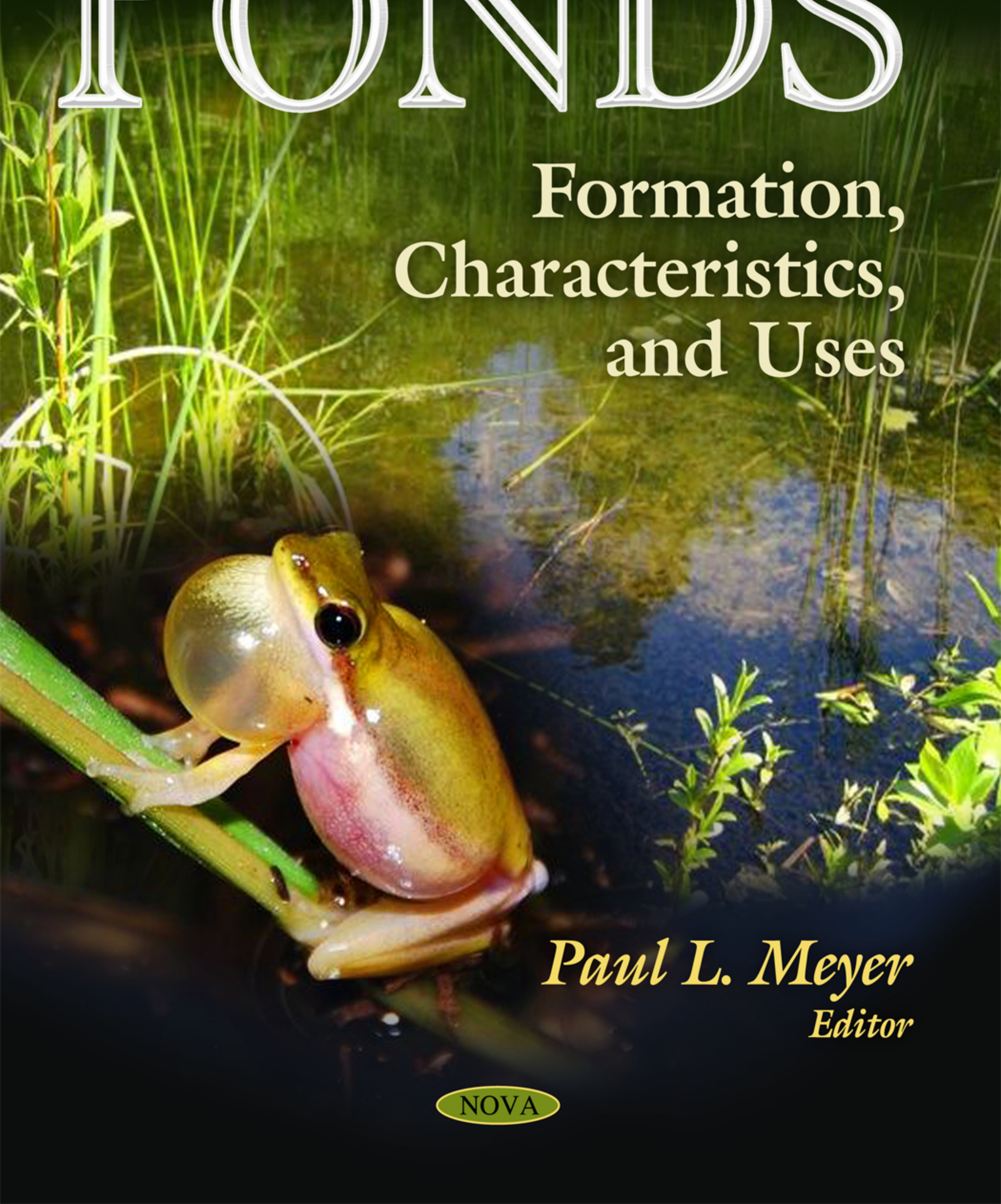
Earth Sciences in the 21st Century

PONDS

Formation, Characteristics, and Uses



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PONDS: FORMATION, CHARACTERISTICS, AND USES

PAUL L. MEYER
EDITOR

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CONTENTS

PREFACE

Most species of anurans require ponds for reproduction. This book discusses the attributes likely to influence a pond's suitability as a spawning site include factors such as vegetation, depth, water chemistry, presence of predators, hydroperiod and water chemistry. But in many landscapes, the availability of suitable ponds is limited. This book also discusses recreational and commercial pond usage in the southeastern United States, which influences nutrient and fish production making the ecological role of shallow lakes and ponds among the most threatened habitats in the world. Also explored are lakes and ponds beyond the Earth, such as the dry lakebeds on Mars and active methane-ehtane ponds on Titan, and the behavior of boundaries between gradient zone and convective zones in a salinity gradient solar pond.

Chapter 1 - Most species of anurans require ponds for reproduction. The attributes likely to influence a pond’s suitability as spawning site include factors such as vegetation, depth, water chemistry, presence of predators, hydroperiod and water chemistry. But in many landscapes the availability of suitable ponds is limited. This reliance on scarce resources makes anurans vulnerable to habitat loss. With an estimated 40% of amphibians worldwide at risk of extinction we need to increase our understanding of basic requirements such as suitable spawning sites. On the other end of the scale a large number of anurans are flourishing in environments far outside of their natural range. Many of these exotics may disturb ecosystems and pose a threat to indigenous fauna, including native amphibians. In this chapter I review pond usage by anurans in relation to the problems of amphibian declines and invasive species. I focus on pond manipulations and ways of using that as a potential conservation tool for conserving threatened species as well as controlling invasive anurans.

Chapter 2 - Recreational fishing is a popular pastime in the United States. Private stakeholders along with state and federal agency fishery managers are dedicated to increasing the productivity of their ponds to enhance this recreation. One of the procedures utilized for the attainment of maximum fish production is the application of inorganic fertilizers. In the southeastern United States fertilization is a widely accepted management tool. The purpose of fertilization is to increase phytoplankton production, which in turn results in an increase of zooplankton biomass and more food for fish by trophic cascade. The use of fertilizers to increase the production of fish in ponds has become widespread in recent years. It has been shown, however, that the physical characteristics and water chemistry of lakes also influence lake productivity. Fish production and condition in unfertilized ponds are inextricably linked to the amount of bioavailable nutrients in the water column. Additional variables such as sediment nutrients, benthic macro-invertebrate communities and macrophytes could play important roles in regulating the amount of available nutrients necessary to influence productivity at different trophic levels. While recreational ponds rely on nutrient availability through trophic cascade, fish production in commercial ponds depend on nutrients from supplemental food in the form of manufactured feed. Commercial catfish aquaculture takes place in earthen ponds where supplemental feed increases biomass for subsequent harvest. Production is often limited by low dissolved oxygen concentrations and nitrogen toxicity in the form of ammonia and nitrite accumulation in the system. The Mississippi River Alluvial Valley in the southeastern United States comprises nearly 65% of the total land devoted to catfish aquaculture in the United States. It is predicted that in the next two decades commercial catfish production will need to increase 5-fold to accommodate the human protein requirements. This increased need in production may prove difficult to accomplish in conventional earthen ponds. Today, new innovative strategies are taking aim at improving pond conditions and increasing production by enhancing dissolved oxygen concentrations and reducing harmful nitrogenous toxicity. The Split Pond System (SPS) is one new strategy which uses mass algal communities to assimilate harmful ammonia and increase dissolved oxygen concentrations through photosynthesis during the day. The SPS uses a low-speed water wheel which circulates pond water between a fish compartment and a waste treatment compartment. The water wheel enables the suspension of particulate matter in the water column facilitating nitrogen biogeochemical transformations. The production associated with a SPS is estimated between 20,000 and 30,000 pounds of catfish acre-1; 3-5 times greater than traditional earthen ponds. Nutrient management strategies in both recreational and commercial fish ponds are an essential tool in sustaining quality fish for both sport and economic value in the southeastern United States.

