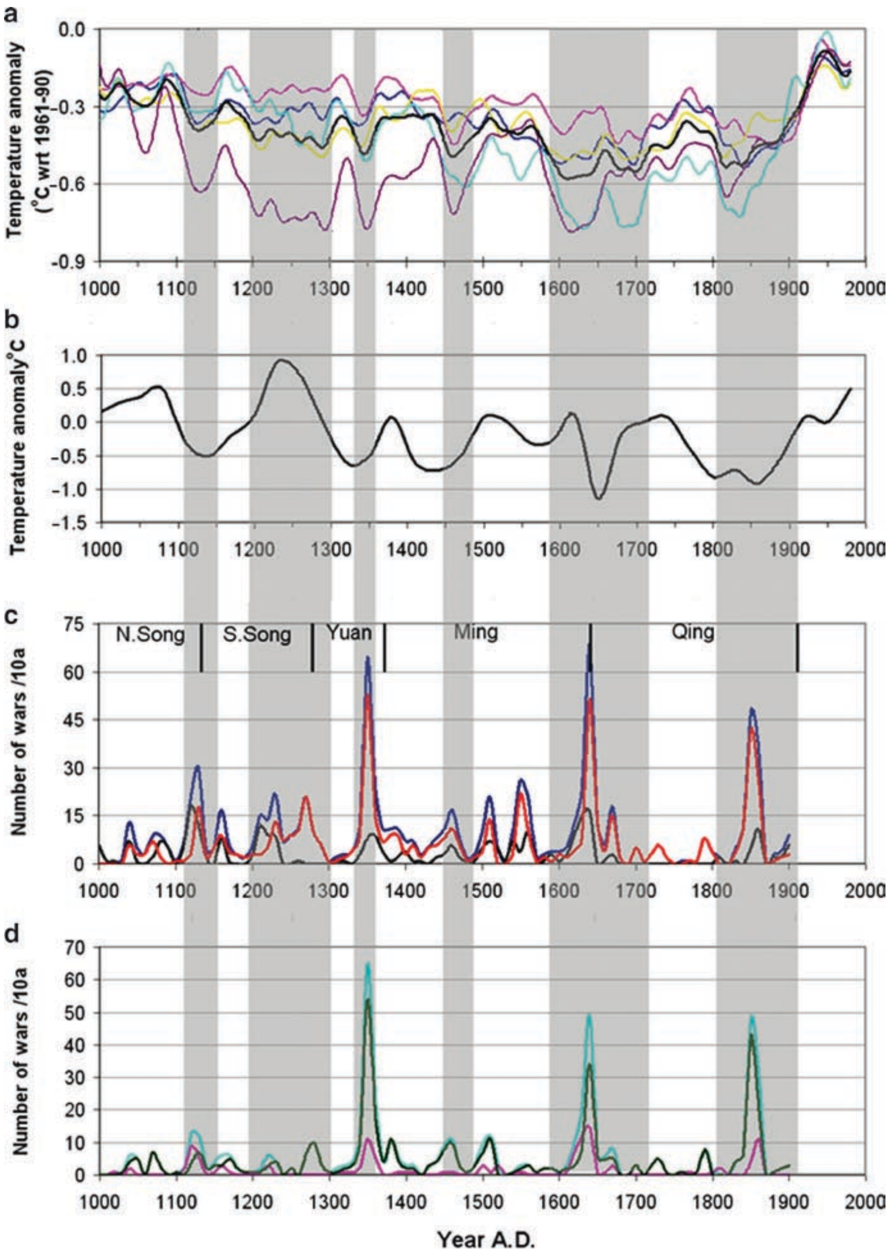

Fig. 1 Climate changes and war frequencies in eastern China during the last millennium: (**a**) Normalized temperature change records of the last millennium over the land areas north of 20°N of the Northern Hemisphere: Mann and Bradley (1999, *pink line*), Briffa (2000, *yellow line*). Jones et al. (1998, *blue line*), Cowley and Lowery (2000, *light blue line*), Esper et al. (2002, *purple line*) and the averages of variation of the above five normalized series (*bold black line*); Cold phases (*gray shade*); (**b**) Normalized temperature changes of winter-half-year in eastern China since AD 1000 (Ge et al. 2002); (**c**) Total war (*dark blue line*), north war (*black line*), and south war frequencies (*red line*); (**d**) Total rebellion (*light blue line*), north rebellion wars (*pink line*), and south rebellion (*dark green line*)

The boundaries between warm and cold phases were delineated at the mean temperature point between the minimum and maximum values of two contiguous phases on the average reconstruction. The aggregate duration of the cold phases was 459 years and that of the warm phases was 453 years. The cold phases spanned 1110–1152, 1194–1302, 1334–1359, 1448–1487, 1583–1717, and 1806–1911, while the warm phases spanned 1000–1109, 1153–1193, 1303–1333, 1360–1447, 1488–1582, and 1718–1805 (Fig. 1a). The winter-half-year temperature reconstruction of eastern China (30-year resolution) was also included (Fig. 1b). This reconstruction is on the basis of historical documentation, and then recalibrated with mathematic equations and models. While it also approximately agrees with Fig. 1a, it is used for visual comparison only because its time-resolution did not reach the annual scale that we achieved in this research.

Population Data

Whereas warfare and temperature change are comparatively well documented, it is very difficult to obtain records of population changes and agricultural production for the study's entire time frame because early dynasties had no registry systems for the collection of such data. Fortunately, records were compiled under the *Baojia* system introduced in China in 1741 which gathered annual population, harvest, and land data for taxation and administrative purposes. It continued until 1851 when the Taiping Rebellion (1851–1864) disrupted the entire system. Population counts in the *Baojia* period are generally valid in terms of the magnitude of China's population changes over a long period. As there were no major changes in territory and frequency of warfare during the *Baojia* period, which covers both warm and cold climatic phases, we deem the associated data appropriate for identifying the effect of climate change, if any, on population growth and spatial distribution. We also included the first modern Chinese census conducted in 1953 for comparison.

Results and Analyses

Temperature and War Cycles

Warfare frequency in eastern China demonstrated a cyclic pattern (Fig. 1c). War frequencies are summed by decades and grouped into three classes: very high (>30 wars/10 years), high (15–30 wars/10 years), and low (<15 wars/10 years). All four very high peaks and eight out of the 11 peaks above the very high and high groups coincided with cold phases. Three high peaks stand well above others, two of which occur in the coldest phases. All cold phases have high warfare frequency. Outbreaks of warfare generally occur 10–30 years after the onset of a cold phase.

The geographic distribution of these wars (Fig. 1c) reveals a discernable pattern. Most warfare occurred in the south. Nevertheless, the high warfare frequencies were generally of wars in the north, except in the fourteenth and nineteenth centuries when China was ruled by northern nomadic tribes (Mongol and Manchu, respectively) and outbreaks of war occurred in the south. Warfare peaks in the north closely matched cold phases – five out of the six peaks (>10 wars/10 years) occurred in cold phases. The frequencies of warfare in the north are relatively constant. Similarly, six of the seven warfare peaks in the south occurred during cold phases. The maximum war frequencies in the south came 20–50 years after the start of cooling, except in the fourteenth century during Mongol rule. The aberrant peaks in the sixteenth century (Fig. 1c) were caused mainly by northern nomadic invasions led by the Mongol leader Altan Khan and wars with "wokou" (Japanese pirates) along China's eastern seaboard. In general, rebellion was the dominant category of war. The variation in the frequency of rebellion was highly correlated with climate change (Fig. 1d) – all three highest peaks were during cold phases.

Eastern China's winter-half-year temperature reconstruction (Fig. 1b) shows that all four very high peaks and nine out of the 11 peaks above the very high and high groups occurred in the coldest periods of a cold phase (<–0.3°C). The notable difference between the two temperature reconstructions (Fig. 1a and b) was the period during the thirteenth century when eastern China had warmer temperatures while the Northern Hemisphere experienced the opposite. However, the war peaks during this time were caused by tribal invasions originating from western China (Mongols and Jin) where the climate was somewhat colder and drier.

Correlations Between Temperature War and Frequency

To refine our analysis, we calculated the number of wars in each climate phase and compared the war ratios in warm and cold phases (Table 1). Results show that the war ratios in the cold phases were higher than in the warm phases, especially for "south wars" and "rebellions."

Pearson's correlation coefficients between warfare frequency and temperature anomalies were calculated at three different time scales: phase, decade, and annual. The phase scale calculation determined whether outbreaks of war were related to

Table 1 Number of wars and ratio of wars in cold and warm phases of various war categories in eastern China

	Total wars[a]	Rebellions	Others	North	South
Cold phases (453 years)	603	378	225	178	416
Warm phases (459 years)	296	156	140	107	186
Ratio of wars (cold/warm phases)	2.04	2.42	1.61	1.66	2.24

[a]Total war is not equal to the sum of the north and south wars because the location of some wars cannot be identified

Table 2 Pearson's correlation coefficients between war numbers, average temperature anomalies, and minimum temperature anomalies at the phase scale

Temperature anomalies	Total wars	Rebellions	North	South
Average	–0.568	–0.680[a]	–0.229	–0.665[a]
Minimum	–0.613[a]	–0.729[b]	–0.254	–0.715[b]

[a]Correlation is significant at the 0.05 level (two tailed)
[b]Correlation is significant at the 0.01 level (two tailed)

Table 3 Pearson's correlation coefficients between rebellion frequencies, average temperature anomalies, and minimum temperature anomalies at the phase scale

Temperature anomalies	Total rebellions	North rebellions	South rebellions
Average	–0.680[a]	–0.594[a]	–0.642[a]
Minimum	–0.729[b]	–0.600[a]	–0.703[a]

[a]Correlation is significant at the 0.05 level (two tailed)
[b]Correlation is significant at the 0.01 level (two tailed)

the lowest or average temperature anomalies. In each phase, the highest war frequency, lowest temperature anomalies, and average temperature anomalies were included in the calculation. Results show that the highest frequencies of "total number of wars," "south wars," and "rebellions" were significantly correlated with the lowest temperature anomalies of the phases (Table 2). Only the highest frequencies of "south wars" and "rebellions" were significantly correlated with the average temperature anomalies. The rebellions were predominantly peasant uprisings induced by famine and tax revolt as farmers were the first to suffer from declining agricultural production. The three highest war peaks were dominated by peasant uprisings. Wherever they occurred, rebellions were always significantly correlated with temperature change (Table 3).

At the decade scale, we computed the correlations between the number of wars in each decade, average temperatures, and lowest temperatures with 0–30 year time lags (Table 4). "South wars" and "rebellions" are significantly correlated with the average temperature anomalies and the lowest temperature anomalies at the 0-, 10-, and 20-year time lags. The number of total wars was significantly correlated with only the two anomalies at the 10- and 20-year time lags. The same pattern appears in the annual scale correlation analysis (Table 5). Annual war counts are significantly correlated with temperature anomalies in the categories of "total number of wars," "south wars" and "rebellions" for 0–30 year time lags. In addition, the highest correlation coefficients for different time lags varied with war categories. For "total number of wars" and "south wars" the most correlated time lag was 10 years, compared to "rebellions" at 15 years.

Nevertheless, analysis based on decadal and annual scales did not reveal a precise correlation between the local short-term temperature changes and war frequencies. The temperature records had been averaged and smoothed so that any local temperature extremes were removed prior to statistical analysis. However, correlation analysis

Table 4 Pearson's correlation coefficients between war numbers and temperature anomalies at the decade scale

Temperature anomalies	Total wars	Rebellions	Others	North	South
	No time lag				
Average	–0.182	–0.204	–0.008	–0.036	–0.214[a]
Minimum	–0.181	–0.214[a]	0.014	–0.017	–0.221[a]
	10-year time lag				
Average	–0.250[a]	–0.271[a]	–0.035	–0.077	–0.282[b]
Minimum	–0.240[a]	–0.268[a]	0.019	–0.086	–0.266[a]
	20-year time lag				
Average	–0.220[a]	–0.251[a]	–0.007	–0.040	–0.261[a]
Minimum	–0.230[a]	–0.263[a]	–0.007	–0.051	–0.267[a]
	30-year time lag				
Average	–0.140	–0.189	0.057	0.064	–0.204
Minimum	–0.136	–0.192	0.074	0.065	–0.200

[a]Correlation is significant at the 0.05 level (two tailed)
[b]Correlation is significant at the 0.01 level (two tailed)

Table 5 Pearson's correlation coefficients between average temperature anomalies and different war categories at the annual scale

Time lag (year)	Total wars	Rebellions	Others	North	South
0	–0.126[a]	–0.148[a]	–0.025	–0.021	–0.142[a]
5	–0.167[a]	–0.187[a]	–0.045	–0.047	–0.178[a]
10	–0.179[a]	–0.206[a]	–0.041	–0.049	–0.192[a]
15	–0.174[a]	–0.208[a]	–0.030	–0.041	–0.190[a]
20	–0.153[a]	–0.192[a]	–0.017	–0.023	–0.174[a]
25	–0.121[a]	–0.166[a]	0.002	–0.008	–0.152[a]
30	–0.090[a]	–0.141[a]	0.024	0.041	–0.132[a]

[a]Correlation is significant at the 0.01 level (two tailed)

Table 6 Pearson's correlation coefficients between eastern China temperature anomalies and different categories of wars at the 30-year scale

	Total wars	Rebellions	Others	North	South
Pearson's correlation coefficients	–0.274	–0.424[a]	0.161	0.070	–0.355[a]

[a]Correlation is significant at the 0.05 level (two tailed)

was still appropriate for war frequency and ambient temperature anomaly. The time lag between outbreaks of war and temperature change (Fig. 1c) revealed from the analysis is most likely accounted for by the buffering capacity of stored food resources which could sustain individuals for some time as well as maintain state control.

When we compute the correlations between the temperature anomalies of eastern China and frequency of war at the 30-year scale, we reach the same conclusion: "south wars" and "rebellions" were both significantly correlated with temperature changes (Table 6).

Table 7 Pearson's correlation coefficients between annual temperature anomalies and annual war records of the north part of eastern China with the period of "conquest/nomadic dynasties" excluded

Time lag (year)	0	5	10	15	20	25	30
Pearson's correlation coefficients	–0.130[b]	–0.161[b]	–0.168[b]	–0.171[b]	–0.170[b]	–0.151[b]	–0.126[a]

[a]Correlation is significant at the 0.05 level (two tailed)
[b]Correlation is significant at the 0.01 level (two tailed)

Northern China is colder and drier and its ecology is more vulnerable to temperature change than the warmer and wetter south. However, in our correlation analysis, the frequencies of warfare in the north were not significantly correlated with temperature anomalies and the cold–warm ratio of outbreaks of war in the north was lower than that in the south. During the periods when China was dominated by northern nomadic tribes (South Song, Yuan, and Qing dynasties – more than half of the study period), people in the north could freely move to the south, either temporarily or permanently, to pursue their livelihoods. Thus, the frequency of warfare in northern China was lower in the cold phases in the thirteenth, fourteenth, seventeenth, and nineteenth centuries. At the annual scale analysis, if we exclude the periods of "conquest/ nomadic dynasties," the correlation of temperature and frequency of war in the north was higher than that in other regions (Table 7). Another interpretation is that during the periods when China was politically divided between the south and the north, the disruption of food supplies in times of cooling led to cross-border wars. During the periods when China was unified under the northern Jurchen, Mongol, and Manchu nomadic tribes, southward migrations driven by cooling led to conflicts between migrants and indigenous groups in the south, which accounts for the closer correlation of temperature and frequency of warfare in the south.

Population Dynamics in Face of Climate Changes

We used official population census data from 1741 to 1850 to compare the population growth rates between warm and cold phases and found no occurrences of large-scale warfare that might affect population growth. For China as a whole, the average annual growth rate for 1741–1805 (warm phase) was 1.27%, while for 1806–1850 (cold phase) the rate was just 0.60%. Such a discrepancy might reflect the effect of cooling in reducing agricultural yields, which subsequently lowered natural population growth. The problem may have been aggravated by population growth during the previous warm period.

The patterns of population growth in the north of eastern China (Henan, Hebei, Shanxi, Sha'anxi, Gansu, and Shandong provinces) and in the south (Jiangsu, Zhejiang, Anhui, Jiangxi, Anhui, Guizhou, Shichuan, Hubei, and Hunan provinces) are shown in Table 8 and are based on the exceptionally accurate censuses of 1787, 1850, and

Table 8 Population distribution in eastern China based on the official population census

Year	1787		1850		1953	
Area	South	North	South	North	South	North
Population ('000)	1,33,964	1,93,355	2,40,258	1,23,130	2,55,797	1,74,893
% of total population	56.4	43.6	66.1	33.9	59.4	40.6
Average annual growth rate (%)			1.3[a]	–0.6[a]	0.0006[a]	0.4[a]

[a] AD 1787–1850

1953 (Liang 1980). From 1787 (warm) to 1850 (cold), population increased rapidly in the south but the growth rate was negative in the north. Conversely, from 1850 (cold) to 1953 (warm) population increased very slowly in the south but very rapidly in the north. At the same time, the north–south ratio of population size varied in different climate phases. Although the ratio difference was only about 10%, the population in question numbered over 30 million.

From 1787 to 1850, the population in the south grew at an annual rate of 1.3%. This figure is higher than that of any other country in the world. The negative growth rate in the north during the same period is puzzling. Except for large-scale warfare or shrinkage of the area controlled by the state, depopulation only occurred at times of frequent pandemics and nature calamities. However, there were no large-scale wars during this period. Further, while several epidemics and natural disasters occurred in Gansu, Hebei, and Shandong (1810, 1811, and 1846) (Deng 1998), population did not decrease in those provinces but elsewhere in the north. The most likely explanation is internal migration. We suggest that during the cold phase, people in the north migrated to the south to take advantage of the relatively favorable climate, and during the warm period, many people from the south migrated north to avail themselves of the increase in arable land in formerly marginal areas. Two waves of large-scale southward migration over the past millennium are recorded in both historical documents and in recent studies, the first from 1000 to 1300 and the second from 1630 to 1900 (Fang and Liu 1992). In fact, all of the three long cold phases (1194–1302, 1583–1717, and 1806–1911) overlap with these two migrations. In the early 1900s, as the Northern Hemisphere became warmer again, people from Shandong and Henan, which were by then over-populated, flooded to northeastern China (i.e., Manchuria).

Between 1787 and 1953, China's total population increased 77%, while the two northwestern provinces of Sha'anxi and Gansu, located in the transitional zone between wheat-farming and pastoral regions that had undergone severe desertification, experienced population declines of –5.4% and –16.2%, respectively. This may reflect the ecological fragility of dry and cold areas in periods of cooling that not only reduce local bioproductivity but also trigger long-term desertification and land degradation. Thus, unlike other provinces, the populations in these two provinces did not regain their previous levels.

The Fall of Ming Dynasty

The two periods of climatic cooling during the Ming dynasty were the coldest since 1000. The first (1448–1487) overlaps a major crisis in the Ming period. In 1448, there were massive famines in the central Yangtze region and on the eastern reaches of the Yellow River coinciding with severe droughts in the southeast and northwest. Conditions in China overall did not improve much over the next several decades. There were major famines in Jiangxi and Huaidong in 1452; the Southern Metropolitan Region in 1455; Shandong and the Northern Metropolitan Region in 1457; Huguang in 1458–1459; Huguang and Guangxi in 1460; Shaanxi in 1462; Henan in 1463; Hebei, Henan, and the lower Yangtze in 1465; Shanxi and the Southern Metropolitan Region in 1466; Huguang and Jiangxi in 1467; northern and central China in 1468; and Shanxi in 1469. Compounding these problems were a series of destructive locust attacks in the mid-1450s, and two unusually cold winters in 1449–1450 and 1453–1454, during which large numbers of people and animals in southeastern China died of cold and starvation; Lake Tai in the heart of the Yangtze delta froze for the first time in perhaps a century. Adverse climatic conditions and food shortages during these years also caused serious difficulties in Mongol-controlled territory north of the Great Wall, possibly contributing to the intensification of Mongol pressure on the Ming Empire that culminated in their invasion of northern China in 1448–1449 (Atwell 2001, 2002).

Antigovernment uprisings that began during the mid-1440s in the border areas of Zhejiang, Fujian, and Jiangxi provinces were not brought under control until the early 1450s. That same period also saw the Ming armies mount a series of costly campaigns in southwestern China and northern Burma. In July 1449, after tensions on the northern and northwestern frontiers had been escalating for some time, in part because of deteriorating climatic conditions, Esen, the leader of the Oirat Mongols, undertook a large-scale invasion of China which led to the capture of the Ming Emperor and the advance of his forces to the walls of Beijing. Although the Ming authorities managed to establish relatively peaceful relations with the Oirat over the next few years, their problems were not over. Between 1459 and 1456, the Ming authorities were forced were forced to put down another series of uprisings in Guizhou, Huguang, Guangdong, Fujian, Zhejiang, and Sichuan. Moreover, climate cooling during the late 1450s and early 1460s appears to have caused serious problems for the Chinese and Mongols living along the Great Wall, with increasing tensions between the two groups contributing to Mongol participation in the abortive coup of 1461 in which disaffected members of the Ming aristocracy attempted to overthrow the emperor (Atwell 2001, 2002). However, this cooling period was comparatively short and had been preceded by a long warm phase that may have allowed sufficient food storage to preserve the dynasty in power. By the mid-sixteenth century, warfare focused mainly on rebuffing northern Mongol invasions led by Altan Khan and wars with "wokou" (Japanese pirates) along the eastern seaboard.

While neither Altan Khan nor the "wokou" mounted challenges serious enough to force a major reorganization of the Ming Empire, the fate of the dynasty seems to have been sealed during the second cooling period of 1583–1717. There was drought in the Beijing region in the autumn and winter of 1584, famine in Huguang during the late summer of 1585, severe flooding in Jiangnan, Zhejiang, Huguang, Fujian, Yunnan, and Liaodong in the summer of 1586, and heavy rains and serious flooding in both northern and southern China during the summer of 1587. At various points during 1587, drought and famine were reported in areas north of the Yellow River. By early months of 1588, areas experiencing severe food shortages included parts of Shaanxi, Shanxi, Shandong, Henan, Zhejiang, and Jiangnan. In 1589, an extended period of severe drought began in southeastern China, with parts of Zhejiang, Huguang, Jiangxi, and Jiangnan being particularly hard hit. After a brief respite in 1590, the next few years saw heavy rains and floods damage agricultural production in many regions of the country. By 1594, people in some parts of China were reduced to eating the bark of trees, the seeds of grasses, or even seeds from the excrement of wild geese (Atwell 2001, 2002). Although the epicenter of the 1594 famine is usually considered to have been north-central China, there also were very poor harvests in the southeastern provinces of Fujian and Guangdong. During the autumn of 1596, there were persistent rains and severe floods in northern Zhejiang, one of China's key agricultural regions. In 1601, there was extended drought in northern China, followed by summer floods in both the north and the southeast of the country. In 1609, an extended drought affected Huguang, Sichuan, Henan, Shaanxi, and Shanxi, while Fujian, Zhejiang, and Jiangxi suffered from heavy rains and flooding. By the late spring of 1610, famine conditions were reported in parts of Bei Zhili, Shandong, Shanxi, Henan, Shaanxi, Fujian, and Sichuan (Atwell 2001, 2002).

As conditions deteriorated during the late sixteenth and early seventeenth centuries, the Ming authorities faced a number of significant military challenges. Among the more notable were a major rebellion in Shandong in 1587, repeated attacks in the northwest by the so-called Ordos Mongols, raids by the Eastern Mongols in Manchuria, hostilities between Chinese and Burmese forces on the southwestern frontier, Vietnamese incursions along the southern border, and a lengthy rebellion in central and western China.

The Manchus originated from Mount Changbai in northwestern China and were descended from the Jurchen of the Jin dynasty that ruled between 1127 and 1234. In the early seventeenth century, the Manchu leader Nurhaci began to organize his people into a powerful political and military force. In April 1619, his forces routed a 1,00,000 strong Ming army in Manchuria. To what extent Nurhaci was spurred by climatic and economic problems in the Manchu homeland is unknown, but the rise of the Manchus, like the rise of the Jurchens in the late eleventh and early twelfth centuries and that of the Mongols in the late twelfth and early thirteenth centuries, occurred in a cold climatic phase (Atwell 2001, 2002).

Drought and famine continued to plague northern China the years following this defeat forcing the Ming armies to fight a protracted two-front war against both rebellious peasants and the Manchu cavalrymen. Unusually severe weather struck in 1620–1640, when the earth's climate fell to the lowest temperatures since 1000 AD. Extreme droughts were followed by major floods. Frequent famines, accompanied by plagues of locusts and outbreaks of smallpox, resulted in mass starvation and death. The five worst years of consecutive drought in China as a whole occurred from 1637 to 1641. Peasant rebellions spread to the north and south of eastern China and drastically reduced populations in northern China. The population of the Red Basin of Sichuan was nearly exterminated entirely (Ho 1959).

Dire conditions continued into 1641. Not only did unusually heavy snowfalls and food shortages cause serious problems in southeastern China during the early months of the year, but it also remained very dry with infestations of locusts reported in many areas in much of north. As grain prices rose to extraordinary levels, local people organized bandit gangs and reportedly resorted to cannibalism (Jiang 1993). Nor were problems limited to the lower Yangtze region. There was severe flooding in Henan during the summer of 1642 as well as famine in portions of Henan, Shandong, Huguang, Zhejiang, and the Northern Metropolitan Region. By this time, nationwide rebellions had destroyed the military might of the Ming. Ominously, 1642 also saw the final collapse of Ming military power north of the Great Wall and an extended campaign by Manchu forces in eastern China. As was the case for the late sixteenth century, there is considerable evidence to suggest that the Manchu attacks on China during the 1630s were spurred, at least in part, by serious economic problems in the Manchu homeland (Hsu 1998; Atwell 2001, 2002). In early 1644, the peasant leader, Li Zicheng, declared his new dynasty in Xi'an and led his forces across the Yellow River and the entire length of Shanxi Province, and having seized the fortress on the Great Wall and overpowered the capital garrison, he occupied the capital. Finally, the Ming General Wu Sangui opened the gates of the Great Wall to the Manchus, who defeated both the rebels and the remaining forces of the Ming dynasty.