Chapter 3 - Salt gradient solar ponds have history over a century. Kalecsinsky (1902) first reported a pond like phenomenon is Hungarian lakes. Since then researchers have explored various aspects of ponds. Weinberger (1964) first developed analytical solution of pond's equations. This made it possible to design ponds for commercial applications. The first finite difference based computer simulation of pond was presented by Hull (1980). It was based up on the iterative approach proposed by Tybout (1966). Tabor has contributed significantly for commercial use of pond especially in Israel. The country has an ambitious plan of meeting complete electricity demand by ponds only by the year 2020 (Amnon Einav 2004). This shows that with the rising energy demand coupled with the severe environmental concerns of traditional fossil fuel energy; solar ponds are emerging as cost effective, environmental friendly viable technology for twenty first century.

Chapter 4 - In arid regions, where water availability imposes significant constraints on many species, shallow lakes and ponds have a particularly important ecological role. Meanwhile, these aquatic environments have been listed among the most threatened habitats of the world. With an area of over 6.000.000 km^2, the Patagonian steppe is one of the largest arid extensions of South America. Running intermittently along the steppe, a system of basaltic plateaus or mesetas, holding thousands of lakes and ponds, provides primary habitat for numerous species, including a rich waterbird community and numerous endemism. We characterized the array of shallow lakes of the Strobel meseta, analyzing their dynamics along temporal and spatial gradients. Using multivariate analyses, based on limnological, topographic, and geographic variables of 32 water bodies, we identified four lake types: large unvegetated, large vegetated, turbid, and ponds. Based on 114 bird censuses we evaluated the relative importance of each lake type as waterbird habitat. Ponds hold the highest density of waterbirds and, together with large vegetated lakes, the highest number of species. Using satellite images corresponding to periods with contrasting precipitation, we analyzed the hydrologic dynamic by lake type and by location throughout the meseta. Whereas most lakes, including large ones, are concentrated on the west side of the meseta, above 900m of elevation, ponds are distributed throughout the whole area, but are less stable from a dynamic point of view. The total area covered with water on the meseta is strongly affected by seasonal and inter-annual changes in precipitation. During dry periods, most ponds, and particularly those located at lower altitudes, undergo a drastic reduction in water level or even dry out. Variations in water level impinge on the limnological configuration of lakes and ponds, particularly on the emergence of macrophytes, a key habitat attribute for most species of waterbird. Given this strong dependency of hydrology and habitat provision on precipitation, temperature, and wind, meseta shallow lakes and the communities they sustain appear particularly vulnerable to climate change.

Chapter 5 - Microalgae are found in multiple environments as a result of the diversity of their morphological and physiological adaptations, including the production of a large variety of polysaccharides. This chapter describes the growth parameters as well as the patterns of carbohydrate accumulation and release of three green phytoplanktonic strains isolated from different subtropical ponds. A preliminary characterization of the polysaccharides produced by these strains was also carried out in order to identify potential bioactive compounds. *Chlamydomonas* sp. (Chlamydophyceae), *Ankistrodesmus* sp. (Chlorophyceae), and *Onychonema* sp. (Zygnematophyceae) were isolated by micromanipulation and several washes under the microscope. Microalgae were isolated from subtropical ponds smaller than 10,000 m^2, which are found throughout the landscape of the Carreiros campus of the Federal University of Rio Grande. These ponds are located in southernmost areas of Brazil and have different trophic statuses, which range from oligotrophic to hypereutrophic. Experiments were carried out with batch cultures until stationary growth was reached. Samples were collected at 48 and 72-hour intervals to monitor cell growth (direct counts using a microscope), particulate and extracellular dissolved total carbohydrates (phenol-sulfuric), and polysaccharide composition (High Performance Ion Chromatography with Amperometric Detection - HPIC-PAD). *Chlamydomonas* sp. exhibited the fastest growth rate (0.8 div per day), followed by *Ankistrodesmus* sp. and *Onychonema* sp. (0.3 and 0.1 div day^{-1}, respectively). Only *Onychonema* sp. had a senescent growth phase after 33 days of cultivation. Particulate carbohydrate accumulation occurred simultaneously with growth, except in *Onychonema* sp., which accumulated particulate carbohydrates during the stationary growth phase. Extracellular dissolved carbohydrates were released continuously during the experiment even after stationary growth was reached. Polysaccharide analysis by HPIC-PAD revealed the presence of arabinose associated with galactose in *Chlamydomonas* sp., and significant levels of uronic acid in *Ankistrodesmus* sp. and fucose in *Onychonema* sp. Polysaccharides with these characteristics are similar to the pectins produced by vascular plants and the fucoidans produced by brown algae, which are associated with antitumoral, anti-inflammatory, immunostimulatory, and other biological activities. On the other hand, the high content of uronic acid-containing polysaccharides can potentially form complex metals and might be used in biotechnology applications.

Chapter 6 - Ancient water-filled lakebeds were identified on Mars based on shorelines, terraces, sedimentary deltas, in- and outflow valleys, mineral alterations, sedimentary plains and cracks possibly formed during the drying phase. Most of them were probably fed by precipitation or ice melting, and formed at low latitudes before 3.5 billion years under warmer climate. Later in colder periods, ephemeral lakes with ponded water from outbreak of subsurface aquifers were still present, as well as impact of volcanic activity melted lakes. Many lakes were covered with ice layer, and salts decreased the melting point of their water. Their sediments may hold important information of the ancient climate, chemical alterations and the possibility of life.

Lakes on Titan, on the moon of Saturn are present today, where liquid methane-ethane mixture fills about 400 observed lakes in the polar region. The temperature only in the polar region is low enough (about -179 °C) for the liquids to remain stable, while at lower latitudes only dry lakebeds are present. Lakes smaller than 20 km fill roughly circular depressions, while larger lakes have dissected shorelines. Inflow rivers are observed, and subsurface contribution may also be present. Lakes play an important role in the methane cycle of Titan: evaporation, cloud formation and rain events happen above them. Organic sediments may have accumulated at the bottom of lakes, and their characteristics help to reconstruct pathways of abiotic organic material synthesis, which is important to understand prebiotic chemical processes on the Earth too.

Chapter 7 - The zooplankton assemblages in Chilean water bodies is characterized by their low species number and high calanoid dominance, that is due mainly to the oligotrophy of studied sites. Nevertheless, it was reported an increase of penetration of natural ultraviolet radiation, that is due to the ozone depletion. In this scenario, the natural ultraviolet radiation can penetrate into water column that generates damage into biotic components. The present study included two groups of shallow ponds, a first group included oligotrophic mountain shallow ponds in Araucania region (38º S), whereas a second group included shallow ponds located plains of Magallanes region (51º S). The studied revealed that both groups of sites have high exposure to natural ultraviolet radiation. The first group, the trophic status would be the main regulator factor of zooplankton assemblages, whereas in the second group, the conductivity would have a secondary role, because at low conductivity and mesotrophic status would have high species number and low calanoid dominance. Similar results were reported for their counterparts located in Argentinean Patagonia.

Chapter 8 - One of the most important problems in the operation of a salinity gradient solar pond is the stability of boundaries between gradient zone and convective zones. Although mach progress has been made recently, there are still many clarifications such as the mechanism of the heat and mass transfer through the gradient-convective boundary and the kind of dynamic processes that influence the gradient stability. In order to obtain an improved understanding of these dynamic processes, experimental studies have been conducted in a laboratory thermohaline system which is similar to solar ponds.

Based on Particle Image Velocimetry (PIV) visualization-experiments and quantitative measurements, physical mechanisms of these processes are discussed.

Chapter 9 - Various ponds alive can be elucidated in five points as follows. [1] “Ponds” can best be characterized as so many “circles” whose centers are everywhere, and whose circumferences nowhere. Such circles are never at rest but ever continuing to grow out and out, rounding and rounding things that emerge in life. These circles are ponds to nurture us to grow; without them we cannot even survive the day.

These ponds and circles actually exist fivefold way, among so many ways. They are my daily ongoing, my living, my cultures, interculture, and storytelling, and the list goes on; each describes a circle, a pond, and a world. Obviously, these circle-ponds are my self interacting with my world to inter-dance our lifeworld.

Here at the ponds, I am a tiny dragonfly dotting my tail without dotting it fivefold onto the ponds, making ripples of expanding circles inter-mingling and inter-vanishing, only again to dot as rain drops to form many new fascinating ripples of small circles, centers-everywhere, edges-nowhere.

[2] Let us put this situation another way. This lifeworld has so staggeringly many grains of sand, in each of which I see a world, so zillions of sand-grains show zillions of different worlds, each expanding as a pond-circle with center-everywhere, edge-nowhere. All this makes a fabulous world of life, all thanks to me and to my inter-dancing with and within the circular ponds!

[3] Thus the circular ponds are the countless kaleidoscopes of changing patterns and colors of values, fashions, each correlated with all others, interchanging, inter-changing. Now these countless kaleidoscopes are of two sorts, the non-being sort of the Hwa Yen Buddhist vacuity-mirrors inter-reflecting, and the being-sort of Chuang Tzu the Taoist, nothing infused with things, to delightfully slither back and forth between life and death, making Heaven and Earth, season after season.

[4] Worldly people would never have imagined such complex kaleidoscopes of ponds that encircle them, much less realize that they *are* these ponds, and so they laugh at all this, calling it a bad name such as “relativism.” As Lao Tzu said, on hearing the Tao of Heaven Net, low people would greatly laugh Ha Ha; not laughing the Net Heavenly, the countless ponds in circles would not be Heavenly everywhere.

[5] A pond is where a frog of life jumps in to make a sound (as a Japanese haiku intones), and so many ponds would sound so many sounds of so many frogs jumping in. The sounds make us realize: The pond is the frog that is the sound made by jumping in, echoing silence, spreading the pond as circles everywhere-centers, nowhere-edges. To go through all these sounds of the jumping frogs into the ponds of this world is relativism active, inter-dancing the lifeworld. In short, the world is various ponds alive.

Chapter 10 - Strong alteration of waterfowl habitat may derive from fish-farming intensification in fishpond systems. The specific effects of fertilization on duck breeding were described in fishponds of the Brenne region (Central France) where fish stock density is usually lower than in fishpond systems of Central Europe. The study was carried out in 1999, 2000 or 2001 in a sample of 75 ponds, either unfertilized (F0) or fertilized with organic *or* inorganic manure (F1), or with organic *and* inorganic manure (F2). Fish-stock mean density doubled from F0 (215.9 kg.ha^{-1}) to F2 (441.9 kg.ha^{-1}). Biomass density in macrophytes of potential invertebrate prey for ducks was higher in F2 than in F0 and macrophyte abundance did not differ across fertilization categories. Duck brood density (number/square root of pond surface area) in F2 was higher than in F0 and in F1. Moreover, 5-week old pochard *Aythya ferina* brood size was higher in F2 than in F1, probably as a result of a higher persistence of broods with ≥ 4 ducklings. We conclude that manure application and correlative increase in fish density is not necessarily antagonistic with duck breeding provided that fish stock is below 500 kg.ha^{-1}, water turbidity does not hinder macrophyte development and large enough helophyte belts are available for nesting .

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Chapter 1

POND USAGE BY ANURAN AMPHIBIANS

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ABSTRACT

Most species of anurans require ponds for reproduction. The attributes likely to influence a pond's suitability as spawning site include factors such as vegetation, depth, water chemistry, presence of predators, hydroperiod and water chemistry. But in many landscapes the availability of suitable ponds is limited. This reliance on scarce resources makes anurans vulnerable to habitat loss. With an estimated 40% of amphibians worldwide at risk of extinction we need to increase our understanding of basic requirements such as suitable spawning sites. On the other end of the scale a large number of anurans are flourishing in environments far outside of their natural range. Many of these exotics may disturb ecosystems and pose a threat to indigenous fauna, including native amphibians. In this chapter I review pond usage by anurans in relation to the problems of amphibian declines and invasive species. I focus on pond manipulations and ways of using that as a potential conservation tool for conserving threatened species as well as controlling invasive anurans.

INTRODUCTION

In the last two decades, it has become increasingly clear that many of the world's frogs and toads (and other amphibians) are undergoing rapid population declines (Alford et al. 2001; Collins and Crump 2009). This global decline is a serious threat to biodiversity (Collins and Crump 2009). It is also clear that there are a large number of exotic and/or invasive anurans around the world (Lever 2003). For example, up to eight percent of the anuran fauna

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in the big regions of the world are exotic species (Lever 2003; Collins and Crump 2009, Table 1.).

These exotics can disrupt ecosystems functioning and cause declines in native biota (Lever 2003). Declining and exotic anurans are therefore two major problems in applied ecology (Alford and Richards 1999; Alford et al. 1999; Lockwood et al. 2007; Collins and Crump 2009). Most anurans have one trait in common: they rely on ponds for reproduction (Hagman and Shine 2006).

In this chapter I will outline how and why simple manipulations of pond habitats may be a useful method for conserving declining anurans as well as for managing invasive species. But, first I will provide a general overview of the anurans. As always when making generalizations there are many exceptions, some of which I will mention briefly. However, the purpose is not to give a complete account of anuran biology, but to provide the basics required to understand the conservation arguments presented later in this chapter.

It is a prerequisite for any modern conservation plan that there is detailed knowledge of the biology of the organism in focus (Beebee 1996; Groom et al. 2005; Collins and Crump 2009).

For those who are interested in reading more about anuran biology, there are many excellent and comprehensive books (e.g., Duellman and Trueb 1986; Stebbins and Cohen 1995).

These books are good sources of information. However, our knowledge of anuran ecology is far from complete and we need more research in order to better understand population declines, as well as basic ecological issues such as habitat use, behavior and reproduction. Nonetheless I hope that this chapter will be of interest to anyone who is studying ponds, amphibians and conservation biology.

AN OVERVIEW OF ANURAN LIFE HISTORY

The Anura is the largest order of the amphibians, comprising 5602 species of frogs and toads (Collins and Crump 2009). Anurans occur on all continents except Antarctica (Duellman and Trueb 1986). However, the vast majority of the world's frogs and toads are found in the tropics with fewer species occurring in temperate areas (Duellman and Trueb 1986; Beebee 1996; Collins and Crump 2009). A frog or a toad characteristically starts its life cycle as an egg that hatches into a tadpole that subsequently metamorphoses into a juvenile replicate of the adult form (Duellman and Trueb 1986).

This is the classical strategy adopted by most temperate species. However, there are many exceptions to this pattern, particularly in the tropics. For example, some species skip the tadpole stage by developing directly within the egg and then hatch as a fully formed juvenile (Beebee 1996). Frogs and toads are distinguished from other amphibians by their lack of tails (Duellman and Trueb 1986). Leg morphology is a good predictor of locomotion mode in frogs and toads. Species that swim or jump are generally equipped with long and powerful hind limbs, whereas species that walk or burrow have short legs (Duellman and Trueb 1986; Stebbins and Cohen 1995).

Table 1. Exotic anurans of the world. The table provides information on taxonomic affinity, range and reference. With the exception of species that have been introduced to distant islands within the same nation (e.g., species that occur naturally on the mainland of the United States but have been introduced to Hawaii), only species that have expanded their ranges outside of the native country are included. Note that new cases of exotic anurans and range expansions are reported frequently and that this table is not complete in terms of species, ranges or references

Taxa	Indigenous range	Non-indigenous range	Reference
Bufonidae (true toads)			
Bufo bufo	Europe, Palearctic Asia, Mainland Japan, North-West Africa	Ogasawara Islands (Japan)	Lever 2003
Bufo dhufarensis	Yemen, Dhofar, Oman, United Arab Emirates	Saudi Arabia	Balletto et al. 1985; Leviton et al. 1992
Bufo gargarizans	Mongolia, Manchuria, China	Korea, Ryukyu Islands (Japan)	Okada 1931; Lever 2003
Bufo gutturalis	Uganda, Kenya, South Africa	Mauritius	Bour and Moutou 1982
Bufo japonica	Mainland Japan	Ohshima Island (Japan)	Hasegawa 1999
Bufo marinus	Southwestern USA, Central - and South America	More than 41 countries throughout Asia and the Caribbean and Pacific region (see Lever 2001)	Reviewed by Lever 2001
Bufo mauritanicus	North Africa	Spain	Barbadillo et al. 1999
Bufo melanostictus	China, Taiwan, Indonesia	Papua New Guinea, Andaman, Nicobar	Das 1999; Menzies and Tapilatu 2000
Bufo regularis	Africa	Mauritius	Cheke 1987
Bufo viridis	North, middle and eastern Europe, North Africa	Spain, Russia	Kuzmin 1994; Barbadillo et al. 1999; Borkin 1999
Dendrobatidae			