Historians cannot readily explain how the Manchus, with a population of about one million, could seize power in China with such ease. They had devised a writing system only in 1599, and the "banner system," which bureaucratized their tribal organization by regulating mobilization procedures and their agricultural support, was introduced no earlier than 1601. And yet it took less than a half-century for this loose confederation of tribes to swallow an enormous empire with a complex cultural heritage. We argue that the force driving the Manchu invasion was the extreme climatic conditions in northeastern China during the coldest period of the Little Ice Age and the consequent array of serious economic and social problems. This at least would explain why nearly all of the Manchus left their homeland and migrated southward (Ge 1997).

Discussion and Conclusion

Over the past millennium, eastern China suffered from periodic ecological stress and a significantly reduced anthropocentric carrying capacity during climatic cooling. Population expansions during warm phases could not easily be sustained. Famine and nationwide peasant uprisings occurred with greater frequency during cold phases. Such domestic chaos weakened state power, which in turn invited northern nomadic invasions. Competition for shrinking resources among different states, ethnic groups, and tribes were further intensified during the cooling periods, accounting for higher frequencies of warfare. The fact that warfare occurred more frequently in the south than in the north can be attributed to its unique local cultural and geographic settings, which also account for the differing time lags between the onset of cooling and outbreaks of warfare[2] in the north and south, as well as the temperature–war correlation in the north (with the periods of "conquest/nomadic dynasties" removed). We found that dynastic collapses also followed the oscillating temperature cycle over the past millennium. Almost all of the dynastic changes occurred in cold phases, with the exception of the Yuan dynasty, which collapsed eight years after the end of a cold phase (1368), although it had lost most of its territory in the "Late Yuan" peasant uprisings during the cold phase. The delayed collapse was largely a result of power struggles among different rebel groups.

Thomas Malthus (1798) pointed out that population can increase geometrically, while means of subsistence can increase, at best, arithmetically. Thus, if population growth is not controlled, human societies will reach the limits of carrying capacity, triggering wars, famines, and epidemics, and ultimately population collapse. Following Malthus, studies of China's historic war–peace cycles usually conclude that excessive population growth is the ultimate cause of state instability (Usher 1989; Chu and Lee 1994; Turchin 2005). However, our study suggests that from a macro-historic perspective (not relying on particular cases, but on all known occurrences of warfare to reach any conclusions), the oscillations of agricultural production brought on by climate change drove China's historical war-peace cycles. Reduced critical resources during cold phases could not support the population levels achieved during warm phases. Our methodological framework reveals a near perfect match between high war frequencies and cold periods, doubled war ratios in cold phases, and significant correlations between frequency of warfare and temperature variation at phase, decadal, and annual scales in the last millennium.

Recent global warming has attracted much attention. It must be pointed out that, unlike the "warm phases" we discuss here, current global warming is unprecedented in the last two millennia (Mann et al. 2003; Moberg et al. 2005). Global temperature is expected to rise ever faster in the foreseeable future. Its impacts will be fairly unpredictable because both natural and anthropogenic forces are involved. In spite of technological changes, most of the world's populations will continue to rely on small-scale agriculture, which remains as vulnerable to climatic fluctuations as in the past. Furthermore, in an increasingly populated world, habitat-tracking as an adaptive response will no longer be an option (Weiss and Bradley 2001). With the world's population at its current level, even if food supply does not become a problem in highly developed societies, shortages of other essential resources, such as fresh water, agricultural land, energy sources, and minerals, may very likely trigger increasing incidents of armed conflicts.

[2] Although cold phases reduced agricultural yields, outbreaks of warfare generally lagged behind the onset of cooling because of social buffers (i.e., grain storage).

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Section IV
Common Property Management, Conservation, and Development

Section Overview

The five chapters in this section all relate to issues raised earlier, particularly in Section I, where general features of theory and method were discussed. They all address common pool resources – the foundation of equitable sustainability and key to how we might live within our means. In the final analysis problems such as renewable energy, access to adequate fresh water and food, not to mention reduction of greenhouse gas emissions, all depend on local decisions and implementation. Claude Peloquin and Fikret Berkes explore a complex and highly informative "folk model" of dynamic environmental relations – one which institutionalizes practices that track resource availability. Amber Wutich treats a common property resource problem vital to the well-being of over half of the world's population, namely urban water supply. James Eder looks at a large USAID project to see what exactly "community participation" means in practice. James M. Acheson and Jon McCloskey show that while deforestation is a world-wide problem it has to be understood in terms of local circumstances. The case of deforestation in central Maine highlights the complexity of forest ownership and the wide variety of motives of those involved in cutting or burning forests. David Pimentel and colleagues take a jaundiced view of current efforts, promoted by many, to alleviate the world's need for more energy through the use of supposedly renewable biofuels.

At no time in human history has an understanding of the environmental impacts of human activities been as vital as it is today. A person from any point in time prior to the eighteenth century would find the earth unrecognizable today as a result of human impacts. So much so that the Noble Prize-winning scientist Paul Crutzen of the Max Planck Institute has proposed that we need to designate a new geological era reflecting the last 300 years of human activities: he suggests calling it the "Anthropocene" (New Scientist Feb 28, 2009, p 29). Should current projections of a global temperature rise of 2–6.40°C this century come to pass there will be a further massive change in human settlement patterns and a high probability of significant conflict over resources. This is not to embrace a doomsday scenario, although it is possible that there will be a culling of human population from the 9 to possibly 12 billion projected for 2100 (ibid). But at whatever level of population, human adaptability will be put to the test. Global problems will be solved or not at the local level and will undoubtedly entail the management of common resources, be they forests, savannahs, fisheries, or water tables. How people perceive their environments and how they structure their productive or extractive activities will be of crucial importance. Conservation efforts, sometimes regarded as optional individual virtues, will become a collective necessity if current scientific thinking is even remotely on target.

But how we collectively plan for this is highly problematic. Environmental scientists offer numerous often scary scenarios to which decision makers and economists have begun to respond with countermeasures, such as subsidies for biofuels, carbon trades or off-sets, regulations to curtail marine and fresh water pollution, standards for smoke stack emissions – the list is long. It is hard to argue that these measures are merely wrong or misguided palliatives, but there may be a fundamental flaw in our paradigm for assessing risks, costs, and long-term benefits. Robert Nadeau, a distinguished philosopher of environmental science and public policy has argued that the economic theory most used in planning and corporate decision-making has no way to assess the environmental cost of economic activities and internalizing these costs in pricing systems. To paraphrase his argument, he faults the current paradigm as being based on the following wrong-headed assumptions (2008):

1. That the market is a closed system uniting producers and consumers.
2. Natural resources exist outside of this closed system, but their economic value is determined by the market system.
3. Current costs or damages to natural resources cannot be included in the pricing mechanism.
4. Natural resources are either inexhaustible or can be replaced by others or by technological innovation.
5. There are no biophysical limits to the growth of the market system.

In some respects Nadeau's critique of neoclassical economic theory mirrors the shortcomings with ecosystem approaches that assume closed systems we discussed earlier. Certainly, the failure to bring environmental costs into commodity pricing is a problem which aggravates the current environmental crises and such looming disasters as a projected 59% increase in the rate of annual ice loss in west Antarctica, which will accelerate a decline in fisheries and regional fresh water shortages globally. We see everyday instances of this failure to internalize collectively borne costs in pricing to users (and often to producers). Cheap access to water for farmers and city dwellers alike is taken as a right, turning agricultural land into shopping malls is heralded as economic development, and in a number of countries, including the United States, the costs of ore mined by leveling mountain tops are essentially limited to those of extraction and transportation.

One huge anthropogenic calamity is the Sea of Aral, once the world's fourth largest lake, which was turned into a barren wasteland by 1985. This case is often thought of as emblematic of the chaotic and reckless central planning peculiar to the USSR, although analogous situations, driven by market pressures, perhaps not quite as dire, can be found throughout the world. Philip Micklin, an American geographer, and Nickolay Aladin, a Russian brackish water hydrologist, have documented the unfolding of this disaster and the steps now underway to reverse it. By the late 1960s the effects of several decades of projects diverting the Amu and Syr rivers to vastly expand irrigated crop land in this arid zone had begun to have visible effects. In 1960, there were over 100,000 ha of wetlands around the Sea of Aral, which by 1990 were reduced to 15,000 ha. Fish were reduced from 32 species to 6, and birds from 319 species to 160. The lake itself, which once offered a harvest of 40,000 metric tons of fish annually by 2000 had no commercial fishing left at all as over 54,000 km^2 of seabed were exposed by the receding waters. Not only was shipping abandoned, but the seabed itself became the source of toxic dust storms affecting surrounding populations in four countries who came to experience high rates of often lethal skin and respiratory diseases. Since 2005 there has been a partial rebound at the north end of the lake due to closing of some irrigation canals and the repair of others, while at the same time a barrier restricting run off to the main basin of the Aral to the south is being built. Nevertheless, it is impractical to attempt to bring the entire system back to its 1967 level. Not only would this be hugely expensive, but also population growth now means that several million people depend on the land irrigated by the Amu and Syr rivers for food and cash crops.

Micklin (2007) and Micklin and Aladin (2008) offer some general conclusions from their observations. Among them are that humans can quite rapidly wreak environmental damage which is costly and time-consuming to repair, if repair is possible at all; that an environmental system may appear relatively stable and productive until the point at which it tips into disaster; and that sustainable solutions to man-made problems must be politically and socially feasible not simply technically possible – it is technically possible to restore the Aral, but would not be a sustainable solution if human impacts and consequent social upheaval were ignored.

About 50 years ago, most developed countries mandated that foreign aid be contingent upon studies of its impacts on equity and the poor, as well as assessments of the social and environmental impacts of proposed development projects. As a consequence, a large number of social scientists are employed world-wide in efforts to understand what works and what does not in development assistance while assuring appropriate conservation and sustainability. Development projects may have a profound effect on local ecological systems. Large dams, for example, almost always have a legacy of large-scale environmental damage such as destruction of habitat, downstream pollution, increased salinity of the soil as a result of a rise in the water table, increased risk of flooding and erosion, and even, many people argue, an increase in the risk of earthquakes. But innovations need not be so massive as a huge irrigation project or a giant dam to have significant effects on ecological systems. A new strain of rice introduced in Nepal increased yields as much as 200%, but because the rice grew on short, tough stalks that produced little fodder for cattle and required threshing machinery that was not available locally, the potential benefit was offset by serious costs.

The researcher concerned with development must always consider the strengths as well as the weaknesses of the local system of knowledge or practices. In Bali, Indonesia, according to Stephen J. Lansing (1991), an elaborate network of temples dedicated to water goddesses is controlled by priests who regulate and coordinate the irrigation of fields belonging to thousands of farmers. In an effort to modernize farming, the government encouraged farmers to irrigate their fields according to whatever schedule they judged would increase their rice production. As a consequence, fields were irrigated according to individual farmer's timetables, and unexpectedly, this provoked an ecological crisis that resulted in a massive decline in overall yields. When farmers planted and irrigated on their own schedules, pests that were formerly controlled by the coordinated flooding dictated by the temples simply moved from field to field. Coordinated irrigation turned out to be a vital means of crop cycling and pest control. In this case, we see a traditional religious institution playing a critical, even if unplanned, role in resource management. Lansing, an anthropologist, was instrumental in making government planners aware of the value of this supposedly noneconomic and anachronistic cultural system.

Much of the present crisis in food production is attributable to the fact that the growth rates of the populations of many countries in the tropics have outstripped their ability to feed themselves. But most of the agricultural techniques that are being imported by such countries are based on farming methods first developed in temperate climates. In the Amazon region of South America, large development projects involving the clearing of forests, introduction of new food crops, and mechanization have had very poor economic results. Tropical soils are generally thin and subject to rapid erosion and breakdown of nutrients once the protective cover of the rain forest is removed. As a consequence, intensification of agriculture or other uses of once-forested land often result in less rather than more food. Most cleared land in the Brazilian Amazon is used for cattle ranching but 85% of recently cleared land is now altogether unproductive because of soil degradation. Many people who have worked in tropical agricultural systems think the way out of this dilemma is to pay more attention to developing more productive farming based on plants and techniques that are already locally established.

George Appell, who has worked on development projects in Indonesia, offers a set of principles that, in somewhat abridged form, aptly summarize the sorts of negative impacts that planned change occasions and that have to be weighed against possible benefits (Appell 1988, quoted in Bates 2005, p 223ff):

Every act of development necessarily involves an act of destruction.

Any new activity introduced is likely to displace an indigenous activity.

Each act of change has the potential to cause physiological, nutritional, psychological, and/or behavioral impairment among some segment of the subject population.

Modernization can erode indigenous mechanisms for coping with social stress, such as regulating conflict and solving family problems.

One more caution might be added to this list: the costs and benefits of any innovations or planned changes are not going to be distributed equally throughout the population; some people will benefit more than others, and some may lose altogether. What must be kept in mind is whether the distribution of costs and benefits is fair or desirable.

The ultimate cost–benefit outcome of any development project or effort to effect some form of desired social change can be influenced by many factors. Some of the most important are environmental and ecological factors, traditional values and beliefs, and social ties. All of the chapters in this section address such issues.

Claude Peloquin and Fikret Berkes note that scholars studying human–environmental systems necessarily deal with complex relationships emerging from numerous interactions and they employ the scientific models discussed or exemplified in many of the preceding studies in this volume. The people who are the object of studies are also part and parcel of larger complex adaptive systems and they too operate within recognized models which are similarly complex, nonlinear, and dynamic even though such indigenous models may differ greatly from one another. In some cases, institutional arrangements may encode or encourage practices which track the availability of resources in a manner which promotes sustainability. Such institutional mechanisms may be religious beliefs and rituals, as well as more explicitly conservation-directed measures such as hunting seasons, harvest limits, etc. Peloquin and Berkes look at one extractive activity of local importance, the hunting of wild geese in eastern Canada, and show how the James Bay Cree hunters evaluate and respond to shifts in the abundance and availability of this resource. Where the scientific observer might quantify a number of key variables and infer change and causality from the data reflecting, say, temperature, kill rates, body weight of prey, subcutaneous fat, and the like, the Cree "eyeball" a large number of seemingly disparate variables and note unusual occurrences to arrive at a qualitative and probabilistic model that parallels the scientific model in detecting change in a complex system.

Over half of the world's population, which currently stands at close to seven billion, lives in cities or in villages now absorbed by urban sprawl. A recent United Nations report by the World Water Assessment Programme states that urgent action is needed if we are to avert a global water crisis. The water problem that has attracted the most scientific attention to date is clearly related to food production. Local shortages in water for agriculture have been occurring regularly around the world. In 2009 alone, there were major water crises in Korea, the United States, Madagascar, Australia, and China. But during the last decade, the rate of increase in urban water consumption for sanitation and drinking has vastly outstripped increases in water used for irrigation. This is due to growing rural-to-urban migration worldwide. In many instances, the urban poor lack adequate drinking water, let alone what is needed for sanitation. Amber Wutich's fine-grained study of water use and management among the poor in Cochabamba, Bolivia, is very important in a number of ways. In Cochabamba, as in most cities, water is a common pool resource where sustainability has to be balanced against needs in the face of acute scarcity. For the purposes of her study, Wutich uses and expands on the six principles

Trawick identifies in long-enduring Andean irrigation institutions: *Community autonomy*; *uniform, equitable access; proportionality,* i.e., people should consume only what they need and contribute accordingly to the common system; *contiguity*, i.e., people take turns in the order in of their allotments of water; *transparency*, i.e., everyone can monitor and sanction everyone else; and *regularity*, i.e., the system's ability to respond to abnormal scarcity.

Worldwide, forests are being cut or burned at an unsustainable rate and the species diversity and composition of extant woodlands is being altered. In almost every instance this is, as James M. Acheson and Jon McCloskey show for Central Maine, USA, a classic collective action dilemma. Some individuals foist the costs of their actions onto others: the larger population suffers the costs of air pollution (in the case from burning), soil erosion, stream siltation, loss of wildlife habitat, and the short-term impacts of accelerated CO_2 emissions, not to mention diminished recreational opportunities. Their case study of deforestation in central Maine is particularly insightful because it documents the complexity of the problem with excellent data from ownership records, direct observation, and satellite data. While the pattern of ownership or access may be specific to Maine, with its history of major paper factories as well as large nonindustrial landowners, there is much that is worth bearing in mind as one confronts this global problem. Deforestation has multiple causes, even within one region, so diverse processes inevitably have to be considered. The motivations of actors to cut or burn are varied and subject to change; any effort to curb overexploitation will have to focus on establishing incentives that fit the specific situation.

James Eder attempts to go beyond the rhetoric of development and conservation to see how practical projects contend with complex social realities. Considering conservation as a social or institutional process, much as does Flora Lu, he examines coastal resource management in Palawan, the Philippines. Looking at a USAID project, he is particularly concerned with the ever-elusive goal of "community participation" or community comanagement, deemed desirable by nearly all designers of development projects. The problem Eder addresses is what actually constitutes "community?" Any local population consists of actors with divergent interests, and many different subsets of these can be thought of as "community," including groups based on subsistence activities, gender, and social class. Moreover, all belong to territorial communities embedded within a hierarchy of national territorial and bureaucratic institutions of governance. If this is not complication enough, one must also ask what exactly is meant by "participation?" Women, the poor, and those marginalized for whatever local reasons may easily have their interests subordinated. Community pluralism has to be accounted for in establishing mechanisms fostering debate and equitable decision making, and resolving conflict.

David Pimentel, Alison Marklein, Megan A. Toth, Marissa N. Karpoff, Gillian S. Paul, Robert McCormack, Joanna Kyriazis, and Tim Krueger offer a considered, hard-hitting empirical response to a major policy issue. Most of the discussions in the political arena in industrial societies have focused on short-term cost–benefit models when it comes to responding to potential global shortages of fossil energy and accordingly many have embraced biofuels as renewable energy sources.

Biofuels by necessity compete with food as both are dependent on the same resources for production. While most policymakers are probably aware of this basic fact, what they seem to miss is what this paper demonstrates: the very high long-cycle costs of processing most of the suggested sources of renewable energy. This chapter examines the uses and interdependencies among land, water, and fossil energy deployed to food production as opposed to biofuel. It also estimates the probable environmental impacts of biofuel production where it replaces food production.

Local Knowledge and Changing Subsistence Strategies in James Bay, Canada[1]

Claude Peloquin and Fikret Berkes

Introduction

The description of ecosystems necessarily reduces their complexity to a few measurable and controllable variables. Environmental monitoring practices of some indigenous and rural societies are significant in this context. In this paper, we examine the ways in which an indigenous people understand and deal with complexity, using the example of Cree hunters of James Bay in the Canadian eastern subarctic. Our unit of analysis is the integrated social–ecological system (Berkes and Folke 1998) or the coupled human–environment system. We investigate social–ecological change in the goose hunt, which provides a resource of prime importance to the Wemindji Cree people of James Bay. First, we establish the context of the relationship between complex systems thinking and indigenous knowledge, reviewing how the two have been linked in the literature, especially the case for presenting indigenous knowledge as a holistic approach with parallels to adaptive management and fuzzy logic.

We then argue that Wemindji hunters perceive change in the goose hunt as resulting from multiple factors and trends in the broader social–ecological system and at multiple scales. Hunters' assessments rely not so much on precise measurements but on linkages between various processes. These processes are evaluated in a probabilistic manner that seems in agreement with fuzzy logic approaches.

[1] The original article *Local Knowledge, Subsistence Harvests and Social–Ecological Complexity in James Bay* appeared in *Human Ecology* Vol. 37, No. 4, August 2009.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_18, © Springer Science+Business Media, LLC 2010

Complex Systems and Indigenous Knowledge

Social–ecological systems are complex adaptive systems encompassing dynamic structures emerging from numerous interactions between social and ecological processes as they span across scales, often in nonlinear patterns (Liu et al. 2007). Such emergent structure is "characterized by lack of dominant periodicity and by great sensitivity to initial conditions" (Levin 1999, p. 238). Human groups which interact closely with their environment often develop knowledge and practices that are pragmatically adaptive to shifts and changes in the environment (Berkes et al. 2000). Indigenous knowledge is dynamic and the social processes underpinning human–environment relations, such as resource use, are often grounded in epistemological frameworks that differ markedly among societies. Some indigenous knowledge systems show a high degree of sophistication in addressing complex environmental processes, such as disturbance regimes and multilevel processes (Berkes 1998; Hunn et al. 2003; Moller et al. 2004). These systems are expressed as individual practices encoded in institutional arrangements that include resource allocation regimes, religious beliefs, and rituals that invite behaviors that adapt to shifts and changes in the environment. Many indigenous practices involve rotation of harvesting effort in space and time, documented in domains as diverse as tropical agroforestry (Dove 1985; Toledo et al. 2003) and subsistence hunting and fishing among northern indigenous peoples (Scott 1986; Feit 1987). As we illustrate in detail, the Cree goose hunt also involves rotation to spread out the effects of disturbance in space and time.

Gadgil et al. (1993) suggest that the key to dealing with complexity might be the use of "rules of thumb," simple prescriptions based on indigenous knowledge and understanding backed up by religious belief, ritual, taboos, and social conventions. Complexity can emerge from simple rules. We are suggesting here the corollary that simple rules can be appropriate for dealing with complexity. Fuzzy logic, or fuzzy-set theory, a form of multivalued logic that seeks explanation through approximate rather than numerically precise reasoning logic, has been invoked as a way to explain how rules of thumb and other simple prescriptions can be used to deal with complexity. Relations between elements are given an approximate probability, making it a useful tool for management in conditions of uncertainty (Zadeh 1973). This approach, combined with systems thinking on the dynamic relations among elements, rather than on elements themselves, has been of great use in computer programming, engineering, and more recently in environmental monitoring and assessment (Silvert 1997; Prato 2005).

Using examples from the Hudson Bay Inuit and other indigenous knowledge systems from northern Canada, Berkes and Berkes (2009) argue that fuzzy logic appears to be a good fit with indigenous knowledge, and an approach that may provide insights on the question of how local and indigenous knowledge systems may be dealing with complexity. Indigenous knowledge seems to build holistic pictures of the environment by considering a large number of variables qualitatively, whereas science tends to concentrate on a small number of variables quantitatively. The holistic, qualitative approach does not replace science, but it does provide a different way to think about ecosystems and other kinds of complexity.

In the sections that follow, we examine James Bay Cree hunters' evaluation of the shifts and changes affecting the goose hunt. By "scanning" and evaluating a large number of variables, hunters grasp the implications of complex interactions of social and ecological processes occurring at multiple levels, and respond to them in various ways.

Study Context and Methods

This study was conducted in the boreal region of James Bay, in mid-northern Quebec (lat. 52° N). The environment consists of a patchwork of shallow coastal bays and salt marshes, lichen-spruce heaths and open-crown spruce-lichen woodlands, along with numerous lakes and rivers. The Cree have historically been a semi-nomadic, kinship-based society pursuing subsistence hunting, fishing, and trapping over vast territories. During the last three centuries, they have been key actors in the fur trade, and more recently they have become involved in wage labor. However, a substantial proportion of the population remains full-time occupational hunters and fishers, and an even larger proportion continues to engage in these subsistence activities on a part-time basis. They live in 10 permanent settlements that dot the territory from the coast to the longitudinal center of Quebec. The Cree Nation of Wemindji is a coastal community situated on the eastern seaboard of James Bay with a population of about 1,500.

This paper is based on collaborative research carried out as part of a large team project on aboriginal cultural continuity, economic development, and environmental stewardship.[2] We sought an understanding of Cree ecological knowledge and environmental stewardship practices by looking at how these practices fared in the context of rapid social and ecological change. We focused on the goose hunt because (1) this harvest is among the most important for the coastal Cree (Preston 1978; Scott 1996); (2) it is characterized by sets of customs and practices that are of interest from a human ecology perspective (Scott 1996); and (3) it has been undergoing dramatic changes over the last decade or so (CRA 2005). This study combines years of research experience in James Bay with focused study fieldwork in Wemindji from 2006 to 2007. Favoring an ethnographic approach, we carried out 60 semi-directed interviews with hunters, uuchimaau (customary "stewards" of a given family hunting territory), and elders.[3]

The Goose Hunt, Variability, Unpredictability, and Change

The hunt takes place in the spring and in the fall as migratory Canada geese (*Branta canadensis*) travel to and from their nesting and breeding grounds to the north. They usually move in stages, landing in the bays and on the points and islands that dot the coastline, making use of these various habitats for feeding and resting

[2]The Wemindji–Paakumshumwaau Project: Environment, Development and Sustainability in a James Bay Cree Community www.wemindjiprotectedarea.org.

[3]For more details on the methodological approach, see Peloquin (2007, pp. 44–58).

(Reed et al. 1996). Hunters coordinate their efforts around goose hunting territories, each of which has a number of sites suitable for the hunt. During the hunting seasons, hunters seek to intercept small flocks of geese, while remaining careful to avoid alarming the main flocks of geese and disrupting the migration.

Hunters stay at a camp on the territory, and each morning select the site for the day. In most cases, a "shooting boss" (paaschichaau uuchimau) chooses the site, taking into account the direction and strength of the winds, temperature, previous hunting pressure, goose behavior, and so on. Normally a new site is chosen each day, and there are days when the goose-boss decides that no hunting should take place, either because conditions are not favorable (e.g., not windy enough), or simply because he decides that the territory should be "rested" for a time. These practices have the effect of diffusing hunting pressure in space and time, with the goal of not disturbing migratory geese past a threshold beyond which they would avoid the territory altogether.