Table 1. (Continued)

Taxa	Indigenous range	Non-indigenous range	Reference
Dendrobates auratus	Central America, Colombia	Hawaii	Oliver and Shaw 1953; Cochran and Goin 1970; Eldredge 2000
Discoglossidae			
Alytes obstetricans	Western Europe, Iberian Peninsula, Germany, Switzerland	England	Beebee and Griffiths 2000
Bombina orientalis	China, parts of Russia, Korea	Spain	Rivera and Arribas 1993
Bombina variegata	South (Mediterranean) and Central Europe	England	Beebee and Griffiths 2000
Discoglossus pictus	Sicily (Italy), Malta, Gozo	France, Spain	Rivera and Arribas 1993; Haffner 1997; Barbadillo et al. 1999
Hylidae			
Hyla cinerea	USA	Puerto Rico	Hedges 1999; Thomas 1999
Hyla meridionalis	France, Italy, North-West Africa	Mainland Spain, Canary Islands	Rivera and Arribas 1993; Barbadillo et al. 1999
Hyla squirella	USA	West Indies (Grand Bahama)	Crombie 1972
Litoria aurea	Australia	New Zealand, New Caledonia, Vanuatu	Tyler 1979; West 1979; Druett 1983; Low 1999; Eldredge 2000
Litoria caerulea	Australia, Papua New Guinea	USA, New Zealand	Robb 1973; Bartlett 1994; Bartlett and Bartlett 1999
Litoria ewingii	Australia	New Zealand	Gill and Whitaker 1996
Litoria fallax	Australia	Guam (USA)	Low 1999; Eldredge 2000
Litoria raniformis	Australia	New Zealand	Gill and Whitaker 1996

Taxa	**Indigenous range**	**Non-indigenous range**	**Reference**
Osteopilus septentrionalis	Cuba, Bahamas, Cayman Islands	USA, Puerto Rico, Virgin Islands, Hawaii	Conant and Collins 1991; McKeown 1996; Meshaka 1996; Bartlett and Bartlett 1999
Pseudacris crucifer	Canada, USA	Cuba	Conant and Collins 1991; Hedges 1999
Scinax quinquefasciata	Colombia, Ecuador	Galapagos	Snell et al. 1999
Scinax rubra	Brazil, Guyana, Northern South America, Panama	West Indies, Puerto Rico	Kaiser and Henderson 1994, Hedges 1999; Malhotra and Thorpe 1999; Thomas 1999
Leptodactylidae			
Eleutherodactylus antillensis	West Indies, Puerto Rico, Vieques and the British and US Virgin Islands	Panama	De Sousa et al. 1989
Eleutherodactylus coqui	Puerto Rico	Mainland USA, Hawaii, Guam (USA), West Indies	Loftus and Herndon 1984; Conant and Collins 1991; Eldredge 1999; Campbell 2000; Christy et al. 2007
Eleutherodactylus johnstonei	Lesser Antilles Islands	Bermuda, Colombia, French Guyana Guiana, Panama, Venezuela, West Indies	Wingate 1965; Ibanez and Rand 1990; Kaiser and Wagenseil 1995; Lescure and Marty 1996; Murphy 1997; Barrio Amoros 2001; Lever 2003
Eleutherodactylus martinicensis	Lesser Antilles Islands	West Indies	Murphy 1997; Malhotra and Thorpe 1999
Eleutherodactylus planirostris	Cuba, Bahamas Islands, Cayman Islands	Mainland USA, Guam (USA), Mexico, West Indies, Hawaii	Schwartz 1974; Conant and Collins 1991; Bartlett and Bartlett 1999; Kraus et al. 1999; Christy et al. 2007

Table 1. (Continued)

Taxa	Indigenous range	Non-indigenous range	Reference
Microhylidae			
Gastrophryne carolinensis	USA	West Indies (Bahamas Islands, Cayman Islands)	Conant and Collins 1991; Schwartz and Henderson 1991
Kaloula pulchra	China, India, Sri Lanka, Burma, Nepal, Indo-China, Malaysia	Guam (USA), Singapore, Indonesia (Borneo and Sulawesi)	Lim and Lim 1992; Zhao and Adler 1993; Christy et al. 2007
Microhyla ornata	China, India, Sri Lanka, Malayan Peninsula	Yaeyama Islands, Miyako Islands, Tokara Islands (all in Japan)	Chigira 1988; Ota 1983, 1999; Hikida et al. 1992
Microhyla pulchra	Cambodia, China, Guam, Hong Kong, Lao People's Democratic Republic, Macau, Thailand, Vietnam	Guam (USA)	Christy et al. 2007
Pipidae			
Xenopus laevis	Sub-Saharan Africa	Ascension Island, Chile, England, Germany, Italy, Japan, Mexico, The Netherlands, USA	Hermosilla 1994; Tinsley and McCoid 1996; Ashmole and Ashmole 2000; Beebee and Griffiths 2000; Lever 2003; Lillo et al. 2005; Lobos and Jaksic 2005; Arao and Kitano 2006
Ranidae			
Hylarana erythraea	Borneo, Burma, India, Java, Thailand, Vietnam	Philippines	Alcala and Brown 1998

Taxa	**Indigenous range**	**Non-indigenous range**	**Reference**
Limnonectes cancrivora	Indonesia, Malaysia, South-East Asia, Vietnam	Guam (USA), Papua New Guinea, Philippines	Brown and Alcala 1970; Menzies 1996; Christy et al. 2007
Occidozyga laevis	Borneo, China, Indonesia, Thailand	Philippines	Brown and Alcala 1970
Polypedates megacephalus	China, Hong Kong, India, Myanmar, Taiwan, Thailand, Vietnam	Guam (USA)	Christy et al. 2007
Ptychadena mascareniensis	Northern and Middle Africa, Madagascar	Mascarene Islands (Mauritius, Reunion)	Cheke 1987
Rana balcanica	Greece, Albania	Denmark	Jørgensen 1999
Rana bedriagae	Anatolia, Cyprus, Egypt, Greece, Israel, Jordan, Lebanon, Syria	The Netherlands	Jooris 2000
Rana catesbiana	Canada, Mexico, USA	More than 30 countries throughout Asia, the Caribbean, Europe, South America,the Pacific region (see Lever 2003)	Reviewed by Lever 2003
Rana esculenta (Rana lessonae)	Much of mainland Europe	England, Spain, Azores (Portugal)	Beebee and Griffiths 2000; Lever 2003
Rana grylio	USA	West Indies (Andros and New Providence Islands, Bahamas)	Neil 1964; Conant and Collins 1991
Rana guentheri	China, Hong Kong, Taiwan, Vietnam	Guam (USA)	Christy et al. 2007
Rana limnocharis	China, India, Indonesia, Mainland Japan, Nepal, Pakistan, Sri Lanka,	Guam (USA), Ryukyu Islands (Japan), Philippines	Brown and Alcala 1970; Shimojana 1978; Ota 1999; Christy et al. 2007
Rana perezi	France	Belgium, Spain (Balearic Islands, Canary Islands), Morocco	Hemmer et al. 1981; Rivera and Arribas 1993; Barbadillo et al. 1999

Table 1. (Continued)