In addition to this system of rotation, there are a number of other "rules-in-practice" that contribute to this goal: hunters should not shoot into the main flocks, they should not shoot after dusk, and they should avoid creating visible disturbances on the ground (no red or other brightly colored gear, no garbage left visible, etc.). Details of management practices surrounding the coastal Cree goose hunt, along with their significance in cultural anthropology and resource management, have been discussed elsewhere (Preston 1978; Scott 1986, 1996). Here we are concerned with the fact that harvesting efforts and approaches are informed by a constant monitoring of shifts and changes – many of them rather subtle – that amount to a resource use and management system allowing hunters to live with variability to maintain the resource. Over time, perception, creativity, and agency combine with traditional teachings and form sets of practices. This approach is flexible, attentive to initial conditions, and to the effects of various disturbances, including anthropogenic ones. Table 1 lists some of the variables hunters usually look for during their assessment of the situation. It is important to note, however, that these are only some of the factors that often are of higher direct relevance in decision-making pertaining to harvesting strategies and not a comprehensive checklist that automatically takes precedence over other observations. As one hunter said during an interview, "in the bush, everything changes all the time." In such a complex and dynamic context, undue reliance on specific, preidentified variables does not work well. According to hunters, shifts in ecological processes are part of the "normal" course of things in boreal environments. That being said, the last three decades have been characterized by significantly accelerated and aggravated changes in James Bay, namely very rapid socioeconomic and biophysical transformations associated with industrial developments and related aboriginal and claim settlements (discussed below).

For Wemindji hunters, one of the important aspects of these changes has been the dramatic decline in the numbers of geese harvested during both the spring and fall hunts. This problem has been mentioned by Cree hunters since the late 1970s (Scott 1996). Coastal Cree participants in the Voices from the Bay project reported that the situation has been particularly problematic since the mid-1980s (McDonald et al. 1997). More recent accounts suggest that the situation has further worsened since the early 2000s. Hunters have described this trend as follows:

Table 1 Key variables observed in decisions about site selection and hunting technique

Variable	Explanation
Wind	Wind "muffles" the sound of shooting and other human activities, and also influences geese flight patterns. Hunters then seek to attune their efforts both to the strength and the direction of the wind.
Tide level	Geese visit inter-tidal feeding sites at low-tides, and go elsewhere during high tides. Hunters take account of tide levels when choosing a given site.
Flock size and behavior	Some hunting techniques are only suitable when a large, well established flock is present, whereas other techniques are preferred at the onset of the migratory season, when the first arriving geese are in small numbers. Some hunters may guess when geese will be departing the area, as they "prepare" for their travel. Flight patterns from feeding to resting sites are important.
Landing patterns	Geese may not be shot at when they land in a given direction
Flight altitude	Are geese flying low enough to be hunted without unnecessarily scaring them?
Sea-ice	Does sea-ice allow or hinder safe and sensible access to and use of given sites?
Snow melt	Thick snow can prevent geese from accessing certain food sources, may push geese to favor other sites.
Food availability	Where and when are marshy plants, berries, eelgrass, and other food sources available to geese?
Recent hunting pressure	Preference is given to sites that have not been recently used, combined with other factors
Number of hunters	The size of a group may influence the selection/choice of sites.

> It's been getting worse every year, bad goose hunt last two years; I did not catch any goose this spring (2006). Many others also did not catch any. It used to be 100 in a season. (FS)

> Hardly any geese anymore. In 1984, got 50 geese a day, now you get 10 and return home because you know you won't get any more. (JB)

According to hunters, a number of behavioral changes among both geese and hunters have made the hunt less successful in recent years. This explains how the decline in catches has taken place during the same period in which government-mandated wildlife scientists observed unprecedented growth in meta-population numbers of Canada goose (flyway), with estimates suggesting a fivefold increase in breeding pairs from 1996, when the population was at an all-time low, to 2006, when the present study began (Harvey and Rodrigue 2006).

Changes in Goose Behavior

Table 2 enumerates some of the key behavioral changes observed among geese that are seen as related to the decline in catches, along with the temporal and spatial

Table 2 First-order variables, factors, events linked to on-going changes surrounding the goose hunt

Category	Factor	Question	Time	Space
Goose behavior	Flight patterns	Where do geese fly?	a b c d e	v w x y z
	Landing patterns	Where do geese land?	a b c d e	v w x y z
	Feeding habits	Are they eating? Resting?	a b	v w
	Congregation size	How many geese at a given spot?	a b c	w
	Response to hunting efforts	Do they return after chased?	a b	v w
	Geese long-term collective memory	What events in the past may trigger current situation? Have geese previously been scared from a site following hunter recklessness?	c d e	v w x y
Hunter behavior	Site rotation	Are hunting sites adequately selected in function of wind, goose flight patterns, and prior hunting pressure? Are sites sufficiently "rested"?	a b c	v w
	Noise "disturbance"	Do hunters shoot on calm days? Do helicopters fly in the vicinity?	b c d	v w x
	Visual "disturbance"	Do hunters shoot after dark? Are there open fires? Are sites clean from garbage? Is colorful gear camouflaged?	a b c d e	v w
	Coordination of hunting efforts	Are hunters following the directions of the hunting boss?	a b c	v w
	Ability to travel	Can hunters access their territory and various hunting sites reliably and safely?	b c	v w

Temporal scales:
a – hour
b – day
c – week
d – month
e – year(s)
Spatial scales:
v – hunting site/pond
w – goose hunting territory
x – community level territory
y – region
z – continent

levels at which these factors take place. While hunters do not make reference to levels or scale per se, we have added this dimension to better illustrate the flexibility of Cree ways of knowing. For example, the first question, “where geese fly,” is simultaneously applied at multiple spatial and temporal levels (whether or not geese will fly above a given pond on a given morning, whether or not they will visit a given territory over the course of a week) which are also linked to the multiyear shifts in the regional flyway and other trends that play out at sub-continental scales. We have organized these factors as “first order” factors because they are usually linked more directly with the declines in hunting success.

Hunters indicate that goose migratory patterns now occur in ways that tend to contradict the expectations on which hunting practices are based. Migration across the territory takes place over a shorter period than in the past, as geese leave the territory earlier. Geese increasingly fly at night when they cannot be hunted, or they fly too high and simply avoid landing in the territory. Moreover, they are seen as increasingly favoring migration routes that are further inland (100+ km from the coast) as opposed to the coastal route (McDonald et al. 1997). Lastly, some hunting techniques now have diminished success: for instance, geese now often do not return to a site after being chased, whereas key techniques directly rely on the historically correct view that geese are better hunted upon their return to a site from which they were chased.

According to some research participants, the newly observed goose behavior could be partly attributed to changes in the ways some hunters are hunting. They reported that hunters do not always rotate hunting sites as they should, and instances of shooting after dusk, hunting even on calm days (when the sound carries), and hunting every day thus not letting territories “rest” – all transgressions of customary practice and adding to the disturbance caused by increased reliance on motorboats, float planes, and helicopter travel.

Other participants, however, hold that “we do the same things; it is the geese that have changed.” Numerous aspects of the social–ecological system of the Cree have been undergoing many dramatic transformations over the last decades. This includes massive environmental modifications in the aftermath of hydroelectric developments that started in the late 1970s, with impacts on the salinity and thermal regime of James Bay. To this are added concerns over climate change, contaminants in the Bay, and the changes in the way Cree perceive their environment (McDonald et al. 1997; Rosenberg et al. 1997).

“In the Bush, Everything Changes, Not Just the Geese”

Additional discussions helped identify some of the underlying factors that are put forward by hunters as they seek to understand and explain what these changes mean and how they must respond to them. We have grouped these items as second-order factors (Table 3). Again, almost all of these factors operate at more than one spatial and temporal level, and the perceived directness of their influence on the goose hunt is subject to variation.

Table 3 Second order variables, factors, events linked to on-going changes surrounding the goose hunt

Category	Factor	Question	Time	Space
Bio-physical	Temperature, weather	Is spring long and gradual so that geese "stick around"? Do sea-ice conditions ensure safe travel? Is weather predictable? Is it cool and wet enough that berries can grow?	b c d e	v w x y z
	Goose habitat	Do ponds and bays flood or dry out? Are small-dikes sufficient to retain water? Is "goose-food" still available or replaced by woody vegetation?	c d e	v
	Regional physical geography	What are the potential impacts of large-scale modifications following hydroelectric development? Do these influence goose behavior?	d e	y
	Isostatic uplift	Are new sites created/formed to offset the losses due to glacial rebound?	e	y
Social–cultural	Values and lifestyle	Are hunters respectful of the geese? Do they "monitor" the territory just to observe what is happening?	e	x y z
	Economic organization	When must hunters return to the village for work, school? How long can they "wait around" to hunt, to travel back to town?	e	x y z
	Technologies	Where, how, why, and when is one to travel by snowmobile? Helicopter? Trucks? What impacts on the geese?	a b c	w x y
Related eco-logical dynamics	Cycles, fluctuations in time	Has this happened before? What is the time frame of these events?	e	w x y z
	Abundance of other animals	Are certain predators scaring the geese? Are there other unusual patterns that may be related?	d e	x y z

Temporal scales:
a – hour
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Due to the impact of weather patterns on both animal availability and safety, hunters are highly attentive and responsive to shifts in temperature, winds, and freezing and thawing patterns. There are numerous signals on which hunters rely in assessing weather, including the speed and severity of storms, ice freeze-up and break-up dates, ice thickness, temperatures at given dates, and dates at which certain migrations occur. According to hunters, recent trends in weather patterns suggest a departure from the expected.

> The weather has been changing a lot since the late 1970s. It's not as cold in the wintertime, and after freeze-up you have to wait a long time before you can travel on the ice. And people say the ice is not as thick as it used to be, even out in the Bay. In late February I put out my fish nets, five kilometers from here, I was surprised that the ice was very thin, it was about this thin (~30 cm), it used to be about 1 m thick. It makes it easier for digging a hole in the ice. (JM)

> Freeze-up takes longer, we must wait a long time before going on ice (in the fall), and then in the spring ice goes out really fast, too fast. (LU)

Hunters reported that recent weather patterns have diminished the reliability of ecological indicators on which they normally base their decisions, such as the length of time it takes a storm to form, when traveling over sea-ice by snowmobile becomes dangerous, or whether berries will be available on the islands when the geese return in the fall. Thus, their hunting behavior is influenced. For example, the ability to move from one hunting site to another is controlled by the thickness and reliability of ice on the Bay. As one site is "rested," hunters may not be able to go to another if the ice is too thin. Often hunters choose to stay closer to the camp to avoid undue risk, resulting in a concentration of hunting pressure. These factors also directly impact goose availability. For example, early and fast spring break-up, as well as warm weather, are seen as key factors influencing geese:

> It's too warm, it's not good for the geese, they fly right through; it's probably why the geese change their patterns. (AV)[4]

> This year and last year, we had an early spring, early open water. The ice went really fast, so there is less geese. Because the snow is really going fast, and there is hardly any water in the swampy areas, the geese don't land and (they) don't stick around. (SM)

Warmer weather also combines with the effects of background isostatic rebound.[5] This process takes place at the regional scale, but it has implications at the level of specific hunting sites, as ponds dry out and marshy vegetation is replaced with woody species not palatable to the geese. Furthermore, these processes take place in the context of series of large-scale anthropogenic disturbances associated with the

[4] For more details on the climate-related aspects of this study, see Peloquin (2007, pp. 99–103), Berkes (2008, pp. 172–174).

[5] Postglacial isostatic uplift is the slow rebounding of the land after the release pressure of glacial ice. Near Wemindji, the land is currently 'growing back' (as the Cree put it) at a rate of approximately 1 m per century.

massive hydroelectric developments in the area, and their potential impacts on the regional hydrology as well as on Bay-wide oceanography (Rosenberg et al. 1997):

> I think since Hydro-Quebec made the reservoirs, the geese changed their patterns. If you look at the maps all the way to Eastmain River, there is a lot of water, just like James Bay. That's why I think that's one thing that they follow. And along the Bay, there used to be grass… We call it in Cree sishkabash [eelgrass, *Zostera marina*]. Over 10 years now, there used to be lot of sishkabash … there is just a little bit of that now.... (FA)[6]

These biophysical factors affecting the goose hunt are also taking place in a context of rapid social–cultural changes which further influence hunters' behavior. Hydroelectric developments have opened the territory to roads and other transport infrastructure. Gradual changes in the economic and social organization of Cree societies, new institutional arrangements, and changes in cultural identity and aspirations can all be linked to these hydroelectric developments, and they are central to the Cree perception of a changing world (Hornig, 1999; Carlson 2008). Economic changes have meant that many Cree have less flexible schedules due to various commitments in town; so hunters cannot just wait for a week or two for the best conditions to travel and hunt. Some respond to this by hunting even when conditions are not optimal, and some rely on helicopters to travel between their hunting camp and town:

> All the coastal communities do it [use helicopters down the coast], so it must scare them [the geese]. It is since they have been using that, in 1985, that there is less geese. (SG)

All of the factors affecting the goose hunt represented in Fig. 1[7] were mentioned by Cree hunters as relevant in understanding the hunt and the larger context in which it as well as other subsistence activities take place. No specific cause is held solely responsible for all these changes in goose behavior. Rather, each factor is linked with many other kinds of social–ecological change. The factors identified by the Cree are extremely diverse, and include what natural and social scientists may call biophysical and sociocultural factors, although the Cree do not make that distinction (Fig. 2).

During our conversations about changes on the land, Cree experts often juxtaposed specific events and observations. To the researcher, these associations first appear to serve as mere temporal reference points, but they also suggest linkages that may or may not be causal. The processes surrounding the decline in the goose

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[6] The reasons for the decline of eelgrass in Hudson and James Bay have not been resolved but are thought to be associated with changes in water temperature, salinity, and turbidity, with impacts on the ecology of waterfowl, especially brant geese but also Canada geese and ducks (Short 2008).

[7] Each box in the figure represents one category that was mentioned by at least one participant in the study (usually by more). Arrows linking the boxes are relationships, observed or hypothesized, among the different categories of factors. This diagram is conservative in that many other links are plausible among these factors but they were not explicitly mentioned.

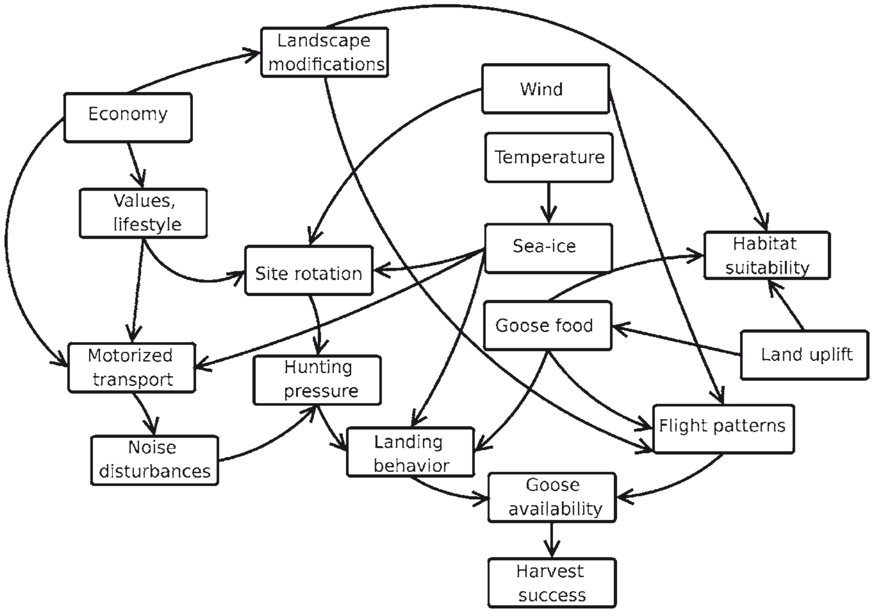

Fig. 1 Categories of factors affecting the goose hunt and how they interact according to Cree hunters

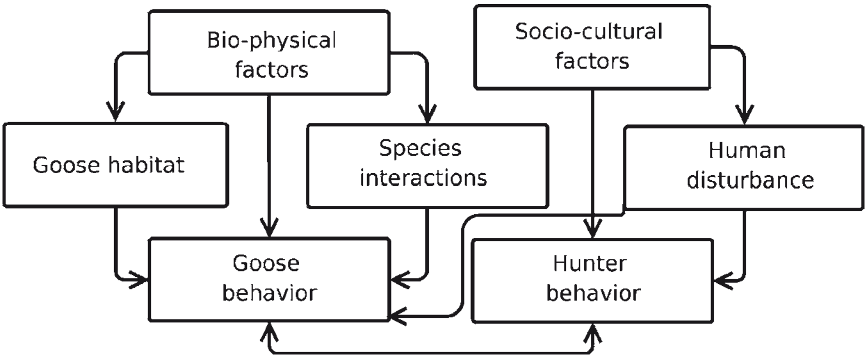

Fig. 2 Clusters of factors that affect the goose hunt

hunt are comprehended by the Wemindji Cree as an integral part of a broad network of social and ecological processes shaping their environment and this informs the ways in which they respond to change.

In recent years, while some individuals continue to hunt as before, others are increasingly favoring road-based travel to inland sites for the goose hunt, both in the spring and in the fall. Roads to inland camps are less vulnerable to changing weather patterns and ice conditions than boat or air travel along the coast.

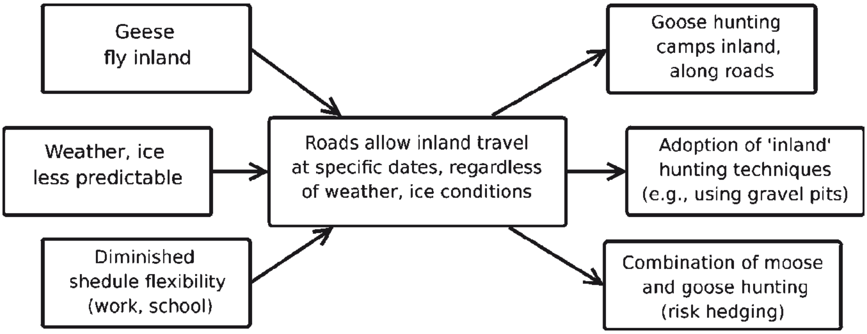

Fig. 3 The role of roads in response to change

In addition there is no need to leave before ice break up, or to wait for the ice to clear before returning to the community. It is safer, less costly, and less complicated than helicopter travel, and does not scare geese (Fig. 3). Thus, moving inland diminishes disturbance and diffuses hunting pressure over a broader area while at the same time allowing the coast to become attractive to the geese once again, extending the Cree notion of site rotation to the regional scale.

The gradual move of the goose hunt inland has led to a number of interesting strategies. For example, some hunters create pond-like features in the snow-covered gravel pits along the roads in which they place decoys; and in the fall, by opting to go inland, hunters can combine their investments and efforts with those for the moose hunt, which also takes place inland and not uncommonly overlaps, as the respective harvest periods are not fixed.

Discussion and Conclusions

These results show that in order to adjust their day-to-day activities to changes in biophysical and socioeconomic processes taking place at multiple scales, hunters rely on constant monitoring of these changes. As the boreal environment is characterized by large year-to-year natural variability, hunters rely on social memory to construct an understanding of the expected range of observations (e.g., goose hunt success, timing of spring ice break-up). They exchange observations of specific events, with a focus on unusual occurrences and anomalies (e.g., unexpectedly thin and dangerous sea-ice) at a particular time and place, rather than on central measures or averages such as those used by climate change models.

Consistent with other northern indigenous peoples (Berkes et al. 2007), the Cree are reluctant to propose simplistic cause–effect conclusions (e.g., the decline of the goose hunt is simply due to the impacts of hydroelectric development). Rather, changes are monitored and evaluated with a wide range of factors in mind and the possibility of causal links among various factors is neither "denied" nor "confirmed."

For example, the goose hunt can be represented as sets of relations linking hunters and geese, and the variables in the complexity of the goose hunt can be assigned diverse degrees of causality. Uncertainty and unpredictability are acknowledged and natural cycles are recognized, common themes in Cree ideology, especially in relation to the return of animals (Berkes 2008).

Returning to the theme of complexity and indigenous knowledge, we suggest that Cree hunters' understanding of environmental processes is not affected by the western assumption of separateness of nature and culture (Bateson and Bateson 1987). Further, it functions without undue fixation on the measurable (Sardar 1994). The Cree do not seek to diminish complexity or uncertainty but embrace it. They act upon a relational model of their environment in which events and patterns are understood in probabilistic terms, an approach that allows for the treatment of a large number of variables, especially at the collective level when hunters and elders deliberate over the implications of their observations.

Hunters communicate, exchange information, and as appropriate, adapt their practices and strategies according to their opportunistic observations of unusual events. Cree ways of knowing, in this context, appear to be largely (but not exclusively) qualitative and probabilistic. They note unusual events but do not seek to measure trends of change as scientists might. Their understanding does not require proving causal links or cause–effect relationships. Instead, they make their observations in a relational context; causality itself remains uncertain. Changes in goose behavior and availability are perceived within a view of their social–ecological system that could be described as a complex and dynamic web of interactions.

Western science approaches issues such as climate change by quantifying a relatively small number of variables, such as mean temperature. By contrast, many indigenous ways of knowing approach these problems by qualitatively scanning a large number of variables. Such an approach is not unique to the Cree and has been observed in other indigenous knowledge systems, for example, Maori ways of "eyeballing" animal abundance (Moller et al. 2004) and Inuit ways of monitoring the health and edibility of their food species (Berkes et al. 2007), and may provide key insights for living with complexity.

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After the Cochabamba Water War of 2000: A Common Pool Resource Institution in the Urban Andes[1]

Amber Wutich

Introduction

The Cochabamba Water War of 2000 was actually a series of protests against the privatization of water resources and their management in the department of Cochabamba, Bolivia. After two months, the protesters were able to secure the nullification of the privatization deal and a return to public control. The protests have come to be considered a moral triumph of impoverished Bolivians over a transnational consortium of private corporations (Assies 2003; Olivera 2003). It has been suggested that the protests began when peasants and urban migrants rose up to defend Common Pool Resources (CPR) and institutions (Perreault 2006; Bakker 2007). This argument has focused on rural communities, as we know little about how common pool water resource institutions function in urban Cochabamba, where water is extremely scarce in the southern region occupied by urban migrants – a condition that may make urban common pool water institutions unsustainable. I here examine three questions: (1) How does a common pool water resource function in urban Cochabamba? (2) Are its rules sustainable during periods of severe water scarcity? (3) Are the underlying institutions (including those for collective choice rules and operational rules) also sustainable during periods of severe water scarcity?

[1] The original article *Water Scarcity and the Sustainability of a Common Pool Resource Institution in the Urban Andes* appeared in *Human Ecology* Vol. 37, No. 2, April 2009.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*, 297
DOI 10.1007/978-1-4419-5701-6_19, © Springer Science+Business Media, LLC 2010

Sustainability and Vulnerability in Common Pool Resource (CPR) Institutions

The coordinated exploitation and preservation of CPR rely on the rules and norms that govern behavior (Crawford and Ostrom 1995). Research on long-enduring commons governance indicates that there are a handful of characteristics shared by sustainable institutions (Ostrom 1990, 2005; Ostrom et al. 1994). Fundamentally, resource users must have the authority to organize themselves independently and to control their CPR. This is the right that Cochabambans fought to defend in the Water War. Once this is established, there must also be clearly defined boundaries for the resource system and its beneficiaries. This is particularly important in urban areas, where settlements are contiguous and may not be separated by natural barriers. If the resource system is large or complex, as is often the case in cities, there should be nested levels of oversight to ensure that CPR governance articulates with the rules at all levels. Because following the rules may not be in everyone's self-interest, there must be monitoring to ensure that all resource users are in compliance with the rules. There should also be graduated sanctioning to counteract self-interested rule-breaking. There must be conflict-resolution mechanisms in place to resolve disagreements over rules or sanctions. There should be collective choice arrangements so that resource users can modify the institutional rules if they are no longer working properly. Such modifications should ensure that the institution maintains a proper balance, first, between resource exploitation and local conditions and, second, between the costs and benefits apportioned to resource users.

While these design principles appear to be necessary for the long-term success of CPR institutions across cultures, they are implemented in culturally appropriate ways in distinct ethnographic contexts. In the Andes, Trawick (2001, 2002, 2003) documented the evolution and sustainability of principles for institutions governing irrigation systems. He identified a set of six basic principles of an irrigation institution in the rural Peruvian community of Huaynacotas, and suggested that these principles may be connected to preIncan forms of social organization and shared broadly across the Andes:

1. *Autonomy*: The community must own and control its water resources.
2. *Uniformity*: Everyone should receive water with the same frequency.
3. *Proportionality*: People should only take the amount of water that their land entitles them to and that their contributions to the system should be in proportion to their use of it.
4. *Contiguity*: A strict system of turn taking is followed in which people are allotted water on the basis of their physical location in the canal system.
5. *Transparency*: Ensures that water is distributed publicly and every community member has the opportunity (and responsibility) to monitor and sanction everyone else.
6. *Regularity*: How the CPR institution responds to conditions of abnormal scarcity.

The idea is that no changes are made to the uniformity, contiguity, or proportionality of the system. When shortages do occur, they must be absorbed equally by all households.

This is crucial for long-term sustainability because it essentially prioritizes the preservation of the institution over the wellbeing of individual households; while individual households may become vulnerable to water scarcity, the system should not.

Trawick's principles of autonomy, uniformity, contiguity, and transparency appeared to be closely followed in Cochabamba's squatter settlements. Even the proportionality principle seemed to be followed in spirit, as equity and fairness were key features in these community-run urban water systems. This was surprising because Trawick noted that these principles had become rare even in socially isolated indigenous Andean farming communities (2001), and they have never been studied in the context of an urban Andean water system (Trawick, personal communication).

The regularity principle, however, appeared to be nearly impossible to adopt in an urban setting because urban water use is generally reserved for household purposes and not for productive activities. In the case that resource users are operating at or below subsistence level, it would be extraordinarily difficult for community members to adopt and enforce rules that provide people less of a resource than they need to survive. In fact, it is in precisely these situations that rebellions and other forms of violent opposition have emerged (e.g., Scott 1976; Popkin 1979). To counteract such threats, people are likely to adopt flexible social norms and tolerance of self-interested rule-breaking *if* they know that their resource system is vulnerable to periods of severe scarcity (Laughlin and Brady 1978). The regularity rule would directly contradict this because it would force people to share shortages even when they lacked water for basic subsistence needs. Thus, I was interested in understanding whether the regularity rule, so crucial to the sustainability of common pool water institutions in the rural Andes, could also operate in an urban setting.

This issue is particularly important because it sheds light on the sustainability of urban CPR institutions in the face of impending global climate change which is expected to make water scarcer in water-stressed areas and increase climatic variability around the world (UNDP 2006). Existing water management institutions may be vulnerable to challenges posed by increasingly unpredictable weather patterns and severe water scarcity (UNDP 2006), particularly in urban areas (Muller 2007). If so, current studies on the institutional impacts of intra-annual climatic variability may shed light on the characteristics that will make CPR institutions sustainable under future conditions of inter-annual climatic variability.

Water Provision and Scarcity in the City of Cochabamba

The Valley of Cochabamba is located in the eastern Bolivian Andes, and contains a number of alluvial fans, a spring zone, confined aquifers, two rivers, a lake, and a *playa* zone (Stimson et al. 2001). The city of Cochabamba spans the valley floor and is bisected by the Rocha River, which once supplied water to the city's agricultural population. Today, municipal water is supplied by SEMAPA, Cochabamba's public water company. SEMAPA acquires water supplied by well-fields located in the alluvial fan system to the northwest of the valley (Stimson et al. 2001), and by reservoirs located outside the valley. Surface water sources located outside the valley provide 40% of Cochabamba's water, while 30 wells provide the remaining supply (SEMAPA 2006). In 2000, control briefly passed from SEMAPA to Aguas del Tunari, the transnational consortium whose actions precipitated the Water War (Assies 2003). Although the return of the water system to municipal control has been widely celebrated, few in the academic community have addressed implications this has for those whose disenfranchisement drove Cochabamba's planners to seek outside funding and management in the first place (Nickson and Vargas 2002). Despite SEMAPA's efforts to improve the existing water system, industrial and domestic pollution have seriously degraded the surface water resources, and over-abstraction and pollution now threaten the aquifer system (Stimson et al. 2001; Ledo García 2002; Terhorst 2003).

Beyond these hydrological and technical problems, Cochabamba's municipal water system has another serious problem – inequity. As national economic crises pushed Bolivians into cities to find work, squatter settlements have filled in the water-poor south side of Cochabamba (Assies 2003). Rural migrants and downwardly mobile urbanites have bought up land and are working to legalize their claims to occupy Cochabamba's impoverished southern districts (Chritéle and Delgado 2007) where even legally recognized communities and land claims have historically not entitled residents to municipal services such as water (CEDIB 2007). In 2004, SEMAPA's service area was enlarged to include southern Cochabamba, but large-scale expansion of the physical water delivery system is not yet financially feasible (Los Tiempos 2004). As a result, municipal water and sewage service is still not available to the majority of residents of Cochabamba's south side (CEDIB 2007).

SEMAPA services are available to approximately 60% of Cochabamba's one million residents (García et al. 2003). About 80% of Cochabamba's water supply goes to the north and central zones of the city where the wealthiest residents live (Terhorst 2003). Water provision in Cochabamba's wealthiest households runs up to 165 L per person per day, and water costs less than 1% of household income (Ledo García 2005). In contrast, about 40% of residences are located in the south side of Cochabamba (García et al. 2003), which is not covered by the water system, and where 93% of the population is considered poor by InterAmerican Development Bank standards (Terhorst 2003). Here, households use less than 20 L per person per day, and water costs more than 10% of household income (Ledo García 2005). Households that lack access to the municipal water system must find alternative sources of water for daily use, including community water systems, private water vendors, surface water, and rainwater collection.

Among the urban poor, community-based water systems are often considered the best alternative to municipal service. In 120 south-side neighborhoods, Water Committees (*Juntas de Agua*) are responsible for securing water access for local residents (Los Tiempos 2004). While many Water Committees have succeeded in erecting some water infrastructure, not all households can rely on water supplied by these systems. In south Cochabamba neighborhoods ranging from relatively new squatter settlements to very established ones, most local water sources provided insufficient water for daily household needs. In some of Cochabamba's squatter settlements, water sources have disappeared permanently, dry out seasonally, are contaminated, or lack the volume of water needed to support growing populations. The stressors on south-side water systems – including rapid population growth, desertification, drought, and the possibility of climate change – are only worsening over time. I here focus on the sustainability of a community water system in a squatter settlement known as Villa Israel.

Methods

I conducted field research in Villa Israel, including participant observation and systematic sampling, with the assistance of four Bolivian colleagues between June 2003 and July 2005, with a follow-up visit in 2008. A detailed description of the research methods, including the sampling frame and complete interview protocols, can be found in Wutich 2006, pp. 53–78, and 2009.

In 2008, I made follow-up visits to participants in the original study and to the president of Villa Israel's Water Committee. During these visits, I asked a series of semistructured questions to clarify my interpretation of the completed data analysis and to verify that the community system was still functioning on the basis of the principles I had identified during the 2004–2005 field research. The results presented here include insights gleaned during these visits.

Villa Israel, Cochabamba

Villa Israel is one of the newer squatter settlements in Cochabamba, located in the foothills at the far southern tip of the city. Like many of Cochabamba's squatter settlements, Villa Israel was established after a *loteador* (land speculator) purchased land reserved for an agricultural greenbelt, illegally subdivided the land for urban settlement, and sold small plots to urban migrants (Goldstein 2004, pp. 76–78). Those who purchased the land are considered lawful landowners within Villa Israel, although few have completed the long process required to legalize land claims at the municipal level (cf. Chritéle and Delgado 2007). The initial settlers were mainly Quechua-speaking highlanders who migrated to Cochabamba after the mining industry collapse of the mid-1980s. Later settlers included urbanites from the cities of La Paz and Cochabamba, ex-coca farmers from Cochabamba's tropical Chapare region, and residents of rural settlements in the highland departments of Potosi, Oruro, and La Paz. The community is now a Bolivian melting pot; with a mix of Spanish, Quechua, and Aymara speakers as well as members of Evangelical and Catholic faiths.

Like many inhabitants of Latin American squatter settlements, Villa Israel residents suffer from the economic insecurities associated with low-income employment in the informal sector. Nearly 90% of household heads work in informal sector jobs such as day laborers, domestic employees, market vendors, and taxi drivers. At the time of fieldwork, average incomes from these sources ranged from about 10 bolivianos ($1.33) to 50 bolivianos ($6.66) a day. As a result, many households struggle to maintain access to food, water, medications, and other necessities (Wutich 2006). The economic stresses are intensified by the lack of public infrastructure in the community, including bridges, paved roads, and especially municipal water supply.

Instead of the municipal supply, people acquire water from four distinct sources (Wutich 2007). The first is a community-run tapstand system, which distributes groundwater from two wells within Villa Israel. The second is a system of private water trucks, which imports water from outside the community. The third is a seasonal creek, which is an open-access water source with no restrictions on its use. Consequently, creek water is highly contaminated and unfit for drinking. The fourth is a system of reciprocal exchange, in which community members recirculate water from these three sources and rainwater collection among themselves. Because of the inadequacy of these water sources, 72% of Villa Israel households lack 50 L of water per person per day (Wutich 2006), the daily allotment needed to maintain minimum consumption and hygienic standards (Gleick 1996).

I selected Villa Israel as a case study site, at least in part, because the water-related challenges it faces appeared to be typical of south-side squatter settlements; it was neither a success story nor a disaster. Like resource users in many settlements, Villa Israel residents struggle to maintain the resource and working institutional rules.

How Villa Israel's Water Institution Functions

Autonomy, Ownership, and Access

Villa Israel's common pool water is supplied from two small hillside wells located a 30 minute walk from the community. The water system is autonomous: water from the well is owned by the community itself. According to the president of the Villa Israel Water Committee, the settlers adapted rural water management principles to create a new set of rules for the management of water in an urban environment. The water system is managed by Villa Israel's local government – the Neighborhood Council (*Junta Vecinal*) – which also is the primary collective choice arrangement in the community. Only community members are eligible to receive water from the community's wells and to participate in the governance of the water system. Community membership is afforded to households that own land within the formal boundaries of the community and send at least one representative to participate in community governance. Fifty-three percent of Villa Israel residents are community members. Another 29% can be considered proxy community members as they live in a Villa Israel residence, participate in community governance in lieu of the landowner, and are permitted to access the community water system. Proxy community members are often family members of an absentee landowner. Another way to become a proxy community member is to enter into an *anticrético* contract, an arrangement in which title is given as collateral against a large long-term loan. The lender occupies the residence until the loan is repaid and has legal claim to title if the loan is defaulted (Farfan 2004). Because community and proxy community members are functionally equivalent categories, I group them. However, 18% of Villa Israel's population comprises people who rent a home or a room in the community. Renters are formally excluded from the rights and responsibilities afforded to community members. The rationale for this is that community members (and their proxies) are required to pay taxes and contribute labor to support local projects such as the construction and maintenance of roadside curbs, soccer fields, and the water system. Once a month, the Neighborhood Council holds an open-air meeting in which the management of the water system can be discussed and modified. While renters are not physically barred from meetings, they are discouraged from attending and voicing their opinions in group discussions, and they are prohibited from voting.

Proportionality, Uniformity, and Contiguity in Water Distribution

Even for eligible community members, there are still several obstacles to gaining access to the tapstand system. Each tapstand typically serves 10–20 households located nearby, but not all households have access to a working tapstand. During my field research, the system delivered water to about 10 tapstands, one new tapstand was built, one was under construction but remained unfinished, one was completely defunct due to siltation, and several zones had no tapstand at all. The responsibility for funding, constructing, and maintaining tapstands falls to user groups. User group organization takes the form of informal interactions among neighbors in a roughly delineated region, rather than a formal organization. The user groups constitute, in essence, a nested enterprise within the Neighborhood Council. At the user group level, the principle of proportionality is followed because people cannot access a tapstand unless they have contributed the funds, materials, and labor required to build or maintain it.

Community members who participate in active user groups and have access to a functional tapstand still cannot collect water unless they pay a fee of 10 bolivianos ($1.25) every two months. Paid-up households receive a yellow punch card that gives them the right to access their local tapstand once a day. The maximum amount of water allotted, when it is being discharged at full capacity, is 40 L per household. This daily allotment system conforms to the uniformity rule, in which everyone is awarded the same water rights and water is distributed with the same frequency to all.

A community elder, chosen because he can live on the modest 450 boliviano ($56.25) monthly stipend paid by the community, is responsible for supervising water distribution. He begins at 4:00 AM and unlocks the tapstands one by one. The supervisor follows a strict contiguity rule, in which water is distributed in a set sequence, in 20 min time blocks, between 4:00 and 9:00 AM. Each tapstand is unlocked only once a day, six days a week (Sundays excluded). The tapstand supervisor blows a loud whistle to alert local users that their tapstand is about to be opened. Users must show the supervisor their yellow punch card to prove that they have paid their dues. After they collect their water, the supervisor relocks the tapstand and continues to the next zone. However, because of the year-round problem of water scarcity, the system often goes dry before the supervisor is able to unlock all of the community's tapstands. When this occurs, the supervisor begins the next morning from the point at which the water ran out. Because distribution is started each day at different points in the system, community members never know when in the five hours time window their tapstand will be opened. This illustrates one of the problems of adopting the contiguity rule in an urban setting, where income generation activities are generally conducted outside of the household and turn-taking can be time-consuming and costly. For families who did not have a full-time homemaker, it was extremely difficult to participate in both water collection and their income-generating activities.

Equivalence of Costs and Benefits at the Household Level

It is clear that the costs involved in tapstand use are quite high, raising the question of whether the benefits do, in fact, outweigh the costs. Community members must attend monthly Neighborhood Council meetings; contribute labor, materials, and money to community-wide and tapstand-level projects; invest up to five hours a day waiting to physically acquire the water; and contribute a bimonthly user fee. As the average household in Villa Israel contains five people, the 40 L household allotment yields, on average, only about eight liters of water per person per day. Even in refugee camps, the World Health Organization recommends that households be provided at least 70 L of water a day (WHO 2005). Thus, it seems that Villa Israel's system does not offer an equivalence of benefits and costs.

I compared Villa Israel households' water use habits with international recommendations (Table 1). On the basis of self-reported diary data, I found that Villa Israel residents use only seven liters per person per day, on average, for cooking and drinking (Wutich 2009). The tapstands, then, do provide sufficient water for basic subsistence needs – at least for an average family with average water consumption levels. The cost–benefit calculus involved in tapstand use seems balanced for Villa Israel residents with low paid labor and modest water needs who are living near subsistence level.

Table 1 Quantity of water used daily in Villa Israel households

Water use task	Mean (lpcd)
Drinking	1.5
Cooking	5.4
Personal hygiene	9.3
Household tasks	26.1

Regularity and Transparency in a Highly Stressed Urban Water System

Given that people are living so close to subsistence level, we might expect that theft and overuse would be serious problems and that defense of the system and its rules must be of utmost importance. In Villa Israel, monitoring, sanctioning, and conflict resolution occur on four levels. First, the Neighborhood Council is responsible for distributing tapstand punch cards and, if necessary, resolving conflicts at general meetings. The second and most crucial level is the interpersonal one. As dictated in the transparency rule, all community members are responsible for making sure that the rules are followed. As a result, much of the monitoring and sanctioning in Villa Israel takes the form of gossip and unpleasant visits from neighbors. The third level, really a special case of the second, occurs at the tapstand, where people gather in a tight group to watch for rule-breaking by other users. Often, a debate will break out in which people defend the rule or take the side of the rule-breaker. Ultimately, the values of the group and the personal relationships of the rule-breakers determine how each violation is treated. The tapstand supervisor, who provides the fourth level of supervision, has the final word on what will be allowed. If there is a clear group consensus, he will conform to it whether it follows the rules or not. If there is no group consensus, he will use his own judgement (and generally follow the rules) to decide a case. The tapstand supervisor has one more very important role – he monitors water availability at the wells, and adjusts the allotted output for all tapstand users if the water level is low. This is meant to ensure that the system is not overexploited, and that a proper balance is maintained between resource exploitation and local conditions at the water source.

To see how the system of monitoring, sanctioning, and conflict resolution actually works in practice, I kept records of all of the violations of system rules that I knew of. I should note that, while we asked over 1,000 survey questions on these topics, respondents admitted that they participated in monitoring, sanctioning, and conflict resolution only four times; underreporting was probably related to the stigma associated with conflict in the community. Respondents were more willing to share stories of their neighbors' experiences with rule-breaking, monitoring, sanctioning, and conflict. Therefore, the data I present here are unsystematic, gathered via participant observation and second-hand reports. Figure 1 shows a list of ten violations of community rules that I documented in Villa Israel. They are arranged from most offensive to least offensive. The violations range from outright theft (which is very rare), to renters receiving water, to legitimate tapstand users being inconsiderate of others. I was particularly interested in the case in which renters receive water from the tapstand system because it violates two of the rules for Andean irrigation systems: proportionality and regularity. It also indicates that the collective choice, monitoring, and sanctioning systems that undergird the water institution may not be functioning properly. Furthermore, it raises a fundamental question: do community members prioritize the preservation of the system at the

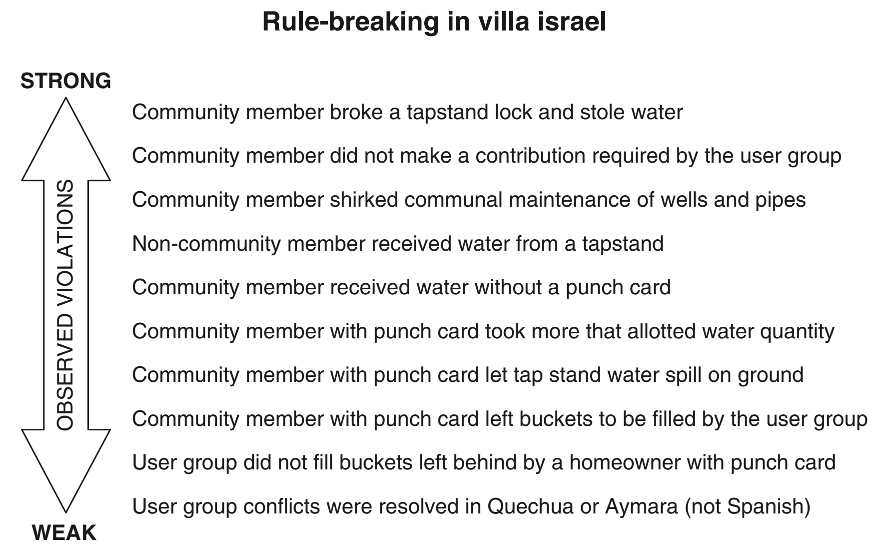

Fig. 1 Institutional rules broken during the field research, arranged from strongest to weakest rule violation

cost of household wellbeing, as the regularity rule suggests, even when households are operating at or below subsistence level?

To explore this, I took a baseline measure of tapstand use in April and May of 2004, at the onset of the dry season. I found that, across all tapstand users, 85% were legitimate and only 15% were free-riding renters. Overall, this seemed to show that the monitoring and sanctioning system was working reasonably well. But the question arises whether the community water system's rules are sustainable during periods of severe urban water scarcity.

Sustainability of Institutional Rules During Periods of Water Scarcity

In the Cochabamba, there is a pronounced wet season during the summer (November–February) and dry season during winter (May–September). The year in which field research was conducted was typical for a semiarid region, with total annual rainfall of 521 mm (SENAMHI 2006). To establish that intra-annual variation in precipitation is, in fact, linked with water scarcity in Villa Israel, I analyzed household-level data on water insecurity collected over four time periods. The analysis was conducted using a 9-point Guttman scale that measured the extent to which households lacked water to complete tasks such as cooking, bathing, and cleaning. I found that there was a statistically significant difference in

Table 2 Variation in household water insecurity scores over four seasonal periods

Season	Mean	Std. Dev.	Min.	Max.
Wet to dry transition	3.8	2.3	0	8
Dry season	3.9	2.5	0	9
Dry to wet transition	3.5	2.7	0	9
Wet season 2	2.8	2.7	0	9

$F(3,54) = 4.24$, Wilk's lambda = 0.81, $p = 0.009$, eta squared = 0.19

water insecurity across the study periods, with high water insecurity between June and September and low water insecurity between October and January (Table 2).

The data indicate that there is no significant difference in free-riding by noncommunity members during the period of severe seasonal water scarcity. Rather, it seems that legitimate beneficiaries tolerate a low level of free-riding by renters when their need can be verified by some member of the tapstand group, regardless of the season or the severity of water scarcity experienced by the group. Interestingly, as the dry season advanced, the daily water allocation was cut from 40 to 20 L per household and affected all households equally. This seems strong evidence that community members uphold the principle of regularity, even in times of severe scarcity. Furthermore, there appeared to be a subsistence ethic in the community that, in some circumstances, allowed all Villa Israel residents (even noncommunity members) to acquire the minimal amount of water they needed to drink and cook.

Sustainability of Nested Institutions During Periods of Stress

In order to establish whether the nested institutions that support monitoring and sanctioning in the community function the same way during times of severe water scarcity as they do during times of relative water abundance, I examined first, participation in the Neighborhood Council, and second, the size of social networks during the five study periods. The Neighborhood Council is the collective choice arrangement associated with the community water system. Social networks provide a way to measure people's engagement in operational rule enforcement.

Neighborhood Council

Figure 2 and Table 3 depict the participation of community members and noncommunity members over the five study periods. As with the test of rule-breaking, I found initially that the monitoring system in the Neighborhood Council was in reasonably good working order at the height of the wet season. While noncommunity

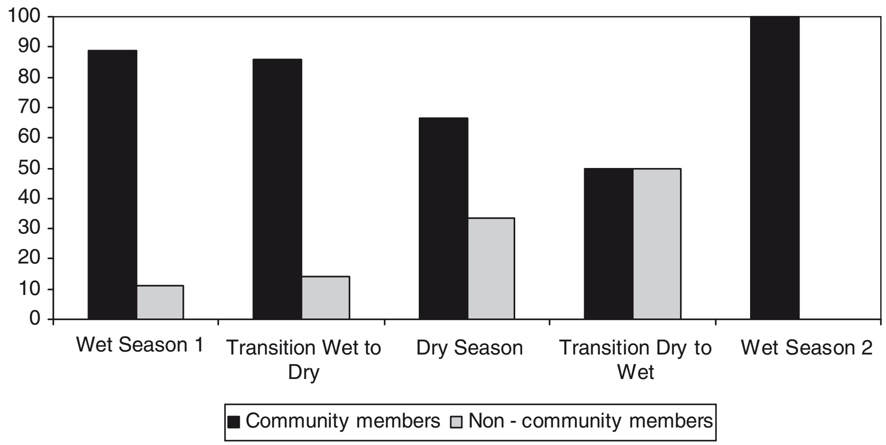

Fig. 2 Community members and non-community members participating in Neighborhood Council meetings over five seasonal study periods

Table 3 Percentage of respondents attending Neighborhood Council meetings over five seasonal periods, by community membership

Season	Community members	Noncommunity members
Wet season 1	88.8	11.1
Wet to dry transition	85.7	14.3
Dry season	66.7	33.3
Dry to wet transition	50.0	50.0
Wet season 2	100.0	0.0

members were not physically excluded from attending, they were actively discouraged from participating in Neighborhood Council meetings. Almost 90% of participants in these meetings were legitimate community members, not renters. However, there were two very interesting trends across the five time periods. First, community members' participation in the Neighborhood Council is high during the two wet seasons and consistently drops off during the dry season. Second, the participation of noncommunity members is low during the wet season but increases steadily during the dry season.

The drop in community members' participation is easily explained, and has very little to do with water scarcity. At the second time period, the president of the Neighborhood Council was accused of a serious act of corruption. A major conflict broke out, and several of the meeting's attendees came to blows. Afterwards, disgusted with the whole affair, community members initiated a movement to *desconocer* or impeach the Council president, which succeeded in fifth time period, when a new president was appointed. The behavior of the renters during this period is particularly interesting. At times when the legitimate government was functioning properly, their participation was low or nonexistent. But when corruption and political instability created an opportunity, they sought to increase their influence in the community and possibly their access to the tapstand system. At the same time, the attendance of community members dropped off as they protested the old administration. As a result, the attendance of noncommunity members rose drastically in proportion to the attendance of community members. However, once the Neighborhood Council was reestablished and in working order, noncommunity members were effectively excluded once again.

Social Networks

To explore what was happening within the social networks that act as gatekeepers for the operational rules at the tapstands, I collected a baseline measure of the interpersonal interactions through which the bulk of monitoring and sanctioning is conducted in Villa Israel. I envision these interactions as social networks, in which the size of each person's network determines his/her ability to enforce operational rules – or to break them with impunity. While personal network size can be measured in a number of ways, I use a measure of food-sharing ties here. Food sharing is a very important symbolic activity in Villa Israel, in which small amounts of food (e.g., a wedge of orange) are offered to reaffirm ties, build rapport, or smooth over rocky relations. This measure is useful because it provides a more sensitive measure of personal network activity than simply counting the number of people a resident knows.

The results of repeated measures ANOVA indicate that there is a statistically significant difference in personal network size across the five time periods, with a large and significant effect for time (Table 4). There was a spike in network activity across all groups at the outset of the dry season as people tried to mobilize their networks to attain more resources (Fig. 3). Then, as the dry season advanced, network activity dropped off as people increasingly tried to protect and conserve their resources. When the dry season ended, social activity increased again. It is interesting to note that, while we see this general pattern across all Villa Israel residents, noncommunity members' networks are always smaller than those of community members (Table 5). However, split-plot repeated measures ANOVA shows that there was no significant difference in the interaction between time and respondents' community membership (Table 6). These results indicate that social exclusion was present at all times, but did not appear to be heightened during periods of severe resource scarcity.

Table 4 *T*-test comparing social network sizes for community members and noncommunity members

	Mean	Std. Dev.	Min.	Max.
Community members	11.1	9.6	0	34.2
Noncommunity members	6.0	4.1	0	11.8

$t(55) = 3.17$, $p = 0.002$

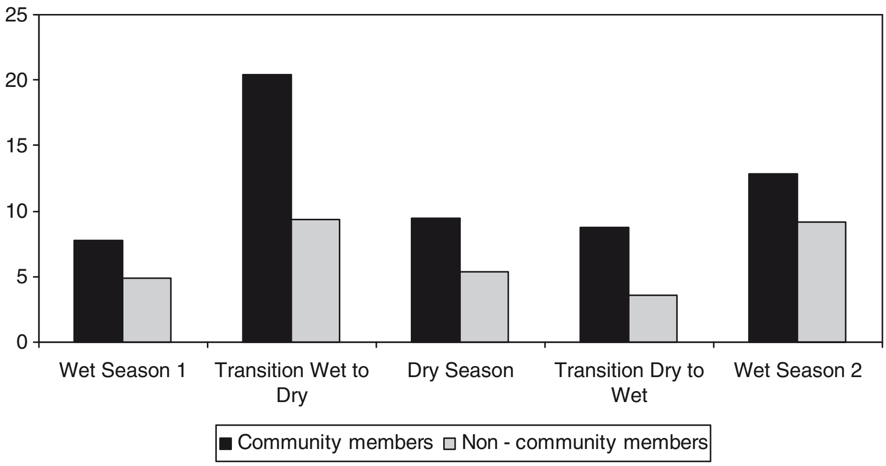

Fig. 3 Average network size of community members and noncommunity members over five seasonal study periods

Table 5 Repeated measures ANOVA comparing social network sizes over five seasonal periods

Season	Mean	Std. Dev.	Min.	Max.
Wet season 1	8.0	12.0	0	59
Wet to dry transition	19.8	29.3	0	149
Dry season	9.8	13.1	0	68
Dry to wet transition	6.8	9.0	0	94
Wet season 2	13.0	17.6	0	100

$F(4,53)=4.09$, Wilk's lambda $=0.76$, $p=0.006$, eta squared $=0.24$

Table 6 Spit-plot repeated measures ANOVA comparing social network sizes between community members and non-community members over five seasonal periods

Season	Community membership	Mean	Std. Dev.	Min.	Max.
Wet season 1	Community members	8.6	12.7	0	59
	Noncommunity members	4.4	5.9	0	17
Wet to dry transition	Community members	20.9	31.5	0	149
	Noncommunity members	14.0	11.3	0	32
Dry season	Community members	10.5	14.0	0	68
	Noncommunity members	6.0	5.3	0	15
Dry to wet transition	Community members	7.3	9.5	0	94
	Noncommunity members	4.6	5.8	0	13
Wet season 2	Community members	13.7	18.9	0	100
	Noncommunity members	9.2	6.9	0	19

$F(4,52)=0.09$, Wilk's lambda $=0.99$, $p=0.99$, eta squared $=0.01$

The overall evidence indicates that noncommunity members were excluded from the community water system and personal networks throughout the five study periods, and that they were excluded from the Neighborhood Council when it was functioning properly. While there is no evidence that social exclusion increased during the dry season, there was evidence that exclusion had more severe impacts on noncommunity members during periods of severe seasonal water scarcity. For example, one family that agreed to participate in the study had been renting a house in Villa Israel for only eight months. As the dry season progressed, the family complained more and more of not being able to make ends meet; they lacked money for water, for ingredients to make the gelatin desserts they sold in the downtown market, and for transportation to the city center. The household head complained that, as water became scarcer, she had nobody she could turn to for help in the community, no one would lend her water or help her get access to the community system, and that with debts piling up, she and her husband were thinking of moving away. By the third round of interviews, the family was no longer living in Villa Israel. While the water system weathered the dry season intact, not all households were able to do so.