Taxa	**Indigenous range**	**Non-indigenous range**	**Reference**
Rana pipiens	USA	Canada (Vancouver island)	Green 1978
Rana ridibunda	Eastern and South-Eastern Europe, Russia, Balkan countries, Western Asia, North-Eastern Africa	Belgium, England, Russia, Spain	Dubois 1983; Kuzmin 1994; Arano et al. 1995; Percsy 1995; Haffner 1997; Beebee and Griffiths 2000
Rana rugosa	China, Mainland Japan, Korea	Hawaii, Izu Islands (Japan)	Oliver and Shaw 1953; Hasegawa 1999
Rana rugulosa	Burma, China, Taiwan, Thailand	Borneo	Zhao and Adler 1993
Rana saharica	Algeria, Egypt, Libya, Marocco, Tunisia, Western Sahara	Canary Islands (Spain)	Barbadillo et al. 1999
Rana sphenocephala	USA	Grand Bahama Island	Schwartz and Henderson 1988, 1991
Strongylopus grayii	Mozambique, South Africa, Zimbabwe	St Helena	Ashmole and Ashmole 2000
Rhacophoridae			
Rhacophorus leucomystax	China, India, Java	Philippines, Ryukyu Islands (Japan)	Brown and Alcala 1970; Ota 1999; Lever 2003: Kuraishi et al. 2009
Rhacophorus arboreus	Mainland Japan	Oh-shima island (Japan)	Hasegawa 1999

All anurans characteristically have a permeable skin without scales, fur or feathers. The high permeability of the anuran skin allows for efficient gas exchange. The skin therefore functions as a respiratory organ (Duellman and Trueb 1986; Stebbins and Cohen 1995). Gas may also be exchanged in the lungs, the buccal cavity or, for tadpoles, in the gills (Stebbins and Cohen 1995). Anurans also absorb water through the skin by osmosis, particularly through a thin area on the posterior underside of the body (sometimes called the seat patch: Stebbins and Cohen 1995). In dry air anurans lose water rapidly through the skin by evaporation (Claussen 1969; Stebbins and Cohen 1995). These traits therefore require anurans to inhabit humid environments. Species differ in their ability to control water loss (depending on habits and/or habitats) and in general toads are more able to endure dry conditions than are frogs (Duellman and Trueb 1986). No anurans can survive in seawater, although a few species can tolerate varied degrees of saline conditions (Dunson 1977; Duellman and Trueb 1986; Degani and Hahamou 1987). Accordingly most anurans live in humid habitats near fresh water, or are fully aquatic. The exceptions are a few species that are able to survive in arid habitats by remaining underground for long periods of time between bouts of heavy rainfall (e.g., spadefoot frogs in the Australian desert: Tyler 1999). Anurans are ectothermic, yet unlike many other ecothermic organisms (e.g., reptiles and insects) frogs and toads, particularly temperate species, are often active at surprisingly low temperatures. For example, the temperature range for a series of temperate and tropical anurans in America is 3ºC to 35.7ºC (Duellman and Trueb 1985). Many temperate species hibernate for a large part of the year. Typical hibernacula include underground burrows, the bottom of ponds and lakes, or under ice. Some species, such as the North American spring peeper (*Pseudacris crucifer*) may even survive being deep frozen in ice by accumulating high concentrations of glycerol in the blood (Schmid 1982). One of the most noticeable things about anurans is the habit of males to gather around ponds and call for females. Worldwide anuran mating calls fill the nights (and sometimes the days) with sound. In certain places males gather in such large numbers that the chorus of calls can become quite deafening (Wells 2001). Males produce their calls by moving air from the lungs and forward through the larynx and into the vocal sack, which inflates (Figure 1.) and amplifies the sound (Stebbins and Cohen 1995).

Figure 1. Male red tree frog (*Litoria rubella*) calling from a pond near Fogg Damm in the Northern Territory of Australia. Photo: Mattias Hagman.

In addition to advertisement calls there are territorial calls, distress calls, sporadic calls and courtship calls (Duellman and Trueb 1986; Gerhardt 1994; Stebbins and Cohen 1995, Toledo and Haddad 2005). Calling activity can be an important factor in mate-selection (Sullivan and Hinshaw 1992; Gerhardt 1994; Sullivan et al. 1995). For example, female poison frogs (Figure 2.) can assess the genetic quality of males by the rate and duration of their chirps (Forsman and Hagman 2006).

Figure 2. Three striped poison dart frog (*Epipedobates trivittatus*) near the Chumilla river in the Tarapoto region of Northeastern Peru. Photo: Mattias Hagman.

Anurans are an important component in the ecosystems where they occur. Eggs, tadpoles and adult frogs are a major food source for many organisms, including insects, fish, birds, reptiles and mammals (Stebbins and Cohen 1995; Collins and Crump 2009). Many species of snakes, for example, feed almost exclusively on frogs and toads (Shine 2007; Hagman et al. 2008a). Adult anurans are carnivorous and generally feed on invertebrates. Frogs and toads thereby assist in keeping insect numbers under control. Anything that can be swallowed is potential prey for anurans. Large species such as the cane toad (*Bufo marinus*) and the bullfrog (*Rana catesbiana*) may even take fledgling birds, rodents, lizards and small snakes (Beebee 1996; Lever 2001, 2003). While adult anurans are completely carnivorous (usually insectivorous), tadpoles have a more varied diet ranging from herbivorous to omnivorous to fully carnivorous (Stebbins and Cohen 1995). Dietary preferences are reflected in habit and morphology of the mouthparts. There are tadpoles with mouths designed for grazing, scraping, filter feeding, biting and combinations thereof (Altig and McDiarmid 1999). Body shapes vary from elongated to stout with more or less pigmentation (Altig and McDiarmid 1999). Tadpoles have delayed reproductive organs and certain body parts in favor of structures for feeding and digestion (Wassersug 1975). Thus it seems that the primary function of a tadpole is to feed. Many anurans are highly fecund and there are species that lay clutches of 25,000 eggs or more (Stebbins and Cohen 1995; Lever 2001). Tadpole densities can therefore become extremely high in popular breeding sites. For example, a small pond in Mississippi had an estimated population of 26,000 tree frog tadpoles (Turnipseed and Altig

1975). In such cases tadpoles could have a significant role in nutrient cycling and regulation of the primary production of phytoplankton, algae and microorganisms. For example, Seale (1980) found that variation in tadpole biomass affected both nutrient flux and production of phytoplankton in a pond in Missouri. Furthermore, a single tadpole can sift one liter of water each day (Polls-Pelaz and Rougier 1990). Hence, when tadpole densities are high the daily turnover of water could be dramatic. For example, in a pond with 50,000 tadpoles (e.g., two or three clutches of cane toad larvae) the volume sifted each day would be around 50m^3 (or nearly 11,000 gallons). Stebbins and Cohen (1995) noted that tadpoles thus could have a large impact on the assemblages of phytoplankton, protozoans and filamentous algae in ponds. Anurans also cycle nutrients between habitats. Mortality rates are highest just after metamorphosis and many juveniles die on the shorelines of ponds where the decaying carcasses enter the soil. Anurans thus transport nutrients out of the water and into the terrestrial habitat (Wassersug 1975).

Many species of tadpoles tend to form large aggregations in the shallows of ponds (Figure 3.). Hypotheses to explain this behavior include predator avoidance (Hamilton 1971; O’Hara 1981; Hagman 2008), feeding facilitation (mass movement stirs up food: Wilbur 1977) and thermoregulation (a mass of darkly colored tadpoles absorb solar radiation, which elevates temperature: Wassersug 1973; Guilford 1988; Caldwell 1989). Some species of tadpoles can produce alarm pheromones when stressed or injured (Chivers et al. 1998; Hoff et al. 1999; Brönmark and Hanson 2004; Rajchard 2006; Hagman 2008; Hagman and Shine 2008a). These pheromones usually induce avoidance behavior in conspecific tadpoles (Hews 1988; Hoff et al. 1999; Hagman and Shine 2008a). Recurrent exposure can cause life-history shifts as well as changes in morphology and chemistry (Rajchard 2006; Hagman et al. 2009). Tadpoles often compete with mosquito larvae (or feed on them: Stebbins and Cohen 1995) and thus can reduce the abundance of species that can be potentially harmful to humans (e.g., vector species for diseases such as Ross river virus and Murray valley encephalitis: Williams et al. 2003).

Figure 3. A mass of common toad (*Bufo bufo*) tadpoles aggregating in the shallow margins of a pond in Stockholm, Sweden. Photo: Mattias Hagman.

For example, by competing with mosquito larvae in ponds, tadpoles can reduce the survival rates, adult body sizes and rates of oviposition of mosquitoes and thus, their ability to carry diseases to humans (Hagman and Shine 2007). Tadpoles of many species frequently feed on conspecific eggs and tadpoles (Black 1970), whereas adults often prey on smaller individuals (Hagman and Shine 2008b). Such cannibalism is commonplace among anurans in all stages of life history and may even involve complex behavioral adaptations that facilitate capture of smaller conspecifics (Hagman and Shine 2008b).

Reproductive Mode of Anurans

As noted above, the anuran life cycle typically involves an aquatic (egg and larvae) and a terrestrial (juvenile and adult) phase (Duellman and Trueb 1986; Stebbins and Cohen 1995). Thus anuran eggs are normally laid in or in the proximity of ponds. There are exceptions to this generalization (Stebbins and Cohen 1995), but in most cases even species that deposit their eggs terrestrially require water for their tadpoles. For example, many species of South American poison frogs (Figure 2.) lay their eggs among leaf litter on the forest floor, but return when the eggs hatch to carry the tadpoles on their back to a suitable waterbody (Donnelly 1989; Kitching 2000; Summers 2002; Brown et al. 2008). Australian frogs in the genus Pseudophryne generally deposit their eggs on leaf litter or rocks in places close to water that are likely to be inundated. The embryos undergo much of the development within the egg and do not hatch until flooded after rainfall, whereupon they continue their development as free-swimming tadpoles (Tyler 1999). Another common strategy is the use of foam nests that are attached to foliage overhanging ponds or floating on the surface of ponds (Figure 4.). Frogs construct these nests using their legs to whip mucus into foam at the time of oviposition (Stebbins and Cohen 1995). The nest protects the eggs from strong light, desiccation and predation (Stebbins and Cohen 1995). After hatching, the tadpoles continue their development in the pond (Stebbins and Cohen 1995). Similarly, many tropical tree frogs lay their eggs on leaves overhanging ponds. When the eggs hatch the tadpoles wriggle free from the jelly and fall into the pond where they remain until metamorphosis (Warkentin 1995, 2000). Thus, although different species may have different strategies for egg deposition, the larvae of most anurans develop in ponds. Frogs and toads often only breed in a fraction of the ponds available in an area (Beebee 1996; Monello and Wright 1999; Hagman and Shine 2006). Presumably they select ponds that offer favourable conditions for their tadpoles. The attributes likely to influence a pond’s suitability as spawning site or tadpole habitat include factors such as depth (Babbitt et al. 2006; Hagman and Shine 2006), vegetation (aquatic and terrestrial: Savage 1961; Hagman and Shine 2006), angle of the slope at the water’s edge (Hagman and Shine 2006), temperature (Seale 1982), water chemistry (Gascon and Planas 1986), pH and aluminum (Anderson et al. 1999), pH conductivity, and depth (Babbitt et al. 2006), presence of predators (Howard 1980) and hydroperiod (Adams 1999; Eason and Fauth 2001; Baldwin et al. 2006; Seigel et al. 2006; Werner et al. 2007). All these variables can affect the composition of tadpole and breeding assemblages at any given pond. Furthermore, the availability of suitable ponds is often a limiting factor for anuran reproduction and population density (Donnelly 1989; Monello and Wright 1999; Rico et al. 2004; Toledo and Haddad 2005).

Figure 4. Foam nest with tadpoles of the striped marsh frog (*Limnodynastes peronii*) floating on the surface of a pond in the Lane Cove area in Sydney, Australia. Photo: Mattias Hagman.

DECLINING AMPHIBIAN POPULATIONS

It is well established that populations of anurans and other amphibians are declining globally (Collins and Crump 2009). The cause of this decline is not fully understood (Collins and Crump 2009).

However, the prevailing view is that several factors interact, including infectious diseases (particularly a chytrid fungus, *Batrachochytrium* dendrobatidis: Lips et al. 2006; Skerratt et al. 2007), overexploitation (e.g. for food, pets, bait, laboratory use and educational purposes: Dash and Mahanta 1993; La Marca et al. 2005; Kusrini and Alford 2006; Tyler et al. 2007; Collins and Crump 2009), pollution, (e.g. road salts, agrochemicals, oil, petrol, gases and other toxic chemicals: Alford and Richards 1999; Blaustein et al. 2003; Relyea 2003; Davidson and Knapp 2007), exotic species (e.g. Hayes and Jennings 1986; Lawler et al. 1999; Adams 2000; Vredenburg 2004; Ahola et al. 2006; Knapp et al. 2007), climatic change (global warming, increasing concentrations of carbon dioxide in the atmosphere, UV-radiation at the earth’s surface: Blaustein et al. 2003; Blaustein et al. 1995; Whitfield et al. 2007) and habitat loss (drainage of wetlands, deforestation and conversion of natural habitats to agricultural landscapes and human occupancy: Shaffer 1981; Ash 1988; Lande 1993; Beebee 1996; Semlitsch and Bodie 1998; Duellman 1999; Green 2003; Azevedo-Ramos and Galatti 2002; Collins and Crump 2009).

The amphibian decline has stimulated much research. For obvious reasons a large part of that research has been devoted to investigating the causes of the decline. However, a lack of information about the ecology of many species has made the work challenging. For example, a major difficulty has been to distinguish real declines from normal population fluctuations (Wake 1991; Crump et al. 1992; Blaustein 1994; Pechmann and Wilbur1994; Travis 1994). To address this problem some researchers have tried to fill the gaps in our knowledge of amphibian ecology and population dynamics (e.g. Skelly et al. 1999; Marsh 2001; Marsh and Trenham 2001; Trenham et al. 2001; Trenham et al. 2003), whereas others have looked for patterns of declines and life history characteristics (e.g. reproduction mode) in order to investigate if there are traits that make certain species more prone to extinction (Williams and Hero 1998; McDonald and Alford 1999; Lips et al. 2003; Hero et al. 2005). Another line of investigation has looked for ecological correlates of local population declines.

For example, Pounds et al. (1997) found an association between habitat use and extinction in Costa Rican cloud forests and concluded that species that depend on water (ponds and streams) are at greater risk of extinction than are terrestrial species that are independent of aquatic habitats. Researchers in other parts of the world have come to similar conclusions (e.g. Laurance et al. 1996; Lips 1998; Williams and Hero 1998; McDonald and Alford 1999; Lips et al. 2003).

Morphology may also influence population processes such as declines and range expansions. For example, Australian species with variable or polymorphic colour patterns have larger ranges, use more habitats, exhibit less negative population trends and are estimated as less vulnerable to extinction than non-variable species (Forsman and Hagman 2009). Of the factors outlined above, loss and alteration of habitat is identified as the major cause of amphibian declines worldwide, followed by the spread of *Batrachochytrium dendrobatidis* and introduction of exotic species (Gardner et al. 2007; Collins and Crump 2009).

HABITAT LOSS AND ALTERATION OF NATURAL ECOSYSTEMS

Extensive alteration and outright destruction of habitat, such as the clearance of tropical rainforests, drainage of wetlands, agriculture and human settlement is a major threat to anurans (Ash 1988; Beebee 1996; Semlitsch and Bodie 1998; Azevedo-Ramos and Galatti 2002). These changes often cause species declines or extinctions even when part of the habitat is left unaltered (Shaffer 1981; Lande 1993; Green 2003). Slighter alterations of a habitat may not cause anuran declines or extinctions directly, but it can do so indirectly if it interrupts their ability to change habitat seasonally (e.g. for breeding or overwintering: Beebee 1996) or during life history transitions (e.g. at metamorphosis: Becker et al. 2007). Thus, even seemingly subtle changes to the habitat may have considerable impact on anurans.