Discussion and Conclusions

On the basis of the data presented here, we can draw some conclusions about the sustainability of Villa Israel's CPR institution in the face of the intra-annual climatic variability. First, the system is managed according to the principles of uniformity, contiguity, and proportionality, which ensure that all eligible community members receive fair and equal access to water from the tapstand system. These rules are enforced via monitoring and sanctioning, although a small amount of free-riding is tolerated in order to help some households meet short-term subsistence needs. Second, the system is governed following the principle of regularity, which ensures that water cutbacks are apportioned to all community members equally – particularly important during times of scarcity, when water use must be cut back to prevent overexploitation of the common pool water resource. Third, while the function of the CPR institution was stable over the five study periods, the social structures that underlie it were noticeably more sensitive to external events. Activity in the nested institutions that organized collective choice (the Neighborhood Council) and oversaw operational rules (social networks) fluctuated in patterned ways over the five study periods, and there is some evidence that seasonal water scarcity played a role in those fluctuations. The results suggest that while institutions with strong historical precedents for contingencies under resource stress can weather periods of scarcity intact, the nested institutions that organize collective choice and operational rules may not be as robust to external stressors.

These findings suggest that long-enduring CPR institutions have contingency rules that enhance their sustainability during severe resource stress. In Villa Israel, flexible rules for water allotment allowed the CPR to be managed adaptively in response to dry season stress; yet the adoption of flexible rules designed to protect the resource did not undermine fairness, equity, and the subsistence ethic – the norms that ensured the social acceptability of the system. This indicates that a well-organized CPR institution may have the ability to remain ecologically and socially sustainable during periods of stress and uncertainty. However, in Villa Israel, the nested institutions that organized collective choice and operational rules were highly disrupted by external stressors; this may create vulnerability in an otherwise sustainable CPR institution. For long-enduring CPR institutions to be sustainable during periods of global climate change, it may be particularly important to protect them from disruptions in nested institutions. For squatter settlements and other impoverished communities, many of which already struggle to survive in the face of vast political, economic, and ecological inequities, insulation from macro-political turmoil may be essential for the sustainability of local CPR institutions.

This study makes two additional theoretical contributions. First, the findings indicate that Trawick's principles for long-enduring Andean irrigation institutions were present in an urban setting. This provides some evidence in support of his argument that Andean CPR management principles are embedded in cultural knowledge passed down through the generations; the findings in Villa Israel also indicate that such knowledge is passed from rural to urban communities. Additionally, this study demonstrates that the principles of Andean CPR institutions can endure in communities suffering from more severe water scarcity than is typically found in rural irrigation communities. This is noteworthy because it proves that community members do, in fact, prioritize the preservation of the system over the well-being of individual households under conditions of severe water scarcity. Second, this study suggests the need for more research on the dynamics of nested institutions. Ostrom's "design principles" establish that nested institutions for resource management, collective choice, and oversight of operational rules are crucial for sustainable commons governance. While a number of scholars have examined how polycentric and nested institutions contribute to CPR management (cf. McGinnis 1999; Ostrom 1999), few have examined how the success of sustainable CPR institutions is affected by disturbances in nested governance institutions. In Villa Israel, the institutions overseeing collective choice and operational rules faced major challenges – corruption and water scarcity, respectively – that disrupted their normal function. However, these disruptions had no visible effect on the function of Villa Israel's common pool water resource institution. Yet there are likely thresholds at which disruptions in polycentric and nested institutions begin to directly affect CPR institutions; if so, this study points to the need for more research on when such thresholds emerge and what makes some CPR institutions robust to such disturbances.

One particularly timely topic for future research is the success of different water institutions under diverse social and ecological conditions. Two recent trends have created an opening – and even a demand – for this kind of research. First, there is now a consensus that climate change is real and obliges us to reevaluate the ways in which water institutions operate around the world (Lenton 2004; Muller 2007). Planners and policymakers are in need of more information about the performance of water institutions under climatic variability and uncertainty. Second, the international development community's renewed interest in smaller-scale water provision solutions, as opposed to large-scale privatization schemes, creates an audience for research on institutional diversity in water provision, particularly in urban settings (Budds and McGranahan 2003; Ho 2003). Social scientists whose work has a cross-cultural and wide historical scope are well positioned to meet these research needs. Another important area of research will examine the sustainability of institutions that violate the tenets of self-interest and strict economic rationality, such as CPR institutions and reciprocal exchange systems. Such systems are generally understood to thrive under conditions of *moderate* resource scarcity (Cashdan 1985), yet we do not fully understand how they are affected by conditions of *severe* resource scarcity. While recent research seems to indicate that severe resource scarcity provokes self-interested behavior that undermines such systems (Moser 1996; González de la Rocha 2001), there is a dearth of comparative longitudinal data that examine the question. Finally, there is a need for more research that examines the dynamics of nested institutions. As new methodological approaches develop, particularly social network methods for studying innovation, diffusion, and collapse, we may be able to examine questions of structure, scale, and complexity in more sophisticated ways than ever before (White 2002; Goldstone and Janssen 2005). The question of how collapses and thresholds, as well as innovation and diffusion, affect different institutional practices may reveal much about the vulnerability, resilience, and sustainability of socioecological systems.

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Gender, Social Difference and Coastal Resource Management in Lowland Philippine Fishing Communities

James F. Eder

Introduction

This paper considers how an effort to institutionalize coastal resource management (CRM) at the municipal level in the Philippines has unfolded against the class, ethnic, and gender divisions characteristic of lowland Philippine society. It draws inspiration from recent suggestions that the study of community-based natural resource management would be better served by focusing on institutions rather than on community per se (King and Durrenberger 2000; Agrawal and Gibson 2001) and, more particularly, on how institutions shape (and are shaped by) the multiple interests and actors within communities (Agrawal and Gibson 1999, p. 640). Of special interest here is how institutional arrangements may influence both the reality and the perception of local community "participation," which is much sought-after in resource management projects in general.

The Coastal Resource Management Project (CRMP), jointly sponsored by USAID and the Philippine government, is one of many such projects in the Philippines and elsewhere in Southeast Asia following growing realization that resource overexploitation and environmental degradation have complex social, economic, and political origins. The basic approach entails higher levels of government providing the regulatory and infrastructural capabilities that local fishing communities lack, while the communities' fishers contribute their greater local knowledge to management initiatives and mobilize one another in support of those initiatives (Russell and Alexander 2000, p. 36). However, a recent review of community-based Marine Protected Areas (MPAs) in the Philippines and elsewhere found that social and economic conditions such as poverty and lack of political will hinder implementation of the broader management policies (Christie et al. 2003 p. 23).

The original article *Coastal Resource Management and Social Differences in Philippine Fishing Communities* appeared in *Human Ecology* Vol. 33, No. 2, April 2005.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_20,

The CRMP has seen aggressive enforcement of existing laws protecting municipal fishing waters from intrusions by large-scale commercial fishing operators; prohibition of compressor-aided spear fishing and confiscation of all privately-owned compressors in the municipality (compressors are also closely linked to the use of cyanide); demarcation of a series of proposed MPAs; and an extensive public education campaign preparatory to an intended crackdown on certain fishing practices, such as beach seining and the use of fine-mesh nets, which are technically illegal but still commonly employed. While local residents are generally agreed that government action is needed to control depletion of fish stocks in municipal waters due to illegal and destructive fishing methods and growing numbers of fishers, they disagree regarding what most needs to be done. This disagreement tracks the social divisions of lowland Philippine society and varies with the degree and kind of household dependence on coastal resources. Ethnicity, class, and gender each influence local understandings of coastal resource issues.

The Research Setting

The municipality of San Vicente lies on the northwest coast of Palawan Island facing the South China Sea. It consists of ten communities or *barangays* (the lowest level governmental unit in the Philippine system), one of which is also the municipal seat. San Vicente's total land area is 840,000 ha and its population (according to the 2000 census) is 21,654.

San Vicente's 10 communities lie along the coast, such that each community includes a stretch of coastline; a corresponding area of ocean out to the 15 km municipal waters limit; and a corresponding area of land. The coastal plain is generally flat and cleared for settlement and irrigated rice agriculture, with a mixed upland agriculture – corn, root crops, coconuts, bananas, and fruit trees – elsewhere on the plain and in the foothills of the interior portion, which is mountainous and forested The municipality's most visible market links are connected to fishing. Most fishers operate motorized boats and employ small-scale, artisan gears, mainly gill nets of various kinds, but also throw nets and drift nets. Hook and line fishing is also common, particularly among fishers with small, oar-powered boats. Fresh and dried fish of all kinds is trucked daily to the east coast of Palawan for sale in Puerto Princesa City and for shipment to Manila. At higher levels of capitalization, a substantial pearl farm operates in municipal waters, and several times weekly a small plane arrives to transport live fish, principally farm-raised leopard grouper, to restaurants in Hong Kong and Taiwan.

The relative contributions of agriculture, fishing, and other economic activities to household livelihoods vary widely, within and between communities and households (Eder 2003). Ecology along with early attempts at CRM by local San Vicente officials have contributed to the municipality's varied subsistence economy. Of greater interest here, however, is that San Vicente's coastal communities are marked by considerable linguistic and ecological variability, such that the nature of dependence upon coastal resources varies widely, within and between communities, lending to the complexity of municipal economic life. Ignoring the history such ethnic variation, for purposes here most of San Vicente's inhabitants can be assigned to one of three categories, based on a timeline of settlement: Tagbanua, indigenous to Palawan but today extensively acculturated and intermarried with Cuyonon and other lowland Filipino peoples, who engage mostly in shifting cultivation, wage labor, and the collection and sale of nontimber forest products; the Cuyonon and Agutaynen, originating from the small islands lying between Palawan Island and Panay Island, who first settled in San Vicente during the 1950s and characteristically combine upland mixed farming or irrigated rice with part-time fishing; and the "Visayans," as Cebuanos, Warays, Masbateños, and other 1960s and 1970s migrants from the central Philippines are known locally, who largely fish for a living.

CRMP in San Vicente

A seven year (1996–2002) joint project of USAID and the Philippine government, the CRMP provided technical assistance and training to coastal communities, local government units, nongovernmental organizations, and national government agencies to improve management of coastal resources. Nationally, CRMP aimed to assist in the Philippine government in finding practical solutions to four key CRM problems: jurisdictional issues, mangrove management, commercial fisheries management, and biodiversity conservation. Locally, the project aimed to help communities and municipal governments institutionalize CRM planning and implementation. The CRMP unfolded at six local "learning areas" throughout the central and southern Philippines, including San Vicente.

San Vicente's CRM experience, however, predated the arrival of the CRMP – indeed it was among the reasons that it was selected as a learning area. The northwest coast of Palawan generally is one of the nation's major fishing grounds (Malampaya Sound, well known in the Philippine fishing industry, lies just to the north of San Vicente), and in decades past fish, squid, crabs, and other marine products were obtained in abundance in San Vicente waters. Since the 1970s, as local coastal populations of migrant fishers have continued to grow, and as encroachments by large-scale commercial fishing outfits based elsewhere have become more frequent, local fish catches (as measured in kilograms of fish per fisher per day) have steadily – even precipitously – declined (Arquiza 1999, pp.114–115). As a consequence local fishers have turned to ever more intensive and efficient capture techniques including blast fishing; use of sodium cyanide to capture live food fish; use of beach seines and other drag nets; use of fine-mesh nets; and use of Danish seines. In addition, encroachment of tourist facilities and resulting problems (littering, discharge of waste, boats anchoring on reefs, and so forth), increased sediment load due to inappropriate agricultural practices, logging, and local residential development, all added to San Vicente's problems (Arquiza 1999; Municipality of San Vicente 2001).

The CRMP joined forces with San Vicente's municipal government to grapple with these issues during its seven year tenure in San Vicente, on the one hand assimilating some of the municipality's own prior CRM initiatives and on the other, attempting to prepare the municipal government to adopt and implement the CRMP's own larger and more ambitious vision of CRM, once the project itself was phased out in mid-2002. Although CRM efforts in San Vincente got off to a promising start at the time of the turnover, two significant budget issues remained unresolved: whether the mayor would or could create a fulltime staff position in the municipal government dedicated to CRM implementation, and where local communities could obtain the funding needed to monitor effectively the marine sanctuaries now being created. In addition, several substantive matters required attention, in particular the need for a zoning system to govern the locations of the growing numbers of seaweed farms and various other marine commercial enterprises.

CRMP Initiatives and Social Divisions in the Lowland Philippines

This paper addresses how the political realities of class, ethnicity, and gender – some of the principal social divisions of lowland Philippine life – affect how local community members perceive CRMP initiatives and how, in turn, community members (acting on these perceptions) have influenced their design and implementation. More specifically, I illustrate how what Christie et al. (2003, p. 22) characterize as inadequately understood and "frequently contentious" social interactions at various levels and across gender, class, and ethnic lines may negatively impact community-based efforts to implement CRMPs.

CRMPs in general ask fishers to curtail certain practices that have proven economically attractive (or necessary) but which have been judged environmentally undesirable, i.e., fishers are asked to make near-term sacrifices, for the longer-term benefit of all. But probably no such project – given preexisting variability in fishing practices, levels of capitalization, and the role of fishing in household economic life – can ensure that the burdens of sacrifice are distributed equally among all community members.

Examining some of the ways that structural variables such as class and ethnicity can shape and restrict collective action in relation to resource use can reveal the inexorably political nature of even the most seemingly straightforward resource use policy measures. More generally, as regards the dilemma that natural resource management poses for collective action, I argue that the ways in which individuals understand and respond to the costs and benefits of existing and potential institutional arrangements are powerfully mediated by their positions on a grid of class, ethnic, and gender differences, each with its own implications for collective action. I consider in turn CRMP efforts to restrict illegal commercial fishing in municipal waters; to end compressor-aided fishing; to create a series of MPAs; and to address a variety of gear issues, particularly the use of beach seines.

Illegal Commercial Fishing in Municipal Waters

One of the most difficult and widespread CRM issues in the Philippines concerns the illegal encroachment on municipal waters of commercial fishing boats using trawls and other highly efficient gear. As elsewhere in Southeast Asia local patterns of resource use (and misuse) are inextricably bound up with a larger political economy marked (in the local view) by a class-based social division between mostly poor and otherwise "small" local fishers and wealthy and politically influential "outsiders" based, in the case of San Vicente, in or near Manila. Despite the longstanding and widely known 15 km municipal fishing waters boundary in the Philippines, intrusions of commercial trawlers into municipal waters are commonplace and are often said to occur with the collusion of municipal mayors, who (it is widely assumed) likely receive some sort of payoff in return for looking the other way.

When the present mayor of San Vicente took office, one of his first big political moves was to vigorously pursue commercial trawlers that entered local waters. A speedboat was acquired, a system of telescopes was set up (to triangulate on the positions of suspected intruders) and, with some regularity, boats have been boarded and seized and their captains brought to Puerto Princesa City to be charged in provincial courts. Whether this pattern of aggressive prosecution will continue remains to be seen, and even at present the mayor's political opponents suspect his motives are not as virtuous as this brief account may make them to appear. But the mayor is, after all, only enforcing the law, and the fishers I spoke with were generally agreed that illegal commercial fishing was less a problem now than in the past. Given that such fishing in neighboring municipalities is reported to continue unabated (Taytay and Cuyo are often singled out in this regard, and the mayors of those municipalities are widely reported to condone or even to have business involvements in illegal fishing) and, more generally, that lack of political will on the part of local officials (Arquiza 1999, p. 109) is so commonly cited as a factor in the persistence of illegal fishing practices of all kinds, that even one mayor in Palawan has apparently found such will is interesting and (or so I would like to believe) encouraging.

Compressor-Aided Fishing

The town mayor made a second dramatic political move when he ordered the confiscation of all compressor rigs in the municipality. Despite denials from their owners, use of compressors is closely linked to the use of cyanide to capture live fish (Lowe 2000, p. 249). Nearly 30 compressors were confiscated from one community alone; their owners received some direct compensation and were also invited to participate in a two week livelihood training program with a daily honorarium. While some persons suffered significant economic losses, the great majority of fishers applauded the move, and as with his willingness to vigorously prosecute illegal commercial fishing, the mayor – now given to claiming that San Vicente owns more compressors than any other municipality in the country – created significant political support for other elements of the municipality's CRM program.

Nonetheless, cracking down on the clearly-illegal and much-decried activities of outside commercial fishing boat operators and of a small minority of local residents (those presumed to be engaged in cyanide and blast fishing) is in some ways easier politically than is implementation of the balance of the CRMP agenda. Indeed, many fishers I spoke with were of the opinion that the municipality's CRM agenda should be limited to just that: crack down on the illegal activities, and let the ordinary person get on with the business of making a living. The problem posed by this view, of course, is that with too many people chasing dwindling numbers of fish, still other conservation measures are needed, but there is less political agreement regarding what measures and how they should be implemented.

Marine Protected Areas

The basic notion behind marine sanctuaries is to rehabilitate habitat, conserve biodiversity and increase fisheries production by designating certain suitable marine areas as off-limits for human entry and exploitation. While marine sanctuaries may also be established to protect mangroves and sea grass beds, in the Philippines they are most commonly and visibly associated with the protection of coral reefs and that is their primary purpose under the CRMP. I explore here the process whereby particular coral reefs come to be designated for protection, because while the CRMP called upon each local community in San Vicente to select one or two such reefs, the final choice was left to the communities themselves, with the understanding that once sites for protection were selected, the CRMP and municipal officials would follow up with the necessary technical and legal assistance.

While conventional coastal management understandings suggest that the most suitable candidates for sanctuary status are coral reefs that are still primarily intact, some local fishers (and some local environmentalists) prefer sites that are already partially degraded, in order to allow them to regenerate (Austin 2003, pp. 297–298). A local view of marine sanctuaries as primarily about food production (rather than biodiversity conservation) is one likely explanation for such a preference; another is ease of surveillance and understandable local concern that distant sites cannot be effectively monitored against intrusion. Both issues certainly figured in community discussions of prospective sanctuary sites in San Vicente. While community selection and official (municipal) designation of MPAs (as they are known under the CRMP) are on-going, those sites that have been selected to date all center on close-in, partially-to-seriously degraded coral reefs.

These decisions highlighted an important local class difference between those fishers owning motorized pump boats able to reach relatively distant fishing grounds and those owning only smaller, oar-propelled outriggers who relied on the closer-in fishing areas. Thus those fishers who for whatever reason (usually relative poverty) relied on oar-power now found themselves significantly disadvantaged by greater travel times.

Growing public awareness of this outcome left the municipal government and the CRMP vulnerable to the politically-dangerous charge that their conservation efforts were hurting the very people that they should endeavor to assist, a charge soon found appealing by the mayor's political opponents. For their part, CRMP personnel well understood that some fishers, often those most poorly-off economically, will necessarily be disadvantaged or even displaced by successfully-implemented CRM measures. Hence the emphasis in all CRMPs in the Philippines on alternative livelihood training. The CRMP's own efforts in this regard centered on seaweed farming and the formation of cooperatives to produce coconut vinegar and bottled sardines. For now, and leaving aside matters of equity, most residents seem at best ambivalent about marine sanctuaries (see Cañete 2000, p. 200); many like the idea in principle but are concerned about community ability to effectively monitor the sanctuaries (in part a budgetary issue) and to discipline those inevitable "others" who would attempt to continue to fish in them.

Gear Issues

While as noted above gear conflicts in Philippine capture fisheries primarily reflect class differences in wider Philippine society, in San Vicente gear conflicts have ethnic dimensions as well. Thus local perceptions of the CRMP's efforts to establish marine sanctuaries in part reflected a characteristic difference between Visayan and Cuyonon capture techniques. Most Visayan residents who fish typically derive their primary livelihoods from fishing and employ motorized pump boats and various kinds of nets. Most Cuyonon residents are primarily farmers, although some fish on a part-time basis with a hook-and-line. Several Cuyonon farmers who fished part-time resented the establishment of the close-in MPAs, which they saw as unnecessarily restrictive. In their view, only the nets and other activities of Visayan fishers damage coral reefs, so why not prohibit net fishing in the proposed MPAs, and let hook-and-line fishing continue as before. For the majority of Visayan fishers who own motorized pump boats, whose interests prevailed in the selection of MPAs, the fact that their nets are excluded from the nearby, degraded reefs is no hardship for them.

Cuyonon perspectives such as these are one element of a wider local discourse that attributes much of the degradation of Palawan's fisheries to the various and increasingly efficient fish capture techniques introduced there by migrant Visayan fishers; e.g., *hulbot-hulbot* or Danish seine, a destructive fishing method that employs large weights and scarelines.

My main concern here, however, is with beach seines, a technique using a long, fine-mesh net set from a boat but hauled from the shore by two teams, one at each wing of the net, composed mainly of women and children. Use of beach seines in the Philippines is restricted by law and in San Vicente is banned by municipal ordinance and the municipality's own CRMP-inspired CRM plan. Although the ban is not presently enforced, there is general agreement among CRM experts that beach seining leads to degradation of sea grass beds, undesirable physical alteration of near-shore sea bottoms, and a high incidence and waste of by-catch.

Beach seining, however, has considerable populist appeal, and it is an important secondary (or even primary) occupation of many women and children from economically-disadvantaged coastal households. There is hence a significant gender dimension to beach seining, and in a coastal economy where men dominate the capture and, to an important degree, even the marketing of fish, female beach seiners, working either as net haulers or net owners, earn incomes from fishing relatively free of the direct control or supervision of husbands or other males. Beach seining loomed particularly large in the household economies of female-headed coastal households, and in one San Vicente community where farming predominated and beach seining was the most common fishing activity, nearly half of women surveyed reported beach seining as either a primary or secondary occupation. In consequence, any attempt by the mayor to enforce the ban on this activity is likely to prove politically costly.

Differing local perceptions of beach seining track the same ethnic division noted above, between Visayan and Cuyonon residents, although now in reverse: Visayan fishers wanted to see the practice eliminated, arguing (as environmentalists do) that beach seining captures juvenile fish that would otherwise grow bigger and move out to sea. Cuyonon and Agutaynen farmers, in contrast, many of whom profited as hog raisers from beach seining (see below) even if they did not engage in it themselves, defended beach seining as a traditional and nondestructive practice. Indeed, some joined a vigorous counter-discourse about beach seining, variously arguing that the small fish captured in the shallow ocean waters near the beach are not of the sort that grow bigger; that the fish caught with beach seines do not ordinarily live near the beach but only approach it during certain climatic conditions (a line of reasoning that explains why beach seiners sometimes capture few fish); and that periodically stirring up the ocean floor near the beach is good for the marine environment.

Discussion

The basic notion behind co-management is cooperative sharing of CRM responsibilities between local groups or communities of fishers and various levels of government. According to McCay, co-management refers to:

> …the democratization of fisheries management such that resource users have a strong say in developing the goals and rules of management. It therefore implies that the goals and needs of resource users – and by extension, their communities – are taken into account. (2000, p. 210)

Co-management was not explicitly referenced by CRMP personnel or in CRMP literature as a project goal. But both it and the other CRMPs I observed in Palawan have certainly aimed to increase local user participation in the management process, with the expectation that such participation would lead to more effective solutions to CRM problems and would otherwise improve the institutional structure of governance, and it seems reasonable to consider these projects in this perspective.

At a minimum, a viable coastal resource co-management arrangement would seem to require, on the local side, (1) the presence of appropriate local individuals able and willing to *participate*, and (2) the presence of suitable *community-level institutions* to mobilize that participation. Both "community" and "participation," of course, are problematic enough notions in the abstract. But in present-day coastal Philippine communities they become more problematic still, for the same sorts of social differences that affect how the burdens of conservation are perceived and experienced also powerfully influence how communities are constituted for CRM purposes to begin with, how institutional arrangements actually work in practice, and how the subsequent participation of differently-situated individuals takes place.

What communities "are" or should best consist of for CRM purposes is a much-discussed topic (see McCay 2000, pp. 208–210; Zerner 2000, p. 12). Helpful here is the distinction between communities of interest or "functional communities," such as fishers' organizations of various kinds, and communities of place or "territorial communities," such as the local *barangay* government units that together compose the municipality of San Vicente. In the event, the CRMP worked directly or (through the apparatus of the municipal government) indirectly with communities of both kinds, and I suspect this is typical of CRMPs in the Philippines generally. Where the aim is simply to consult with or nominally involve as many people as possible, and to ensure representation of as many different interests as possible, this is a workable enough strategy. But where the aim is to *institutionalize* CRM, such a ecumenical approach may be less helpful. Thus CRMP personnel had numerous conversations with and encouraged the participation of fishers and fishers' organizations, but because CRMP's official mandate was to institutionalize CRM at the municipal level of government such "community participation" as the CRMP called forth was ultimately assimilated to the barangay-municipality-state political grid – i.e., to the grid of government-mandated territorial communities. As a result, the customary understandings and participatory efforts of various *other* kinds of communities, be these the self-consciously organized functional communities such as fishing boat operators' associations or the unorganized "communities of interest" that track the various social divisions discussed earlier, had to be mapped on to the barangay-municipality-state system of governance – and hence to the politics of that system.