In many landscapes suitable ponds is a scarce resource. The amphibious life cycle of anurans (i.e. living part of life in water and part on land) is a risky strategy that makes them particularly vulnerable to degradation and destruction of habitats. Both survival and reproduction may be affected if either of the habitats (aquatic or terrestrial) is altered (Skelly 2001; Bradford et al. 2003; Knapp et al. 2003; Van Buskirk 2005; Baldwin et al. 2006; Otto et al. 2007; Collins and Crump 2009). For example, if a pond is destroyed the local anuran community may not persist even if the surrounding terrestrial habitat remains suitable (Collins and Crump 2009). Some anurans occupy habitats that are far from the pond in which they breed (Beebee 1996). In such cases connectivity between the breeding pond and the other habitat is important (deMaynadier and Hunter 1999). Roads can disrupt that connection and affect anurans negatively (deMaynadier and Hunter 2000). Road crossing is also associated with much of the mortality of adult anurans during their migrations to breeding ponds (Beebee 1996). Disruption of habitat connectivity may be one reason why aquatic breeders often decline more than terrestrial breeders. For example, Becker et al. (2007) found a negative correlation between increasing disruptions of habitat connectivity and the species richness of amphibians with aquatic larvae in Brazil. Likewise, a review by Cushman (2006) suggests that connectivity may be a determining factor for the viability of regional anuran fauna and that the impact of fragmentation is likely to affect dispersive species earlier than less dispersive species. Anurans can also be affected by changes in habitat quality. Adults may live in the surrounding terrestrial habitat, yet population recruitment may cease if an alteration of the pond itself makes it unsuitable as a spawning site or as a habitat for tadpoles. For example, contamination not only affects terrestrial anurans directly, but some compounds pass through the soil and enter waterways where they can have negative effects on eggs and tadpoles. Unfortunately, toxins and other contaminants are easily absorbed through the permeable skin of anurans (Collins and Crump 2009). Typical effects of contamination include morphological abnormalities, infertility, endocrine disruption and lower survivorship (Collins and Crump 2009). Introduction of exotic organisms is another type of change in the habitat that can have a severe impact on anurans. Fish and crayfish are among the most widely introduced organisms globally, and many of them prey on the eggs and larvae of native amphibians. It is clear that the introduction of exotic fish has had a significant impact on anuran populations in the United States (Bradford 1989; Bradford et al.1993; Fellers and Drost 1993; Drost and Fellers 1996; Knapp and Matthews 2000; Vredenburg 2004; Knapp et al. 2007; Monello and Wright 1999; Pilliod and Peterson 2001), South America (Ortubay et al. 2006), Australia (Gillespie 2001; Hamer et al. 2002) and Europe (Brönmark and Edenhamn 1994; Meyer et al. 1998; Nyström et al. 2001; Martinez-Solano et al. 2003; Denoel *et al.* 2005; Orizaola and Brana 2006). Similarly, exotic frogs and toads can impact on native anurans by predation (Meshaka 2001), but also through poisoning (Crossland and Alford 1998; Hayes et al. 2009; Crossland and Shine 2010), competition (Lever 2003), hybridization (Hillis et al. 1984; Beebee 1995) and disease transfer (Delvinquier and Freeland 1988; Zupanovic et al. 1998; Dubey and Shine 2008), as discussed further below. The impact of exotic vegetation on native anurans has received less attention in this respect although in many ways the introduction of exotic plants can be as detrimental as the introduction of exotic animals. For example, many plants may possess chemicals that can poison native anurans and other organisms. One of few studies that have investigated the effects of exotic plants on native anurans found that invasive aquatic weeds (Purple Loosestrife, *Lythrum salicaria*) negatively affect tadpoles of the American toad (*Bufo americanus*) through poisoning and by changing the assemblages of phytoplankton on which the tadpoles feed (Brown et al. 2006). Changes in hydroperiod can also affect anurans (Daszak et al. 2005). For example, Gray and Smith (2005) found that changes in land use of the surrounding terrestrial habitat altered hydroperiods, which in turn made anurans metamorphose at a smaller size. In anurans, body size is positively related to survival and reproductive success (Howard 1980; Berven 1981, 1982; Berven and Gill 1983; Smith 1987; Semlitsch et al. 1999; Gerhardt 1994; Altwegg and Reyer 2003; Relyea 2007). Environmentally induced size effects such as those observed by Gray and Smith (2005) are therefore likely to be negative (Hagman 2010).

Exotic Anurans

Not all anurans are declining. Some species are actually expanding their ranges (Table 1.). Often these range expansions are a result of human activities (Lever 2003). Humans have moved frogs and toads outside of their native ranges for decades, either intentionally or accidentally (Lever 2003; Collins and Crump 2009). Hawaii is a place where introductions have been both deliberate and unintentional. For example, the cane toad was intentionally introduced as a biological control agent of pest insects, whereas the coqui frog (*Eleutherodactylus coqui*) was an accidental introduction that arrived with ornamental plants imported from Puerto Rico (Lever 2003). For whatever reason anurans are introduced, they are usually bad news in the recipient ecosystem. They can affect native anurans by predation (Meshaka 2001), poisoning (Crossland and Alford 1998; Hayes et al. 2009; Crossland and Shine 2010), competition (Lever 2003), hybridization (Hillis et al. 1984; Beebee 1995) and disease transfer (Delvinquier and Freeland 1988; Zupanovic et al. 1998; Dubey and Shine 2008). Furthermore, exotic anurans can pose a significant threat to non-anuran taxa (Lever 2001, 2003). Some species have the potential to disrupt the functioning of entire ecosystems. Australian federal authorities recently listed the cane toad as a key threatening process because of its devastating impact on native fauna (Hagman and Shine 2006). Cane toads (and other bufonid toads) have large parotoid glands on their shoulders that contain extremely potent toxins (Zug and Zug 1979). The active components of these toxins are steroid-derived and differ significantly from the peptide toxins of native frogs (Daly and Witkop 1971; Tyler 1987). Being the only member of its genus in Australia, the cane toad introduces deadly toxins into naive ecosystems as it spreads across the continent. Native predators, which have no previous experience with toads, have neither evolved tolerance to their toxins nor avoidance behavior (Lever 2003; Phillips et al. 2003; Hagman et al. 2009b; Shine 2010). Australian snakes, frogs, goannas, crocodiles, fish and predatory marsupials are therefore extremely vulnerable to toads and most will die from poisoning after attempting to consume one (Shine 2010). Unfortunately toads are highly toxic in all life history stages (i.e. egg, larvae and adult: Hayes et al. 2009), and thus affect native predators on multiple levels both in the aquatic and the terrestrial habitat. There are many reports of rapid predator population declines following the arrival of toads in previously toad-free areas of Australia (Oakwood 2004; Shine 2010). Successful exotics are species that are adaptable and able to take advantage of foreign habitats (Collins and Crump 2009). Often these exotics are dispersive, competitive, opportunistic, robust, toxic and highly fecund with a short generation time. Traits such as those just listed enable many exotic species to spread rapidly from the place of introduction and into new areas (Lever 2001, 2003; Meshaka 2001). When this happens the exotic is usually referred to as an invasive species. Invasive anurans (e.g., African clawed frogs *Xenopus laevis*, bullfrogs, cane toads, coqui frogs) have been the focus of intensive research on everything from impact and behavior to evolutionary responses of indigenous fauna. The general view is that invasive anurans are bad news and that we need to develop ways of controlling them. Particularly in Australia there is massive concern about the invasion of cane toads. But despite extensive research in many fields (from trap design through to genetic manipulation), there are currently no viable means of controlling them or of reducing their ecological impact (Molloy and Henderson 2006). A novel approach to controlling invasive anurans is to identify a point of vulnerability in the life history of the invader and to target control measures at that vulnerability. This method may be particularly effective if the invader belongs to a genus not represented in the introduced range because the point of vulnerability will often be specific to the invader. The invasion of cane toads in Australia provides an excellent opportunity for lineage-specific control measures, because the toad is the only member of its genus on that continent (Cogger 2000). The same applies to Hawaii where there are no native anurans but 6 exotic species (Collins and Crump 2009, Table 1). In the following paragraphs I will develop these ideas further.