Granted, there is considerable virtue to be had in drawing territorial communities into co-management arrangements. Particularly in coastal communities where fishing is typically only one of several livelihood strategies, working with local communities of place promises to better represent the interests of those many residents who are not fishers themselves but who depend indirectly on the well-being of coastal resources (Jentoft et al. 1998, pp. 429–430; Wingard 2000, p. 53). But whatever other economic and social characteristics a Philippine *barangay* may have, it is also a unit of local government and inexorably *part* of the state – and hence should not be too easily imagined as having sufficient autonomy to "cooperate" with, much less to bargain with, the state (Li 2001, p. 164). And this is also true of the municipality. Even though the municipality can in some ways be imagined as a kind of "greater community" (this is apparently how the CRMP imagined San Vicente), it is vested with considerably more power and resources than a *barangay* and in important ways functions as a kind of mini-state, with, among other things, the municipal mayor in command of an extensive system of patronage.

This line of reasoning lies behind some of the current skepticism regarding whether local communities actually become empowered by community-based CRM programs in ways that will allow the members of those communities to gain control over local resources and the benefits that flow from them (Austin 2003, pp. 47–49). Certainly the doubts of some social scientists in these regards are matched by uncertainty (and, at times, outright confusion) among the community members themselves regarding the degree to which they as individuals are actually participants rather than bystanders.

Closely linked with the problematic definition of community, in short, is the problematic definition of participation. Not surprisingly, fishers with reservations about particular CRM measures or proposals do not usually say "I'm going to be hurt by that," but rather, "*we're* going to be hurt by that," implicitly referencing other, presumably like-minded people – hence my emphasis on social divisions and positionality. But in the case considered here, fishers with CRM-related objections or concerns also sometimes claimed that they had not *participated* in the relevant decision-making process, even though (as these same fishers would point out) it was ostensibly participatory, and indeed, numerous local community meetings were held. Thus, regarding the earlier-discussed designation of marine protected areas, fishers who relied on oar rather than on motor power did not simply feel that they had lost a vote; they felt that their voices and concerns had not received adequate hearing.

There are, to be sure, considerable logistical difficulties in making the residents of an entire municipality feel they have meaningfully participated (or had the opportunity to participate) in discussions of proposed CRM initiatives. And an important cultural factor is operating here as well. Some of the complaints I heard from local residents were strongly reminiscent of the traditional system of electoral politics, whereby candidates for office are expected to appeal to voters in person for their support. But whatever the reasons, the fact that large numbers of local residents did not appear to feel participant in or ownership of the CRMP became easily exploitable by the mayor's political opponents, a circumstance that has threatened to undermine some of the project's substantial accomplishments. For the many coastal residents for whom social justice is a matter of everyday concern, there was a "politics-as-usual" unfairness about the way the CRMP unfolded.

Agarwal's typology of six different forms of participation in community-based forest management programs, ranging from "nominal" and "passive" participation to "active" and (ultimately) "empowering" participation is helpful here (2001, p. 1624). Much participation in CRMPs projects in Palawan, despite the ubiquitous "community-organizing" of government and NGO project sponsors, remains at the lower end of this scale, suggesting that the efficacy of community participation is still a matter in need of attention. And if this is true of community participation in general, it is also true, as Natcher and Hickey remind us, of the participation of women, the poor, and other local community members most at risk of subordination by local-level and possibly "top-down" political processes (2002, p. 351).

This is where new institutional arrangements are called for (Agrawal and Gibson 2001). At the same time, however, co-management is itself

> not so much about the rules per se as it is about the communicative and collaborative process through which these rules are formed: who participates, how debates are structured, how conflicts of interest are addressed, and how agreements are reached. (Jentoft et al. 1998, p. 427)

These are the elements that were to an important extent lacking in the CRMP initiative. As a government-sponsored project, it was perhaps to be expected that the CRMP would work primarily within the existing institutional environment. Indeed, the CRMP's carefully-crafted "PRO-CRM" plan to turn CRM responsibilities over to a long suite of existing municipal and provincial government agencies following its own termination made a great virtue of working in this fashion. But even CRM-involved NGOs, despite a certain amount of antiestablishment rhetoric, may display a similar zeal to work within existing institutional structures, in part perhaps to seek legitimization within those structures. Thus Haribon Palawan, a UNDP-funded NGO helping fishing communities on Palawan's Honda Bay to establish fish sanctuaries, helped set up formal "fish sanctuary management boards" whose memberships consisted of representatives from several local government units (e.g., the Bureau of Fisheries and Aquatic Resources); POs (peoples organizations, particularly local fishers associations); NGOs (including Haribon); "academe" (the local public school, and a provincial university); cooperatives; and the religious, youth, tribal, and private "sectors" – a virtual roll call of established political and social groupings in the rural Philippines.

Both the PRO-CRM and the sanctuary management board arrangements may have seemed, at the time, to be institutionally innovative. But quite apart from the bureaucratic obstacles that such unwieldy arrangements pose to getting anything done at all, they seem guaranteed to ensure that the existing institutional inequities in wider Philippine society will continue to be projected on to local developments (see, e.g., Lawrence and Bryant 2003). According to Natcher and Hickey,

> despite enhanced local involvement in resource management, final decisions often remain reflective of only the dominant modes of prevailing power at the time, thereby muting alternative perspectives, insights, and systems of knowing. Consequently, by failing to account for community pluralism, local efforts all too often only soften the traditional top-down relationship long inherent in resource management, resulting in the continued subjugation of values and concerns of some community members. (2002, p. 351)

In sum, perhaps too confident in their knowledge of where the collective coastal resource good lies, CRMP sponsors in Palawan have devoted insufficient effort to working with local people to determine where the greater social good lies, and to how existing institutional arrangements might best be strengthened or altered to promote social justice. Absent more strenuous efforts to channel greater power and authority to the weakest and most poorly represented local groups the efficacy of community participation will remain limited and effective co-management regimes will prove difficult to institutionalize.

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Causes of Deforestation in Central Maine, USA

James M. Acheson and Jon McCloskey

Introduction

Deforestation is taking place in many parts of the world, and forests are being cut at an unsustainable rate. In some areas, forests are being completely destroyed and the land converted to other uses such as industry and agriculture. In areas where forests remain, their aggregate value has been decreasing. Moreover, the species composition of many forests has changed considerably. As a result, the incomes of forest users have decreased; erosion, silting of streams and flooding have increased; and wildlife habitat is being destroyed (Moran and Ostrom 2005, pp. 1–3).

Deforestation has been attributed to a variety of different factors, ranging from conversion to agriculture and population growth to corruption and poverty. The fact that such different causes are cited strongly suggests that the processes involved in deforestation in one area may not be operating in others, and/or that multiple factors are involved. More important, such a list hints at, but does not clearly delineate social, cultural, and economic factors motivating people to overexploit forests. If we hope to conserve forests, we must understand the reasons that people are destroying them.

In Maine, different types of people with very different motives have denuded the forests over the past 40 years. Here we first describe the events of the 1970s and 1980s, when the forests of northern Maine were being heavily harvested by the paper companies, which owned most of this land at that time (Lansky 1992, p. 44). Second, we analyze the situation in central Maine after 1991, where other types of owners were motivated to cut their forests. Insight into what is happening in this area comes from an analysis of data on 16 towns in central Maine where our change detection satellite study showed that the most biomass loss has been occurring. Interviews with owners

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The original article *Causes of Deforestation: The Maine Case* appeared in *Human Ecology* Vol. 36, No. 6, December 2008.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*,
DOI 10.1007/978-1-4419-5701-6_21,

of these forest parcels showed that three different types of landowners are harvesting their land heavily, and one landowner type was improving the quality of their forests. Each landowner type is responding to different combinations of factors.

Maine and its Forests

Forests are the most important natural resource in Maine. With 25 million acres of land in its borders and over 90% of that area currently covered with forests, Maine has the highest percentage of forested area of any state in the nation (Nadeau-Drillen and Ippoliti 2006). Approximately 88% of forest is in private hands.

The southern part of the state is heavily populated, urbanized, and relatively highly industrialized. Most of the arable land was cleared for agriculture by the middle of the nineteenth century, but in the twentieth century, this has reverted to woodlands as agriculture declined. The forests are a mixture of deciduous and coniferous trees. Maple, birch, spruce, and white pine are the dominant species in many areas. Most of these forests are held by small landowners whose main income is not connected with the forest products industry.

The northern half of Maine is the largest contiguous forested area in the United States east of the Mississippi. The population is sparse, and the landscape is dominated by spruce-fir forests, punctuated by very large lakes (McWilliams et al. 2004, p. 27). Most of this land has never been cleared for agriculture. Forest products constitute the largest industry, and the only large industrial plants are the seven paper mills scattered over the region. From late in the nineteenth century to the end of the twentieth century, virtually all of this land was owned by 20 timber and paper companies which used the forests on their vast holdings to provide pulpwood for their plants. Since the mid 1990s, most of these lands have been sold to other organizations and corporations interested in investing in real estate or timberlands.

Maine Forest Landowners

In the literature on forests, landowners are commonly classified into five different types.

1. *Industrial landowners*: In Maine, these are the paper companies, which are multinational corporations with headquarters out of state and even abroad. These companies now own nine large mills around the state, producing paper and paper products for the national and international markets.
2. *Large non-industrial landowners* own large tracts of land in the northern two-thirds of the state. Two kinds of companies fall into this category. First are timber companies, many owned by "prominent" Maine families who have held land for decades, which produce sawlogs to sell to sawmills or cut into lumber in their

own mills, and pulp wood, which is sold to the paper companies. Second are the Real Estate Investment Trusts and companies, REITs, which have their land managed by Timber Investment Management Corporations (TIMOs). The REITs are large banks, insurance companies, and trusts of various kinds with headquarters in large U.S. cities.

3. *Private landowners*, commonly called NIPFs (non-industrial private forests) in some of the forestry literature, own less than 5,000 acres of land. There are an estimated 222,000 NIPFs in Maine (McWilliams et al. 2004, p. 17). Most NIPFs are owned by Maine residents and are concentrated in the southern part of the state.
4. *Forest contractors*, about 30 in the state, make their living by buying up wood lots, cutting the timber, and then selling the lots. Contractors are distinct from "loggers," who are generally hired by landowners to harvest their trees.
5. *Other*: This category includes a number of different kinds of entities, including the state and federal governments, universities, Indian tribes, and non-governmental organizations such as the Audubon Society and the Nature Conservancy.

The Economics of the Forest Products Industry

The returns on forest investment in the central region and elsewhere in Maine are currently very low and there is little incentive to maintain forest land for wood products. Much more can be earned by converting the land to alternative uses. One official of the Maine Forest Service (personal communication) pointed out that in 2006, an acre of average land can produce about one-half cord of wood per year – about $20 or 2% of the cost of an average acre of forest land. At the same time, land values are rising rapidly. Unimproved forest land in the central Maine area is appreciating about 8–10% per year. A forest parcel costing $1,000 per acre in 2006 would have sold for about $500 per acre in the mid 1990s.[1]

Under these conditions, there are strong incentives to cut the forest or convert the land to another use. According to officers of the Maine Forest Service, both are occurring on a large scale: "The financial returns on long-term forest management do not justify either retaining forest land if other uses (e.g., development) are possible or practicing long-term silviculture" (Mansius 2005, p. ix). But the rapid increase in land prices also means that it is rational to retain land as an investment. Some people are buying and holding land to make a profit by selling it at a much higher price rather than for the value of annual timber sales.

[1]There is great variation in the price of land depending on road or lake frontage, access, area in wetlands, availability of electricity and the value of the wood. Area realtors reported asking prices between $35,000 and $125,000 for 50 acres.

Heavy Harvesting in the 1970s to the 1990s

McWilliams (1997, p. 18) summarized the state of the forests in the early 1990s: "… the area of timberland has remained stable, total growing stock volume decreased by 7%, and the current growth to removals ratio was 0.8 to 1," indicating that for every cord of wood cut only 0.8 cords are growing back. However, softwood was being cut at twice the rate it was growing back. The annual harvest rate figures also indicate the forests were being cut heavily. As a result, the forest is younger; there has been considerable change in the stand class sizes; and the species composition has been changed. Between 1959 and 1995, the percentage of land in large saw timber decreased from 39% to 34%, while the amount of forest acreage in seedlings and saplings rose from 14% to 25% (McWilliams 1997, pp. 177–178; Gadzik et al. 1998, pp. 3–4). Between 1982 and 1995, there was a 20% decrease in the area of spruce/fir timberland along with a 16% increase in northern hardwood stands (Seymour and Lemin 1989; Irland and McWilliams 1997; McWilliams 1997). The quality of trees also decreased – a 46% decline in the amount of high quality red spruce and balsam forests, as well as a decline in the high quality hardwood forests. Officers of the Maine Forest Service showed that the rate of cutting in the late 1980s and early 1990s was not sustainable, and if it continued, the growth to removals ratio would be negative well into the twenty-first century.

This deplorable situation in Maine as a whole was due in large part to very heavy cutting in northern Maine, where the cut to growth ratio averaged 2 to 1, although in some areas it was as high as 3.6 to 1. Two important factors need to be taken into account in interpreting these figures. First, there is general agreement among those familiar with the forest products industry that the amount of acreage cut had been under-reported. Second, these figures were compiled only a few years after a severe outbreak of spruce budworm disease that resulted in a lot of heavy salvage cutting.

The Paper Companies in Northern Maine: Economic Pressures and Cost Cutting

The heavy cutting of northern Maine forests was being done by the paper companies, the largest landowners in the region. The timber companies, who owned much less land, did not cut their land as hard. Several factors played a role in the paper companies' heavy harvesting of their forests. By the 1970s, the Maine paper industry was coming under heavy competition, which has continued to this day. Demand for paper was down, the price for paper was low, and production costs were lower in plants in other parts of the country and the world.

In response the paper companies employed four cost cutting strategies. First, they reduced the size of their labor force so that between 1992 and 2003, employment in the forest industry declined 30% (Innovative Natural Resource Solutions LLC 2005, p. 10). Second, they kept investment in mills as low as possible. As a result, there is not a single state-of-the-art paper mill in Maine, and many still running use equipment built in the 1940s or even earlier. Third, the companies increased efficiency and cut costs per unit of output by running their mills continually, even on national holidays. Fourth, the paper companies began cutting their forests heavily using low cost techniques such as clear cutting, poor quality partial cuts, and herbicide spraying (Lansky 1992 p. 6149). While clear cutting has received the most notoriety in the media, the most damaging practice is poor quality partial cuts, so-called "high grading," in which the good quality big trees are taken, leaving small, diseased, deformed trees which then become the breeding stock (Irland 1999 p. 98).

Industrial Downsizing, Forest Divestment and Liquidation Cuts

During the 1970s and 1980s all of the paper companies that had been in Maine for decades (Brown Company, Great Northern Paper Company, International Paper Company, Saint Regis and Scott) left and their assets were purchased by other paper companies. In the 1990s, the paper mills at Augusta, Gardiner, Pejepscot, and Winslow were closed, followed by mills at Brewer and Old Town in 2004 and 2005 respectively. In addition, several other mills have been substantially downsized, including those in Millinockett, East Millinockett, Rumford, and Westbrook. At the same time, the paper companies sold virtually all of their forest land. Between 1990 and 2000, approximately 11.1 million acres of forest land changed hands in transactions of 10,000 acres or more (Nadeau-Drillen and Ippoliti 2006, p. 3), representing about 44% of Maine – a massive sell-off. The paper companies that remained entered into a variety of long-term contracts to get the pulp wood from other companies (McWilliams et al. 2004, p. 17).

Much of this land was purchased by the REITS and TIMOs. Smaller amounts were sold to conservation organizations, such as the Nature Conservancy, and to some of the large forest contractors. In many cases forest parcels were subject to multiple sales, and while in all cases the land remained in forest, this blizzard of transactions did not lend itself to maintaining well-stocked forests. All too often, paper companies would clear-cut a piece of land or harvest it very heavily before selling it – a strategy called "liquidation cutting" – which provided income from both the trees and the land. Even though the price of heavily cut-over land was lower than for well-stocked land, the difference was small enough to make this a very profitable strategy. Heavy cutting makes it impossible to harvest trees from the land for several decades. But a company selling all its assets and leaving Maine will care little for the future productivity of forests.

However, even the paper companies that remain are still selling their forest land. This strategy is more difficult to understand, since harvesting land they owned provided a hedge against wood shortages and sudden price jumps. Two explanations have been offered by knowledgeable observers. First, the value of timber land has climbed greatly in the past two decades, so that companies could obtain badly needed cash by selling "overvalued" land (Hagen et al. 2005, p. 1). Second, selling forests may also make sense from the point of view of corporate headquarters. The returns on investment in forests are low, which reduces stock prices, but the value of land has risen dramatically. If public companies' stock prices are low and their assets are high, they are vulnerable to take-over attempts. Thus, even though this makes them dependent on other firms for pulpwood, selling forests may be completely rational in an era when land values are increasing.

Deforestation After 2000: The Central Maine Situation

Given the results of the 1995 forest inventory, we expected that the area where the biomass had decreased the most would be in northwest Maine. Instead, our satellite study in 2006 indicated that the largest decrease in biomass had occurred in central Maine – most notably in townships in northern Kennebec County and southern Somerset County. Our study of forests and landowners in this area revealed that the factors causing deforestation in this part of the state were very different from those in the north. The area where a large proportion of biomass had been removed includes 16 townships in central Maine (see Fig. 1). In the southern part of the study area, where towns such as China and Benton have become heavily suburbanized in recent years, there are a good many houses built along rural roads. Here, virtually all forest parcels are privately owned by small landowners. However, there is also still a fair amount of agriculture, and some of the largest dairy farms in the state. The northern part of the study area, however, is decidedly rural, sparsely populated and undeveloped, with little agriculture and larger forest parcels, many owned by the large timber companies or investment companies.

Satellite Study Methodology

We used LandSat TM satellite imagery captured on several dates to develop change detection maps of the central Maine area. The acquisition dates of the LandSat scenes (1991, 2000, and 2005) corresponded to periods after the Maine Forest Practices Act and during periods of significant land ownership change (Jin and Sader 2006). All LandSat TM images were rectified using USGS 1:24,000 scale topographic maps and image-to-image rectification (Jin and Sader 2006). Changes in forest biomass were detected using the Normalized Difference Moisture Index (NDMI). NDMI was selected because it closely tracks changes in plant biomass.

Using the appropriate techniques, we identified all the large sites in this 16 town area where the biomass had been reduced. The location of these sites was described using UTM coordinates. There were 41 such sites all told. (We use the term "site" to refer to locations identified by satellite and "parcel" to identify owned pieces of land which have legally defined boundaries and for which a deed has been issued.)

The PI (Acheson) located all these sites using a handheld GPS unit, visited them, and photographed the forests on each (as close to the UTM coordinates as possible)

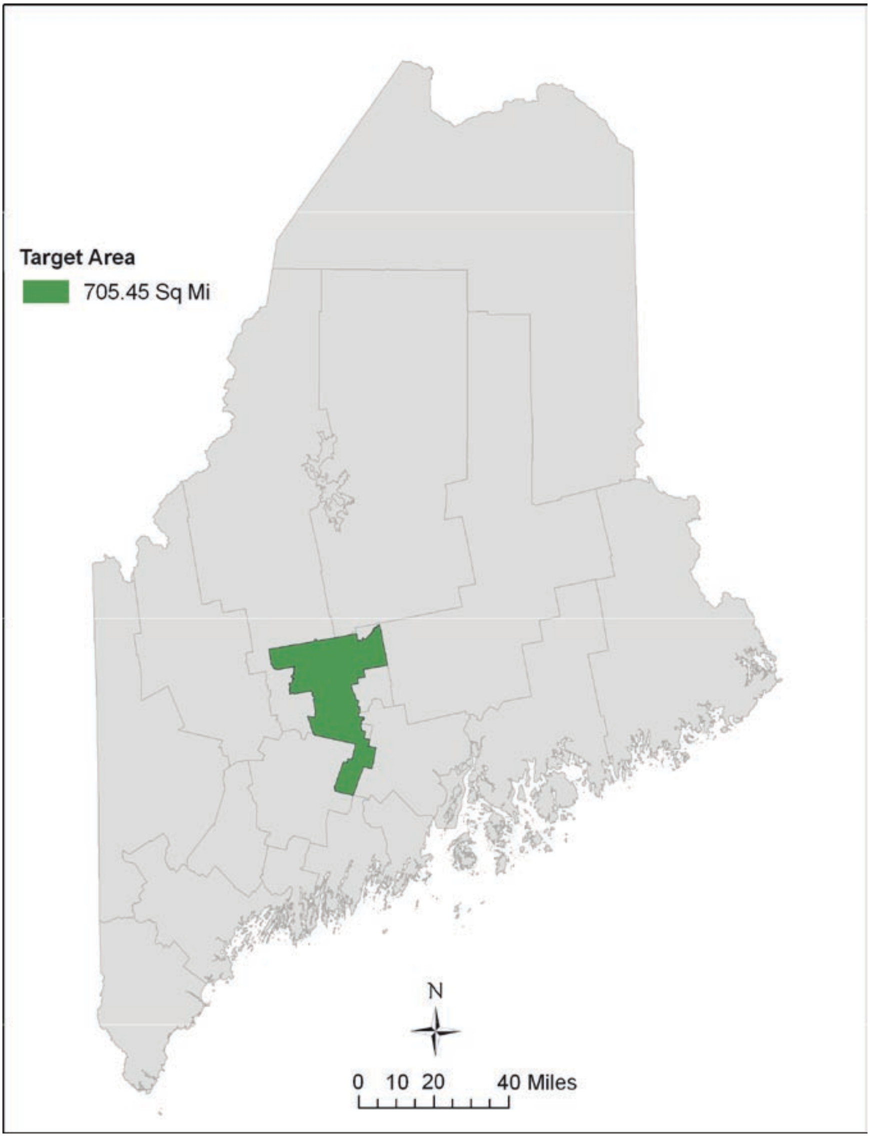

Fig. 1 Central Maine study area

to assess their current condition. He then got the names of the owner(s) from the respective town offices, and interviewed the landowners either in person or by phone. (Land ownership records are public.) Two kinds of information were gathered from all respondents using a structured interview form: personal information on the owner (i.e., residence, age, education, place of employment, etc.), and information about the way the forest parcel had been managed (size of parcel, legal owner, harvest history, future plans, etc.). These data were coded, and analyzed using SPSS. Many of the questions were precoded; the open ended questions were coded after the interviews were completed.

Results of the Central Maine Study

After visiting these 41 sites, it became apparent that there were 50 landowners involved because nine were held by two different landowners. Our survey revealed that 30 of these forest parcels were NIPFs. Another 13 were owned by forest contractors, and five were owned by large non-industrial forest owners (REITS, TIMOS and timber companies). Only one of the 50 parcels was owned by an industrial forest owner. None of the parcels is owned by any organizations in the “other” category. With the exception of the contractors who usually have their own crews, most of these landowners hired local loggers to harvest their wood. Loggers generally have small crews (three to five people) and two or three harvesting and log hauling machines. They typically do not own much land, but earn most of their income by cutting forests owned by others.

Twenty-one of the 50 forest parcels have been or are being converted to non-forest use and of these, three are owned by businesses. One is constructing a large industrial facility while the other two are operating recreational facilities. In all three cases, most of the trees have been stripped from the part of the property being developed. Another nine of these 21 have been cleared (or partially cleared) for housing subdivisions and divided into multiple lots where houses or cottages are being or will be built. Eight of the nine subdivisions are being built on land with no shore frontage, and on these lots the houses will be permanent, year-round houses. The other subdivision is being built along the shore of a large lake, where both year round and vacation homes have been or are in the process of being constructed. Another seven parcels have had houses built on them in the past few years. While most of the land on these parcels is forested, a sizeable proportion has been cleared. Another two forest parcels have been harvested by contractors and are being sold. They are likely to be converted to housing. In short, 21 of 50 or 42% of the forest parcels have either been converted to non-forest use or are likely to be converted to non-forest use.

Of the 29 parcels remaining in forest, only 12 have been lightly cut and remain well stocked with trees. The other 17 have been heavily harvested, in many cases high graded and all of the valuable trees taken, leaving only deciduous trees. In other cases, only small and undesirable trees remain. In five cases, land has been clear cut. In two of these, the landowner is converting some forest land into field. In another two, owners are clear cutting a few acres of their forest each year, leaving ample trees adjacent to the clear-cuts so that good regeneration can occur. The other involves a very unfortunate case in which a 40 acre parcel was clear cut illegally by a logger without the owner’s permission.

With the exception of the single illegal clear-cut, all the 29 parcels remaining in forest have been left with enough trees to meet the minimal stocking standards required by the Forest Practices Act. But state regulations require that only a minimum amount of trees remain on an acre (35 basal feet or about five to six cords of wood).[2] In some cases, there is little more than this remaining.

Buying, Selling, and Harvesting: Strategies of Central Maine Landowners

Farmers

Of the 50 forest parcels, 39 were or had been owned by farmers. After 1920, as farming and timber harvesting became less and less profitable, these people turned to other occupations, and no small number moved to other regions of the state or other parts of the country (Russell 1976, p. 393, 517). In some cases the family farms or forests were maintained in the hands of family members for generations. Gradually, however, most of the land has been sold. Of the 50 parcels in our study, only five were inherited by the current owner from parents or other relatives. One parcel is held by a person whose family has owned it since 1864.

Interviews with these five owners and data gathered on another 26 landowners from established families who sold family land revealed that in general they are torn between sentiment and practical necessity. For many, attachment to their forest land appears to be especially strong if the land has been in their family for a long time. However, they also are very pragmatic and view their land as a source of income. Many want to hold the land in the family, but in the meanwhile the land is appreciating in value and they will harvest wood from it periodically for income.

Owners of these NIPFs will sell family land under certain circumstances: to supplement retirement income, for emergencies, or for pressing consumption needs, including college tuition. Others sold when they moved away and these people often harvested their trees first. There is a strong incentive to do so, since even heavily harvested land is bringing unheard of prices by Maine standards (i.e., $800 to $1,200 per acre).

Family farm land is being bought by four categories of people: businessmen, home owners, contractors, and large forest landowners.

Local Businessmen

A few forest parcels are bought (or inherited) by people best described as local businessmen. Sometimes they use the land for a business or recreational facility; in

[2] Basal area refers to a cross-section of a tree at 4.5 ft from the ground. Thus, a tree with a diameter of 13 in. has a cross section that represents about one basal foot of wood. If an acre of land has trees with 13 in. diameters every 12 ft, then there will be about 300 trees/acre. Thus, an acre meeting only minimal stocking standards will have 35 such trees, or about 12% of what a well-stocked acre will have.

other cases, they keep the land as an investment, hoping to sell it for a profit due to the rise in land values. Many parcels purchased by these people are close to cities or along commercial highways.

Home Owners and Developers

Many small parcels – especially those within a half an hour drive of larger cities – are bought by permanent Maine residents to build year round houses. Many parcels in more remote regions are bought for vacation homes. This vacation property is very expensive by Maine standards. A lake lot in central Maine costs at least $100,000. In all cases, the land is being transferred from farmers and local people of modest means to middle class people with far larger incomes, many from the cities and other states, who have very different attitudes to the land. These middle class newcomers are not maintaining or holding land for profit, as was apparent from our summer 2005 survey of small forest landowners. When asked “Why do you own forest land?” the majority said the most important reason was “privacy and esthetic values;” the second was to “conserve wildlife and nature;” the third was “legacy for the family;” and the least important was “income from timber sales.” Many of these people have built houses in rustic rural locations and they do not want their houses surrounded by stumps and slashed vegetation. However, these new owners are fully aware that their land is appreciating rapidly.

Some new owners have a strong interest in forestry and conservation and spend a lot of time improving their forests. Interviews with vacation home owners revealed that they all plan the cutting of their forest land. Most will use high quality selection cuts to harvest their wood, while others will do little more than thin the stands and remove diseased trees.

Contractors and Loggers

In the recent past, contractors were responsible for some of the worst forest harvesting in Maine. They cut very large amounts of land without meeting minimal stocking standards and with no concern for conservation or acceptable forestry practices, leaving many parcels without enough trees to harvest for decades. Unfortunately, their practices were completely rational. By stripping all the harvestable trees from a parcel and selling the land as quickly as possible, contractors maximized profits by avoiding the costs of high quality silviculture and long-term investment in slow-growing trees, as well as the costs of keeping the land. This strategy of liquidation harvesting passes the costs of unsustainable cutting onto future owners and the public.

Since the 1990 Forest Practices Act, contractors’ harvesting practices have improved. They are no longer clear-cutting much land, and some practice reasonably good forestry. Others, however, are still cutting barely within the law, and are responsible for much of the heavy exploitation going on in our study area. All the 13 parcels owned by contractors have been harvested in the past seven years. On six parcels a minimal amount of trees remains; two involve small clear-cuts. Only two parcels have been lightly cut, and these are being offered for sale as vacation home property. In other parts of the state, contractors are taking all the high grade timber and leaving enough small, malformed or diseased trees to avoid the accusation of clear-cutting.

In our central Maine study area, most, but not all, of the loggers and contractors are still turning over their land rapidly. Ten of the 13 parcels owned by contractors were on the market or had been sold recently. In addition, four of the housing developments are owned by loggers. The forests on these development parcels have been cleared or partially cleared by their owners, the land is surveyed into house lots, and the lots are now being offered for sale. In other areas of the state, contractors are harvesting trees and dividing up land into large lots, which are then being sold to the public. Many of these developments are sold in 40 acre lots to people who want to use them for hunting camps.

In summary, while "cut and run" does not characterize the activities of all the contractors in our study area, many do try to avoid the costs of holding forest land for long periods of time – a longstanding strategy of contractors.

Large Landowners

Six of the 50 parcels in our study area are owned by large firms: one by a paper company, the other five by timber companies or REITs. These new owners have been in Maine for such a short period that little is known about their strategies and what their long-term effect on the forests and timber management will be (McWilliams et al. 2004, p. 7). Knowledgeable observers say that they buy forest land because it is an asset that will lower risk, since returns on forest operations usually go counter to the economy in general, so stocks in forest companies even out portfolio returns. These companies are more interested in maximizing the gains of long-term investment and less interested in annual sales of timber and pulpwood. The new large landowners are probably not planning to hold Maine land far into the future, perhaps only 10 or 15 years.

Some of these organizations have already left Maine. Hancock Investment bought 650,000 acres of land in 1993 and sold all of it by 2004 because, according to one informant, high company officials were "appalled at the low returns to be earned" on forest investments. Other recent purchasers of large amounts of land are cutting their forests heavily. One timber company in central Maine is leaving about 10 cords per acre after harvest; high quality selection cuts leave about 15–20 cords per acre. Another has cut its land so heavily that it has been severely fined for violating the Forest Practices Act (Natural Resources Council of Maine 2006; Miller 2007).

Plum Creek, a timber company that recently bought a lot of land, is proposing to develop 900 lots for vacation homes and two resorts on its land bordering Moosehead Lake, the largest lake in Maine. As part of this plan, Plum Creek would place 425,000 acres in a forest easement, stipulating that this would never be developed and that the public would have access to it for hunting, hiking, and camping. Currently, the Maine Land Use Regulation Commission (LURC) is holding hearings on this controversial proposal, which is the largest development ever considered by this agency. At least one other large company is developing plans for a large resort in the same county.

In summary, in central Maine many forest parcels are being heavily harvested by old NIPF owners, contractors, and timber companies. Moreover, 21 of the 50 parcels in our study area are being converted to non-forest use (e.g., housing, industry).

Deforestation in State-Wide Perspective

In Maine deforestation involves two very different processes: forest conversion and massive harvesting over large areas. Forest conversion occurs when forested land is cleared and converted to non-forest use. Most conversion in Maine is the result of housing and industrial development on a massive scale in the southern part of the state, where sprawl is now a major problem. Increasingly, people are living in rural areas and commuting to work. Over the past 30 years, the fastest growing towns in Maine have been "new suburbs 10–25 miles from metropolitan areas... [which] have accounted for virtually all of the state's population growth" (O'Hara 1997, p. 5). The population in these towns is not clustered into high density neighborhoods but is spread out along rural roads.

The problem of sprawl is moving north and is clearly affecting the towns in our central Maine study area where fully 42% of forest parcels harvested were being converted into housing developments or industrial use. Sprawl not only takes land out of timber production but also brings a number of other problems, ranging from habitat fragmentation to destruction of wildlife. A recent U.S. Forest Service report concludes that there are 20 watersheds in the United States where the forests are truly endangered by housing development. Two are in Maine: the lower Penobscot and the lower Kennebec (Stein et al. 2005). Part of our study area is certainly in the lower Kennebec watershed.

The second cause of deforestation is heavy cutting. Large areas of forest in northern Maine were heavily cut by paper companies using poor quality harvesting methods. Thousands of acres were clear cut which caused a number of problems ranging from erosion and silting of streams to changes in wildlife habitat and species composition. Most important, it resulted in a very young forest. In 2004, 25% of the forest area in Maine was in saplings and another 43% was in poletimber (McWilliams et al. 2004, p. 3). This means that 68% of the forest land, much in the northern part of the state, is covered with trees so small they cannot be sawed into timber.

But the figures on forest condition and quality give only part of the reality. Fifty years ago, the north had extensive regions of pristine wilderness; the senior author, canoeing the 150 miles from Greenville on Moosehead Lake to Fort Kent at the northern tip of Maine, saw only a handful of people. Today, the forested regions of central and northern Maine are studded with hunting cabins, gravel pits, and patches of cut-over land covered with brush. Many of the lakes are ringed with cottages. The whole region is crisscrossed by logging roads and hiking, ATV, and snowmobile trails. There are no stands of old growth forest and virtually no places where one can hike or canoe for 10 miles without running into evidence of humans.

Maine may be going counter to trends in much of New England, North America, and Europe where deforestation has given way to reforestation (Rudel 1998; Falconi 2007). Even though a lot of land is reverting to forest from agriculture, this is "balanced out by the amount of land being taken out of forest by housing development and sprawl" (McWilliams et al. 2004, p. 7). Perhaps worse, the remaining forests are younger and of poorer quality. The abandoned farm land reverting to forests will not produce marketable-sized trees for decades.

Remedial Legislation

By the 1990s, several well-publicized events had convinced much of the public that Maine's forests were being poorly managed and overexploited – especially by the paper companies. In response, the Maine Legislature passed a number of laws to conserve the forests and the environment. Several deserve mention.

1. The Land Use Regulation Commission (LURC) was created in 1970 to serve as a "combination planning board and zoning authority for the 10.4 million acres of Maine lying outside any town or city boundary" (Clark 2005, p. 67). In an effort to limit siltation, the LURC passed rules prohibiting cutting trees along all waterways.
2. The *Tree Growth Tax Law* (1972) was designed to give an incentive to maintain forest land and promote high quality forestry by lowering the taxes of landowners who sign a contract to manage their land sustainably and hire a forester to plan and supervise the cutting of forest parcels.
3. The *Forest Practices Act* (1989) regulates the size of clear-cuts and promotes "sustainable forests," forbidding clear-cuts over 50 acres and mandating that a minimal number of trees be left on every acre harvested (Maine Public Law 1989).
4. In order to deal with the persistent underreporting of the amount of land harvested, the legislature passed a law requiring the State Forest Service to do an annual forest inventory beginning in 1999.
5. In 2003, the legislature authorized the commissioner of the Department of Conservation to adopt rules to substantially eliminate liquidation harvesting. The rule promulgated by the Department of Conservation states that if a logger or harvester harvests more than 50% of the volume of wood off a parcel he cannot sell that land for five years (Maine Forest Service 2004).

As a result of these measures there have been four notable changes in harvesting practices in recent years. First, large scale clear-cutting has ended. Most of the forests are being harvested using "partial harvesting or shelterwood cutting" techniques. This change almost certainly is due to the Forest Practices Act.

Second, the amount of acres being harvested in the state has increased from nearly 250,000 to more than 500,000 acres (McWilliams et al. 2004, p. 6). While some cutting may be pruning or thinning which can improve forest quality, other cutting may diminish the stock of trees and lower the value of the forest. This increase in cutting may also be due, in some part, to the Forest Practices Act as well, as firms which have responded to the end of clear-cutting by harvesting smaller amounts of trees from more acres.

Third, the amount of cutting per unit of land has declined to the point where growth and harvest rates are about equal, at 0.35 cords per acre. If the forest stock is not increasing, it is not decreasing. This is likely due to the end of the salvage cutting that followed the spruce budworm epidemic, and changes in cutting practices due to the Forest Practices Act.

Fourth, most loggers have been careful since the 1970s to avoid cutting trees adjacent to lakes, streams, and rivers. This is certainly due to the regulations of the LURC and the Department of Environmental Protection.

Theoretical Implications

In recent decades, forests in widespread parts of the world are being heavily harvested and converted to non-forest use. Many scholars concerned with the environment and conservation have recognized that deforestation is a major problem. Unfortunately, there is a strong tendency to see the causes of deforestation in terms of one or two key factors that explain all deforestation in an entire region; this does little to illuminate the incentives of landowners. This is a serious oversight, since deforestation, in the last analysis, is due to decisions of humans who have an incentive to cut trees – a problem recognized by some scholars who are concerned with the "limited ability to explain the social causes of deforestation" (Wood and Skole 1998, p. 71).[3]

The Maine case illustrates that even in a relatively small area, deforestation can have multiple causes. To explain them we need to consider complexes of factors that have motivated different landowners to cut their trees. From the 1970s to the 1990s the paper companies cut their forest land in northern Maine at an unsustainable rate. Here the deforestation was due to the spruce budworm disease in combination with shoddy forestry practices instituted to cut costs in the face of severe international competition. In addition the companies were engaging in liquidation

[3] Some explanations of deforestation involve more sophisticated analysis of multiple social and ecological variables (e.g., Moran and Brondizio 1998; Tucker 1999).

cutting to sell “overvalued” land both to get cash and to prevent takeover attempts by other companies.

The causes of deforestation in southern and central Maine are quite different. Our study shows that deforestation is due to the activities of different kinds of landowners responding to different incentives. A lot of forest land is being harvested and sold by farmers and other older long-term residents with low incomes. Some parcels were bought by developers and businessmen who cleared the forest to make way for housing and businesses; some were purchased by contractors, many of whom continued liquidation harvesting. Still other land was sold by paper companies and bought by TIMOs and REITs, which harvested heavily to get an acceptable short-term return on their investment. A bright spot is that some of this land is being bought by new NIPF owners, generally educated middle class people who are improving the quality of their forest parcels and are more interested in conservation than immediate profit. In summary, changes in forest cover are due to multiple causes and they are very complicated. Ostrom (2007) stresses the importance of understanding the cause of environmental problems in terms of complexes of variables.

From another theoretical perspective, the vast majority of resource management problems, including deforestation in Maine, are the result of “collective action dilemmas” in which what is rational for individuals leads to disaster for the society at large (Elster 1989, p. 17; Taylor 1990, p. 223). Most such dilemmas can be modeled as prisoner’s dilemma games. In the absence of rules, rational action by individual actors will bring suboptimal results for the society as a whole. This provides an incentive to enact rules and norms to constrain the behavior of individuals. The imposition of rules changes the costs and benefits of behavior and thus influences incentives and strategies (Ostrom 1999).

In collective action dilemmas, as Coleman points out (1990, p. 251), the activities of one person produce externalities for others. That is, some individuals are permitted to foist the costs of their activities onto others. It is the existence of externalities that produces the demand for rules. However, the imposition of rules will almost certainly be contentious. People whose interests are compromised by the activities of others have a strong incentive to produce rules to curb the damaging behavior; those who stand to gain in the short run have an incentive to oppose such rules.

The Maine forest situation presents a classic collective action dilemma. It was rational for several types of forest landowners to cut their forests heavily (though for different reasons). This heavy cutting was not in the long-term interests of the people of the state of Maine, who were being asked to assume the costs of several different kinds of externalities, ranging from increased unemployment and reduced recreational opportunities to stream siltation and loss of wildlife habitat. The Maine Legislature is attempting to solve this problem by devising several different kinds of rules or laws to encourage landowners to maintain and conserve their forests.

The effectiveness of these measures will depend on how well they alter incentives of resource users. The Tree Growth Tax Law, for example, is designed to give landowners an incentive to maintain their land under conditions where land is very expensive and returns from timber harvesting are low. If landowners are converting land to non-forest use when returns on forest investment are high, very low taxes would not prevent conversion. When framing effective resource management rules is the goal, understanding incentives is everything.

Acknowledgments Research on which this paper is based was funded by a grant from the National Science Foundation, project title: "Maine Forest Landowner Study." (Award No. BCS-0449529). Special thanks are due to Dr. Ann Acheson who edited and proofread multiple drafts of this article.

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Environmental and Economic Costs of Biofuels

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Introduction

With global shortages of fossil energy, especially oil and natural gas, and heavy biomass energy consumption, emphasis on biofuels as renewable energy sources has developed globally. Though it may seem beneficial to use renewable plant materials for biofuel, the use of crop residues and other biomass raises many environmental and ethical concerns.

Food and biofuels are dependent on the same resources for production: land, water, and energy. In the United States, about 19% of all fossil energy is utilized in the food system: about 7% for agricultural production, 7% for processing and packaging foods, and about 5% for distribution and preparation of food (Pimentel et al. 2008a). In developing countries, about 50% of wood energy is used primarily for cooking (Nonhebel 2005). This article analyzes (1) the uses and interdependencies among land, water, and fossil energy resources in food versus biofuel production and (2) the characteristics of the environmental impacts of food and biofuel production.

Food and Malnourishment

Based on availability of cereal grains, the Food and Agricultural Organization (FAO) of the United Nations confirms that worldwide food available per capita has been declining *continuously* over the past 23 years (FAO 1961–2006). Cereal grains

The original article *Food versus Biofuels: Environmental and Economic Costs* appeared in *Human Ecology*, Vol. 37, No. 1, February 2009.

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D.G. Bates and J. Tucker (eds.), *Human Ecology: Contemporary Research and Practice*, DOI 10.1007/978-1-4419-5701-6_22,

make up an alarming 80% of the world's food supply (Pimentel and Pimentel 2008). Worldwide the rate of increase in grain production is not keeping up with the rapid annual population growth rate of 1.1% (PRB 2007). For example, from 1950 to 1980, U.S. grain yields increased at about 3% per year. Since 1980, the annual rate of increase is only approximately 1% (USDA 1980–2006). The resulting decrease in food supply has resulted in more deaths from malnutrition than from any other cause in the world today. The World Health Organization reports that more than 3.7 billion people (56% of the global population) are currently malnourished and that the number is steadily increasing.

World Cropland and Water Resources

More than 99.7% of human food comes from the terrestrial environment, while less than 0.3% comes from the oceans and other aquatic ecosystems (FAO 2002). Of the total 13 billion ha of land area worldwide, the percentages in use are cropland, 11%; pasture land, 27%; forest land, 32%; urban, 9%; and other 21% (mostly land unsuitable for crops, pasture, and/or forests because of infertile or shallow soils or because the climate and region are too harsh, too cold, dry, steep, stony, or wet (FAOSTAT 2001)). Most suitable cropland is already in use.

As population continues to increase rapidly, there has been an expansion of diverse human activities that have dramatically reduced cropland and pasture land, for example, the development of transportation systems and urbanization. In the U.S., about 0.4 ha (1 acre) of land per person is covered by urbanization and highways (USCB 2007). In 1960, when the world population numbered only three billion, approximately 0.5 ha was available per person, an area widely agreed to be essential for the production of a diverse, nutritious diet of plant and animal products (UN 1999). China's recent explosion in development provides an example of rapid declines in the availability of per capita cropland. In China current available cropland is only 0.08 ha per capita, which provides the people with a predominantly vegetarian diet requiring less energy, land, and biomass than the typical American diet.

In addition to land, water is a vital controlling factor in crop production. Many crops require large amounts of water. For example, the production of 9 tons/ha of corn requires about seven million liters of water (about 700,000 Gal of water per acre). Irrigation provides much of the water for world food production – 17% of irrigated crops worldwide provide 40% of the world food supply (FAO 2002). Of major concern is the projected continued decline of world irrigation water because of global warming.

Energy Resources and Use

Since the industrial revolution of the 1850s, the rate of energy use from all sources has been growing even faster than the world population. From 1970 to 1995, energy use increased at an annual rate of 2.5% (doubling every 30 years) compared with annual worldwide population growth of 1.7% (doubling every 40–60 years). Developed countries annually consume about 70% of fossil energy worldwide, while developing countries, with about 75% of the world population, use only 30% (International Energy Annual 2006).

Although about 50% of all the solar energy captured worldwide by photosynthesis is used by humans for food, forest products, and other systems, it is still inadequate to meet all human food production needs. To make up for this shortfall, about 473 quads (1 quad = 1×10^{15} BTU) of fossil energy – mainly oil, gas, coal, and a small amount of nuclear energy– are utilized annually worldwide. However, the U.S., with only 4.5% of the world's population, consumes about 22% (about 100 quads) of the world's total energy output (USCB 2007).

Each year, the U.S. population uses three times more fossil energy than the total solar energy captured by all harvested U.S. crops, forests, and grasses (Table 1). Industry, transportation, home heating and cooling, and food production account for most of this. Annual per capita use of fossil energy in the United States amounts to about 9,500 L of oil equivalents – more than seven times per capita use in China, where most fossil energy is used by industry, although approximately 25% is now used for agriculture and in the food production system (Pimentel and Wen 2004).

Worldwide, the earth's supplies of natural gas and coal are considered adequate for about 40 and about 100 years respectively (Youngquist 1997; BP 2005; IEA 2007; Konrad 2007; Lunsford 2007). In the U.S., natural gas is already in short supply and projected to be entirely depleted in about 20 years. Many agree that the world reached peak oil and natural gas in 2007 and that these energy resources are now declining continuously and will ultimately disappear completely (Youngquist and Duncan 2003; Campbell 2006; Heinberg 2007; IEA 2007; Konrad 2007; Lunsford 2007).

Youngquist (1997) reports that earlier estimates based on exploration drilling of amounts of oil and gas to be found in the United States were very optimistic. Domestic oil and natural gas production have been decreasing for more than 30 years and are projected to continue to decline (USCB 2004–2007). Approximately 90% of U.S. oil resources have already been exploited.[1] The U.S. currently imports more than 63% of its oil, which makes the economy vulnerable to fluctuating oil prices and volatile international political situations.

Table 1 Total amount of above ground biomass except for some crops that include underground biomass and solar energy captured each year in the United States

Crops	901×10^6 tons	14.4×10^{15} BTU
Pasture	600×10^6 tons	9.6×10^{15} BTU
Forest	527×10^6 tons	8.4×10^{15} BTU
Total	$2{,}028 \times 10^6$ tons	32.4×10^{15} BTU

An estimated 32×10^{15} BTU of sunlight reaching the US per year suggests that the green plants in the US are collecting 0.1% of the solar energy ((Jölli & Giljum 2005); (Crop 2007b); (Crop 2007a); (Forest Service 2007))

[1] W. Youngquist, personal communication, petroleum geologist, Eugene, Oregon, 2002.

Biomass Resources

The total sustainable world biomass energy potential has been estimated at about 92 quads (10^{15} BTU) per year (Parikka 2004), which represents 19% of total global energy use. The total forest biomass produced annually worldwide is 38 quads, which represents 8% of total energy use. In the U.S., only 1%–2% of home heating is achieved with wood.

Forest area degraded worldwide each year totals 15 million ha (Forest Degradation Data 2007). Annual global forest biomass harvest is just over 1,431 billion kg/year, of which 60% is industrial roundwood and 40% is fuel wood (FAOSTAT 2005). About 90% of the fuel wood is utilized in developing countries. A significant portion (26%) of all forest wood is converted into charcoal, which causes a loss of between 30% and 50% of wood energy (Demirba 2001) and produces large quantities of smoke. On the other hand, charcoal is lightweight and cleaner burning (although dirty to handle), producing less smoke than burning fuel wood directly.

Worldwide, most biomass is burned for cooking and heating. In developing countries, about 2 kcal of wood are utilized in cooking 1 kcal of food (Fujino et al. 1999). Thus, more biomass, land, and water are needed to produce cooking fuel than are needed to produce food. However, biomass can also be converted into electricity. Assuming that an optimal yield globally of three dry metric tons (tons/ha) per year of woody biomass can be harvested sustainably (Ferguson 2001, 2003), this would provide a gross energy yield of 13.5 million kcal/ha. Harvesting this wood biomass requires an energy expenditure of approximately 30 L of diesel fuel per ha, plus the embodied energy for cutting and collecting wood for transport to an electric power plant. Thus, the energy input per output ratio for such a system is calculated to be 1:25.

Per capita consumption of woody biomass for heat in the U.S. amounts to 625 kg/year (Kitani 1999).[2] Woody biomass has the capacity to supply the U.S. with about 5 quads (1.5×10^{12} kWh thermal) of its total gross energy supply by the year 2050, provided that the amount of forest land stays constant (Pimentel 2008). A city of 100,000 people using woody biomass for electricity requires approximately 200,000 ha of sustainable forest (3 tons/ha/year), based on an average electrical demand of slightly more than one billion kWh (electrical energy [e]) (860 kcal = 1 kWh).

Air quality impacts from burning biomass are less harmful than those associated with coal, but more harmful than those associated with natural gas (Pimentel 2001). Biomass combustion releases more than 200 different chemical pollutants, including 14 carcinogens and four co-carcinogens, into the atmosphere (Burning Issues 2006). As a result of this, approximately four billion people worldwide suffer from

[2] The diverse biomass resources (wood, crop residues, and dung) used in developing nations averages about 630 kg per capita per year (Kitani 1999).

continuous exposure to smoke. In the U.S., wood smoke kills 30,000 people each year, although many of the pollutants from electric plants that use wood and other biomass can be mitigated. These controls include the same scrubbers that are frequently installed on coal-fired plants.

An estimated 2.0 billion tons of biomass is produced per year on U.S. land area (Table 1). This translates into about 32 quads of energy, which means that the solar energy captured by all the plants in the U.S. per year equates to only 32% the energy currently consumed as fossil energy (Pimentel et al. 2008b). In the U.S., ethanol constitutes 99% of all biofuels (Farrell et al. 2006), but there is insufficient biomass available for ethanol and biodiesel production to make the country oil independent.

Of the total world land area, about 38% is cropland and pasture and about 30% is forests (FAOSTAT 2001). Devoting a portion of this cropland and forest land to biofuels will stress both managed ecosystems and will not be sufficient to solve the world fuel problem.

Corn Ethanol

Fermenting and distilling corn ethanol require large amounts of water. The corn is finely ground and approximately 15 L of water are added per 2.69 kg of ground corn. After fermentation, 1 L of ethanol must be extracted from the approximately 10 L of the ethanol/water mixture to obtain a liter of 95% pure ethanol from the 10% ethanol and 90% water mixture. To be mixed with gasoline, the 95% ethanol must be further processed and more water must be removed, requiring additional fossil energy inputs to achieve 99.5% pure ethanol (Tables 2 and 3). Thus, a total of about 12 L of wastewater must be removed per liter of ethanol produced, and this relatively large amount of sewage effluent has to be disposed of at energy, economic, and environmental costs.

In terms of energy costs, production of the corn feedstock alone requires more than 33% of the total energy input. Adding this to the steam energy and electricity used in the fermentation/distillation process produces a total energy input to produce a liter of ethanol of 7,474 kcal (Table 3). However, a liter of ethanol has energy value of only 5,130 kcal. Based on net energy loss of 2,344 kcal of ethanol produced, 46% more fossil energy is expended than is produced as ethanol. The total cost, including the energy inputs for the fermentation/distillation process and the apportioned energy costs of the stainless steel tanks and other industrial materials, is $1,045 per 1,000 L of ethanol produced, or $1.05 per liter ($3.97/Gal)[3] (Table 3).

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[3] In addition, capital expenditures include new plant construction costs from $1.05 to $3.00 per gallon of ethanol (Shapouri and Gallagher 2005).

Table 2 Energy inputs and costs of corn production per hectare in the United States

Inputs	Quantity	kcal × 1,000	Costs ($)
Labor	11.4 h[a]	462[b]	300.00[c]
Machinery	55 kg[d]	1,018[e]	310.00[f]
Diesel	88 L[g]	1,003[h]	500.00[i]
Nitrogen	155 kg[k]	2,480[l]	255.00[m]
Phosphorus	79 kg[n]	328[o]	150.00[p]
Potassium	84 kg[q]	274[r]	78.00[s]
Lime	1,120 kg[t]	315[u]	60.00
Seeds	21 kg[v]	520[w]	230.00[x]
Irrigation	8.1 cm[y]	320[z]	350.00[aa]
Herbicides	6.2 kg[bb]	620[cc]	372.00
Insecticides	2.8 kg[dd]	280[cc]	180.00[j]
Electricity	13.2 kWh[ee]	34[ff]	27.00
Transport	204 kg[gg]	169[hh]	180.00[j]
Total		8,228	$2,992.00
	Corn yield 9,400 kg/ha[ii]	33,840	kcal input:output 1:4.11

[a]NAS 2003
[b]It is assumed that a person works 2,000 h/yr and utilizes an average of 8,000 L of oil equivalents per year
[c]It is assumed that labor is paid $26.32 an hour
[d]Pimentel & Pimentel 2008
[e]Prorated per hectare and 10 year life of the machinery. Tractors weigh from 6 to 7 tons and harvesters 8–10 tons, plus plows, sprayers, and other equipment
[f]Estimated
[g]Estimated
[h]Input 11,400 kcal/L
[i]Estimated
[j]Input 10,125 kcal/L
[k]NAS 2003
[l]Patzek 2004
[m]Cost $1.65/kg
[n]NAS 2003
[o]Input 4,154 kcal/kg
[p]Cost $1.90/kg
[q]NAS 2003
[r]Input 3,260 kcal/kg
[s]Cost $0.93/kg
[t]Brees 2004
[u]Input 281 kcal/kg
[v]Pimentel & Pimentel 2008
[w]Pimentel & Pimentel 2008
[x]USDA 1997a
[y]USDA 1997b
[z]Batty & Keller 1980
[aa]Irrigation for 100 cm of water per ha costs $1,000 (Larsen et al. 2002)
[bb]Larson & Cardwell 1999
[cc]Input 100,000 kcal/kg of herbicide and insecticide
[dd]USDA 2002

(continued)

Table 2 (continued)

[ee]USDA 1991

[ff]Input 860 kcal/kWh and requires 3 kWh thermal energy to produce 1 kWh electricity

[gg]Goods transported include machinery, fuels, and seeds that were shipped an estimated 1,000 km

[hh]Input 0.83 kcal/kg/km transported

[ii]Average: USDA 2006; USCB 2004

Table 3 Inputs per 1,000 L of 99.5% ethanol produced from corn[a]

Inputs	Quantity	kcal × 1,000	Dollars $
Corn grain	2,690 kg[b]	2,355[b]	856.22
Corn transport	2,690 kg[b]	322[c]	21.40[d]
Water	15,000 L[e]	90[f]	21.16[g]
Stainless steel	3 kg[h]	165[i]	10.60[d]
Steel	4 kg[h]	92[i]	10.60[d]
Cement	8 kg[h]	384[i]	10.60[d]
Steam	26,46,000 kcal[j]	2,646[j]	21.16[k]
Electricity	392 kWh[j]	1,011[j]	27.44[l]
95% ethanol to 99.5%	9 kcal/L[m]	9[m]	40.00
Sewage effluent	20 kg BOD[n]	69[p]	6.00
Distribution	331 kcal/L[o]	331	20.00[o]
Total		7,474	$1,045.18

[a]Output: 1 L of ethanol = 5,130 kcal (low heating value). The mean yield of 2.5 Gal pure EtOH per bushel has been obtained from the industry-reported ethanol sales minus ethanol imports from Brazil, both multiplied by 0.95 to account for 5% by volume of the #14 gasoline denaturant, and the result was divided by the industry-reported bushels of corn inputs to ethanol plants. (*see* http://petroleum.berkeley.edu/patzek/BiofuelQA/Materials/TrueCostofEtOH.pdf; (Patzek 2006))

[b]Data from Table 2

[c]Calculated for 144 km roundtrip

[d]Pimentel 2003

[e]Fifteen liters of water mixed with each kg of grain

[f]Pimentel et al. 2004

[g]Pimentel et al. 2004

[h]Estimated from the industry-reported costs of $85 million per 65 million Gal/year dry grain plant amortized over 30 years. The total amortized cost is $43.6/1,000 L EtOH, of which an estimated $32 go to steel and cement

[i]DOE 2002

[j]Illinois Corn 2004. The current estimate is below the average of 40,000 BTU/Gal of denatured ethanol paid to the Public Utilities Commission in South Dakota by ethanol plants in 2005

[k]Calculated based on coal fuel. Below the 1.95 kWh/Gal of denatured EtOH in South Dakota, *see* j)

[l]$0.07 per kWh (USCB 2004)

[m]Ninty-five percent ethanol converted to 99.5% ethanol for addition to gasoline (Patzek personal communication, University of California, Berkeley, 2004)

[n]Twenty kilograms of BOD per 1,000 L of ethanol produced (Kuby et al. 1984)

[o]Newton 2001

[p]Four kilowatt hours of energy required to process 1 kg of BOD (Blais et al. 1995)

Subsidies for corn ethanol total more than $6 billion per year (Koplow 2006). This means that the subsidies per liter of ethanol are 60 times greater than the subsidies per liter of gasoline. In 2006, nearly 19 billion liters of ethanol were produced on 20% of U.S. corn acreage, representing only 1% of total U.S. petroleum use (USCB 2007).

However, even if we completely ignore corn ethanol's negative energy balance and high economic cost, it remains absolutely infeasible to use ethanol as a replacement for U.S. oil. If all 341 billion kg of corn produced in the U.S. were converted into ethanol at the current rate of 2.69 kg/L of ethanol, then 129 billion liters of ethanol can be produced. This would provide only 7% of total oil consumption in the U.S. and of course there would be no corn available for livestock and other needs.

In addition, the environmental impacts of corn ethanol are enormous:

1. Corn production causes more soil erosion than any other crop grown (NAS 2003).
2. Corn production uses more nitrogen fertilizer than any other crop grown and is the prime cause of the dead zone in the Gulf of Mexico (NAS 2003). In 2006, approximately 4.7 million tons of nitrogen were used in U.S. corn production (USDA 2007). Natural gas is required to produce nitrogen fertilizer. The U.S. now imports more than half of its nitrogen fertilizer. In addition, in the same year about 1.7 million tons of phosphorus were used in the U.S.
3. Corn production uses more insecticides and more herbicides than any other crop grown.
4. More than 1,700 Gal of water are required to produce 1 Gal of ethanol.
5. Enormous quantities of carbon dioxide are produced. This is due to the large quantity of fossil energy used in production, and the immense amounts of carbon dioxide released during fermentation and soil tillage. All this speeds global warming.
6. Burning ethanol emits pollutants into air such as peroxyacetyl nitrate (PAN), acetaldehyde, alkylates, and nitrous oxide (Davis and Thomas 2006). These can have significant detrimental effects on human health as well as impact other organisms and ecosystems.

In addition to corn ethanol's intensive environmental degradation and inefficient use of food-related resources, its production also has a great effect on world food prices. For example, using corn for ethanol production has increased prices of U.S. beef, chicken, pork, eggs, breads, cereals, and milk by 10%–20%. Corn prices more than doubled during 2008.

Grass and Cellulosic Ethanol

Tilman et al.'s (2006) suggestion that all 235 million ha of grassland available in the U.S. plus crop residues can be converted into cellulosic ethanol causes concern among scientists. Tilman et al. recommend that crop residues such as corn stover be harvested and utilized as a fuel source. This would be a disaster for the agricultural ecosystem because crop residues are vital for protecting topsoil. Leaving the soil unprotected would intensify soil erosion by tenfold or more and may increase soil loss as much as 100-fold. Furthermore, even a partial removal of the stover can result in increased CO_2 emissions and intensify acidification and eutrophication due to increased runoff (Lal 2004; Kim and Dale 2005). Already, the U.S. crop system is losing soil ten times faster than the sustainable rate (NAS 2003). Soil formation rates, at less than 1 ton/ha/year, are extremely slow (NAS 2003; Troeh et al. 2004). Increased soil erosion caused by the removal of crop residues for use as biofuels facilitates soil-carbon oxidation and contributes to the problem of greenhouse emissions (Lal 2004).

Tilman et al. assume about 1,032 L of ethanol can be produced through the conversion of the 4 tons/ha/year of grasses harvested. However, Pimentel and Patzek (2007) report a negative 50% return in ethanol produced compared with fossil energy inputs in switchgrass conversion (Tables 4 and 5). Converting all 235 million ha of U.S. grassland into ethanol even at the optimistic rate suggested by Tilman et al. would provide only 12% of annual consumption of U.S. oil (USDA 2006; USCB 2007). Verified data, however, confirm that the ethanol output would require 1.5 L of oil equivalents to produce 1 L of ethanol (Tables 4 and 5).

Table 4 Average inputs and energy inputs per hectare per year for switchgrass production

Input	Quantity	10^3 kcal	Dollars
Labor	5 h[a]	200[b]	$65[c]
Machinery	30 kg[d]	555	50[a]
Diesel	150 L[e]	1,500	75
Nitrogen	80 kg[e]	1,280	45[e]
Seeds	1.6 kg[f]	100[a]	3[f]
Herbicides	3 kg[g]	300[h]	30[a]
Total	10,000 kg yield[i]	3,935	$268[j]
	40 million kcal yield	Input/output ratio 1:02[k]	

[a]Estimated
[b]Average person works 2,000 h/year and uses about 8,000 L of oil equivalents. Prorated this works out to be 200,000 kcal
[c]The agricultural labor is paid $13/h
[d]The machinery estimate also includes 25% more for repairs
[e]Calculated based on data from Brummer et al. 2000
[f]Data from Samson 1991
[g]Calculated based on data from Henning 1993
[h]100,000 kcal/kg of herbicide
[i]Samson et al. 2000
[j]Brummer et al. 2000 estimated a cost of about $400/ha for switchgrass production. Thus, the $268 total cost is about 49% lower than what Brummer et al. estimates, and this includes several inputs not included in Brummer et al.
[k]Samson et al. 2000 estimated input per output return of 1:14.9, but we have added several inputs not included in Samson et al. Still the input/output return of 1:11 would be excellent if the sustained yield of 10 tons/ha/year was possible

Table 5 Inputs per 1,000 L of 99.5% ethanol produced from U.S. switchgrass[a]

Inputs	Quantity	kcal × 1,000	Dollars $
Switchgrass	5,000 kg[b]	1,968[c]	500
S. Grass transport	5,000 kg[b]	600[c]	30[d]
Water	250,000 L[e]	140[f]	40[g]
Stainless steel	3 kg[h]	165[h]	11[h]
Steel	4 kg[h]	92[h]	11[h]
Cement	8 kg[h]	384[h]	11[h]
Grind switchgrass	5,000 kg	200[i]	16[i]
Sulfuric acid	240 kg[j]	0	168[k]
Steam	8.1 tons[j]	4,404	36
Lignin	1,250 kg[l]	−1,500	−12
Electricity	666 kWh[j]	1,703	46
95% ethanol to 99.5%	9 kcal/L[m]	9	40
Sewage effluent	40 kg BOD[n]	138[o]	12
Distribution	331 kcal/L[p]	331	20
Total		8,634	$929

[a]Output: 1 L of ethanol = 5,130 kcal. The ethanol yield here is 200 L/ton dry biomass (dbm). Iogen suggests 320 L/ton dbm of straw that contains 25% of lignin. This yield is equal to the average yield of ethanol from corn, 317 L/ton dbm (2.5 Gal/BTU). In view of the difficulties with breaking up cellulose fibers and digesting them quickly enough, the Iogen yield seems to be exaggerated, unless significantly more grinding, cell exploding with steam, and hot sulfuric acid are used
[b]Data from Table 4
[c]Calculated for 144 km roundtrip
[d]Pimentel 2003
[e]Fifteen liters of water mixed with each kg of biomass
[f]Pimentel et al. 2004
[g]Twenty kilograms of BOD per 1,000 L of ethanol produced (Kuby et al. 1984)
[h]Pimentel 2003
[i]Newton 2001
[j]Calculated based on grinder information (Wood Tub Grinders 2004)
[k]Sulfuric acid sells for $7/kg
[l]Estimated based on cellulose conversion (Arkenol 2004)
[m]Wood is about 25% lignin and removing most of the water from the lignin by filtering, the moisture level can be reduced to 200% (Crisp 1999)
[n]Ninty-five percent ethanol converted to 99.5% ethanol for addition to gasoline (Patzek personal communication, University of California, Berkeley, 2004)
[o]Four kilowatt hour of energy required to process 1 kg of BOD (Blais et al. 1995)
[p]DOE 2002

To achieve the production of this much ethanol, U.S. farmers would have to displace the 100 million cattle, seven million sheep, and four million horses that are now grazing on 324 million ha of U.S. grassland and rangeland. Overgrazing is already a serious problem on U.S. grasslands and around the world. Tilman et al.'s assessment of the quantity of ethanol that can be produced in the U.S. and worldwide and the costs of production – the cost of producing a liter of ethanol using switchgrass was 93¢ (Table 5) – appears to be unduly optimistic. Converting switchgrass into ethanol results in negative energy return of 57%, a slightly higher negative energy return than corn ethanol production (Tables 3 and 5).

There are several problems with the conversion of cellulosic biomass into ethanol. First, corn grain has two to five times more starches and sugars than the same quantity of cellulosic biomass. Thus, two to five times more cellulosic material must be produced and handled compared with corn grain. In addition, in the cellulosic biomass the starches and sugars are tightly held in lignin and can be released using a strong acid to dissolve the lignin. Once the lignin is dissolved and the acid action is stopped with an alkali, the solution of lignin, starches, and sugars can be fermented.

Some claim that the lignin can be used as a fuel. Clearly, it cannot when dissolved in water, although some – usually less than 25% – can be extracted using various energy intensive technologies (Pimentel and Patzek 2007).

Soybean Biodiesel

The U.S. annually provides $500 million in subsidies for the production of 850 million liters of biodiesel (Koplow 2006), which is 74 times greater than the subsidies per liter of diesel fuel. Vegetable oils processed from soybean, sunflower, rapeseed, oil palm, and other oil plants can be used as fuel in diesel engines, although this is costly in terms of economics and energy (Ozaktas 2000; Pimentel and Patzek 2007) (Tables 6 and 7). A slight net return on energy from soybean oil is possible only if the soybeans are grown without commercial nitrogen fertilizer. The soybean, since it is a legume, will produce its own nitrogen under favorable conditions. Still soy has a 63% net fossil energy loss (Table 7).

The detrimental environmental impacts of producing soybean biodiesel are second only to that of corn ethanol:

1. Soybean production causes significant soil erosion, second only to corn production (NAS 2003).
2. Soybean production uses large quantities of herbicides, second only to corn production (USDA 2006). These herbicides cause major pollution problems with natural biota in the soybean production areas (Artuzi and Contiero 2006; Pimentel 2006).
3. The USDA (2005) reports soybean yield worldwide to be 2.2 tons/ha. With an average oil extraction efficiency of 18%, the average oil yield per year would be approximately 0.4 tons/ha. This converts into 454 L of oil per ha. Based on current U.S. diesel consumption of 227 billion L/yr, this would require more than 500 million ha of land in soybeans or more than half the total U.S. planted with just soybeans! All 71 billion tons of soybeans produced in the U.S. could only supply 2.6% of total U.S. diesel consumption.

Rapeseed and Canola Biodiesel

The European Biodiesel Board (2007) estimated a total biodiesel production of 4.89 million tons for the year 2006. Well suited to colder climates, rapeseed is the

Table 6 Energy inputs and costs in soybean production per hectare in the US

Inputs	Quantity	kcal × 1,000	Costs $
Labor	7.1 h[a]	284[b]	112.00[c]
Machinery	20 kg[d]	360[e]	181.00[f]
Diesel	38.8 L[a]	442[g]	25.00
Gasoline	35.7 L[a]	270[h]	16.00
LP gas	3.3 L[a]	25[i]	1.00
Nitrogen	3.7 kg[j]	59[k]	28.00[l]
Phosphorus	37.8 kg[j]	156[m]	29.00[n]
Potassium	14.8 kg[j]	48[o]	6.00[p]
Limestone	2,000 kg[q]	562[d]	56.00[q]
Seeds	69.3 kg[a]	554[r]	59.00[s]
Herbicides	1.3 kg[j]	130[e]	32.00
Electricity	10 kWh[d]	29[t]	1.00
Transport	154 kg[u]	40[v]	56.00
Total		2,959	$602.00
Soybean yield 2,890 kg/ha[w]		10,404	kcal input:output 1:3.52

[a]Ali & McBride 1990
[b]It is assumed that a person works 2,000 h/year and utilizes an average of 8,000 L of oil equivalents per year
[c]It is assumed that labor is paid $13 an hour
[d]Pimentel & Pimentel 2008
[e]Machinery is prorated per hectare and a 10 year life of the machinery. Tractors weigh from 6 to 7 tons and harvesters from 8 to 10 tons, plus plows, sprayers, and other equipment
[f]Agricultural & Consumer and Environmental Sciences 1997
[g]Input 11,400 kcal/L
[h]Input 10,125 kcal/L
[i]Input 7,575 kcal/L
[j]Economic Research Statistics 1997
[k]Patzek 2004
[l]Hinman et al. 1992
[m]Input 4,154 kcal/kg
[n]Cost 77¢/kg
[o]Input 3,260 kcal/kg
[p]Costs 41¢/kg
[q]Mississippi State University Extension Service 1999
[r]Pimentel et al. 2002
[s]Costs about 85¢/kg
[t]Input 860 kcal/kWh and requires 3 kWh thermal energy to produce 1 kWh electricity
[u]Goods transported include machinery, fuels, and seeds that were shipped an estimated 1,000 km
[v]Input 0.83 kcal/kg/km transported
[w]USDA 2004

dominant crop used in European biodiesel production. Often confused with canola, rapeseed is an inedible crop of the Brassica family yielding oil seeds high in erucic acid. Canola belongs to the same family but is a hybrid created to lower saturated fat content and erucic acid content for human consumption in cooking oil and margarine (Tickell 2006).

Rapeseed-based biodiesel yields in Europe averaged 1,390 L/ha in 2005 (Frondel and Peters 2007). Using the density of biodiesel defined as 0.88 kg/L the average

Table 7 Inputs per 1,000 kg of biodiesel oil from soybeans

Inputs	Quantity	kcal × 1,000	Costs $
Soybeans	5,556 kg[a]	5,689[a]	1,157.00[a]
Electricity	270 kWh[b]	697[c]	18.90[d]
Steam	13,50,000 kcal[b]	1,350[b]	11.06[e]
Cleanup water	160,000 kcal[b]	160[b]	1.31[e]
Space heat	152,000 kcal[b]	152[b]	1.24[e]
Direct heat	440,000 kcal[b]	440[b]	3.61[e]
Losses	300,000 kcal[b]	300[b]	2.46[e]
Stainless steel	11 kg[f]	605[g]	18.72[h]
Steel	21 kg[f]	483[g]	18.72[h]
Cement	56 kg[f]	2,688[g]	18.72[h]
Total		12,564	$1,251.74

The 1,000 kg of biodiesel produced has an energy value of 9 million kcal. In addition, 200 mL (2,080 kcal) of methanol must be added to the soy oil for transesterification. With an energy input requirement of 14.7 million kcal, there is a net loss of energy of 63%. If a credit of 7.4 million kcal is given for the soy meal produced, then the net loss is less

The cost per kg of biodiesel is $1.25

[a]Data from Table 6

[b]Data from Singh 1986

[c]An estimated 3 kWh thermal is needed to produce a kWh of electricity

[d]Cost per kWh is 7¢

[e]Calculated cost of producing heat energy using coal

[f]Calculated inputs

[g]Calculated from Newton 2001

[h]Calculated

annual production of rapeseed biodiesel in Europe is 1.1 million tons total. Because of its high oil content (30%) rapeseed is preferred as a biodiesel feedstock source. While Europe currently dominates rapeseed production in the world, as the market for high-yield oilseed feedstock for biodiesel grows, interest in canola and rapeseed oil is likely to increase in many northern states of the U.S., and Canada.

Rapeseed and canola require application of fertilizers and pesticides. The energy required to make these pesticides and fertilizers detracts from the overall net energy produced. Although soybeans contain less oil than canola – about 18% soy oil compared with 30% oil for canola – soybeans can be produced with nearly zero nitrogen inputs (Pimentel et al. 2008b). The biomass yield of rapeseed/canola/ha is also lower than that of soybeans – about 1,600 kg/ha for rapeseed/canola compared with 2,890 kg/ha for soybeans. The production of 1,568 kg/ha rapeseed/canola requires an input of about 4.4 million kcal/ha and costs about $669/ha. About 3,333 kg of rapeseed/canola oil is required to produce 1,000 kg of biodiesel. Therefore, all 333 million tons of rapeseed and canola produced in the U.S. in 2006 could be used to make 100 million liters of biodiesel, or 0.005% of the total diesel oil used in the U.S. The total energy input to produce the 1,000 L of rapeseed/canola oil is 13 million kcal. This suggests a net loss of 58% of energy inputs (Pimentel et al. 2008b). The cost per kg of biodiesel is also high at $1.52. Rapeseed and canola are energy intensive and economically inefficient biodiesel crops.

Oil Palm

There is a major effort to plant and harvest oil palms for biofuels in some tropical developing countries, especially Indonesia, Malaysia, Thailand, Colombia, and in West Africa. Palm oil makes up 23% of biological oils and fats produced worldwide – more than 123.5 million tons in 2003. Indonesia and Malaysia are the world's leading producers.

Four years after it is established, the oil palm will produce about 4,000 kg of oil per ha per year (Carter et al. 2007). The data suggest that about 7.4 million kcal are required to produce 26,000 kg of oil palm bunches. This 26,000 kg is sufficient to produce 4,000 kg of palm oil. A total of 6.9 million kcal are required to process 6,500 kg of palm nuts to produce one ton of palm oil (Pimentel et al. 2008b). Thus, the net return on fossil energy invested in production and processing totals 30%. This is clearly a better return than corn ethanol and soybean biodiesel. However, an estimated 200 mL (2,080 kcal) of methanol is a required addition to the 1,000 kg of palm oil for transesterification. This results in a negative 8% net energy output for palm oil.

There are several negative environmental and social issues associated with oil palm plantations. First, the removal of tropical rainforests to plant oil palm results in an increase in CO_2. Secondly, the removal of tropical rain forests for the planting of oil palms reduces the biodiversity of the ecosystem. Finally, using oil palm for fuel reduces the availability of palm oil for human use and increases the price of the oil.

Algae for Oil Production

Some cultures of algae consist of 30%–50% oil (Dimitrov 2007). Thus, there is growing interest in using algae to increase U.S. oil supply based on the theoretical claims that 47,000–308,000 L/ha/year (5,000–33,000 Gal/acre) of oil could be produced using algae (Briggs 2004; Vincent Inc 2007). Despite all the algae-related research and claims dating back to 1970s, none of the projected algae and oil yields have been achieved (Dimitrov 2007). To the contrary, one calculated estimate based on all the included costs associated with using algae would be $800 per barrel. Algae, like all plants, require large quantities of nitrogen and water in addition to significant fossil energy inputs for the production system.

Conclusion

A rapidly growing world population and rising consumption of fossil fuels are increasing demand for both food and biofuels that will exacerbate both food and fuel shortages. Producing biofuels requires huge amounts of both fossil energy and food inputs, which will intensify competition for these resources.

Using food crops to produce ethanol raises major nutritional and ethical concerns. Nearly 60% of humans in the world are currently malnourished, so the need for grains and other basic foods is critical. Growing crops for fuel squanders land, water, and energy resources vital for the production of food for people. Using food and feed crops for ethanol production has caused increases in the prices of U.S. beef, chicken, pork, eggs, breads, cereals, and milk of 10%–20%. In addition, Jacques Diouf (2007), Director General of the U.N. Food and Agriculture organization, reports that using food grains to produce biofuels is already causing food shortages for the poor in many parts of the world. Growing crops for biofuel not only ignores the need to reduce natural resource consumption, but exacerbates the problem of malnourishment worldwide by turning food grain into biofuel.

Recent policy decisions have mandated increased production of biofuels in the United States and worldwide. For instance, in the Energy Independence and Security Act of 2007, President Bush set "a mandatory Renewable Fuel Standard (RFS), requiring fuel producers to use at least 36 billion Gal of biofuel in 2022." This would require 1.6 billion tons of biomass harvested per year and would require harvesting 80% of all biomass in the U.S., including all agricultural crops, grasses, and forests (Table 1). With nearly all biomass harvested, biodiversity and food supplies in the U.S. would be decimated.

Increased biofuel production also has the capability to impact the quality of food plants in crop systems. The release of large quantities of carbon dioxide associated with the planting and processing of plant materials for biofuels is reported to reduce the nutritional quality of major world foods, including wheat, rice, barley, potatoes, and soybeans (Southwestern University 2008). When crops are grown under high levels of carbon dioxide, protein levels in the crops may be reduced as much as 15%.

Many problems associated with biofuels have been ignored by some scientists and policy-makers. The biofuels that are being created in order to diminish dependence on fossil fuels actually depend on fossil fuels. In most cases, more fossil energy is required to produce a unit of biofuel than the energy it can produce (Tables 1–7). Furthermore, the U.S. is importing oil and natural gas to produce biofuels, which is increasing its oil dependence. Researchers promoting biofuels have used incomplete, insufficient, or entirely untested theoretical data to support their claims. Finally, environmental problems including water pollution from fertilizers and pesticides, global warming, soil erosion and air pollution are intensifying as a result of biofuel production. There is simply not enough land, water, and energy available in the world to produce biofuels.

Most conversions of biomass into ethanol and biodiesel result in negative energy return based on careful up-to-date analysis of all the fossil energy inputs. Four of the negative energy returns are: corn ethanol at −46%; switchgrass at −50%; soybean biodiesel at −63%; and rapeseed at −58%. Even palm oil production results in a −8% net energy return when the methanol requirement for transesterification is factored into the equation.

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Index