MANIPULATION OF POND HABITATS AS A POTENTIAL CONSERVATION STRATEGY

One obvious point of vulnerability for many anurans is their reliance on ponds for reproduction. So, how can we best use information on pond preferences for conservation efforts? In terms of controlling local populations of invasive anurans (Table 1.), the most obvious answer is to manipulate habitat characteristics to make ponds unsuitable (Hagman and Shine 2006). As discussed earlier, anurans are often highly selective in their choice of spawning sites. Presumably that selection is based on certain characteristics of the pond habitat (Savage 1961; Beebee 1996; Monello and Wright 1999), suggesting that we might be able to manipulate those characteristics to reduce its suitability as spawning site (Hagman and Shine 2006). The first step is to identify the characteristics used by the invasive (Hagman and Shine 2006). The widely introduced cane toad (Lever 2001; Table 1.) is a good example of a species for which this approach might be useful. Cane toads prefer shallow (often ephemeral) ponds with open surroundings and a gentle slope at the water's edge (Hagman and Shine 2006; Semeniuk et al. 2007, Figure 5.).

Thus, eliminating such traits of ponds in the introduced range would presumably discourage cane toads from spawning. Many of the sites that are used by invasive cane toads in Australia are by-products of road construction (Hagman and Shine 2006), reflecting the tendency for toads to use roads as dispersal corridors (Seabrook 1993; Brown et al. 2006). A minor shift in road construction techniques, such that roadside ponds had steeply sloping sides rather than gently sloping banks, would eliminate a high proportion of all suitable toad-spawning sites at the current invasion front in tropical Australia (Hagman and Shine 2006). Similarly, regular slashing of roadside vegetation by traffic authorities not only facilitates toad dispersal (Brown *et al.* 2006), but also generates open banks around potential spawning sites. Leaving dense vegetation on those road surrounds would impede toads significantly in both respects.

More generally, toads are a highly conservative group with many species apparently having similar criteria for spawning site selection (Hagman and Shine 2006). The same type of habitat manipulations may thus be effective against other exotic toads in other parts of the world (Table 1), for example the black-spined toad (*Bufo melanostictus*) in Papua New Guinea and the green toad (*Bufo viridis*) in Spain and Russia (Lever 2003). Reversing these habitat manipulations (i.e. clearing the surrounding vegetation and creating gentle slopes and extensive shallows) may conversely help to conserve disadvantaged species such as the natterjack toad (*Bufo calamita*), which is declining in many parts of Europe (Beebee et al. 1990; Beebee 1996), or the endangered Houston toad (*Bufo houstonensis*) in the United States (Beebee 1996). Figure 6 provides a simple model of the ideas outlined above.

Anuran reproduction and population density is often limited by the availability of suitable breeding ponds (Donnelly 1989; Rico et al. 2004; Toledo and Haddad 2005). Manipulations to increase the density of suitable ponds may therefore be useful for conserving threatened and vulnerable populations. Such manipulations may sometimes be surprisingly cheap and easy to achieve.

Figure 5. Typical pond (a) used for spawning by invasive cane toads (*Bufo marinus*) in the wet tropics of northern Australia, compared to a nearby pond (b) that was not used by cane toads. Note how the two ponds differ in the degree of surrounding vegetation, water depth and angle of the slope at the water's edge. Photo: Mattias Hagman.

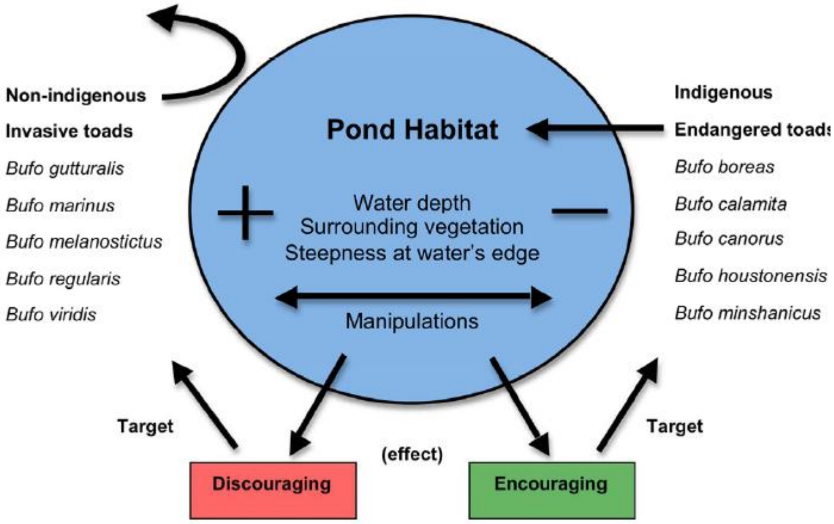

Figure 6. A simple model of how manipulations of pond habitats could either discourage use by invasive toads or (if reversed) encourage use by endangered toads. The model lists a few potential candidate species in each of the two categories.

An interesting example comes from the rainforests of South America, where many species of poison frogs deposit their tadpoles in phytotelma; small pools of water that form in leaf axils of bromeliads and other plants (Donnelly 1989; Kitching 2000; Summers 2002; Brown et al. 2008). Such pools may be the only aquatic environments available in many parts of the rainforest and are also home to an astonishing number of other species, including communities of dragonfly larvae, mosquito larvae, crustaceans, algae, protozoa and a host of microorganisms (Kitching 2000). These miniature ponds thus form small and enclosed ecosystems complete with food webs of detritus and guilds of saprophages, herbivores and predators (Kitching 2000; Forsyth 2008). In a Peruvian project wild poison frogs were provided with artificial pools in the form of discarded and modified soda bottles to increase the density of tadpole rearing sites in patches of rainforest. The frogs readily utilized these artificial ponds, which resulted in increased breeding activity and production of additional tadpoles (Summers 2002). The project recruited poor people who live in the forest and encouraged them to harvest some of the surplus frogs for export to the pet trade (no adult frogs were collected, and a certain percentage of the young were left to form the next generation). Conservation efforts based on manipulating the availability of anuran spawning sites in the landscape thus benefited the frogs as well as the forest and the people who live in it (offering local people a way to increase their income from frogs also gave them an economic incentive to preserve the forest in which the frogs live: Summers 2002).

Will habitat manipulations to discourage use by exotic anurans affect native species? My observations in Australia suggest that native frogs spawn in many of the sites not used by invasive cane toads, so that habitat manipulations in that area are unlikely to significantly affect spawning-site availability for native anurans (bear in mind that the cane toad is the only member of its genus in Australia, and that its spawning-sites preferences is likely to differ from those of native frogs). Generally native species can be expected to prefer natural habitats, whereas invasive species often are generalists that are adaptable and able to exploit a wider range of habitat types, including disturbed areas (Lever 2003; Collins and Crump

2009). For example, broad-scale clearance of native vegetation in Australia caused declines in many native frogs (and other vertebrates) but increased the number of exotic invaders (Woinarski et al. 2006). Many invasive anurans do indeed appear to benefit from anthropogenic activities and may even prefer to spawn in sites such as roadside ditches, scrapes, concrete pools and farm ponds (Collins and Crump 2009). Thus, changing the habitat characteristics of such sites to make them more natural (e.g. by allowing dense growth of native vegetation, etc) may well encourage use by native species while, at the same time, discouraging use by invasive anurans. However, this inference needs to be tested before any control measures are implemented; it would be highly counterproductive to modify ponds in ways that reduced their usage by native anurans, or other native taxa, rather than by invasive anurans. Hence, studies to assess the impact of pond modification on usage by native taxa (especially anurans), as well as by invasive anurans are warranted.

Although reducing the availability of suitable ponds to prevent invasive anurans is an attractive prospect, it may often be impossible to eliminate breeding opportunities on a landscape scale. Heavy rains may cause many small ponds to form, some of which will prove attractive to invasive anurans. Even if all available ponds were modified, presumably the invasive would be flexible enough to compromise and eventually, spawn in less than optimal situations. Thus, no feasible habitat modifications will actually eliminate breeding. Instead, the end result of habitat modification of this type would be to concentrate reproduction into a smaller number of sites. That is, it would effectively encourage communal breeding in a few sites, rather than having solitary pairs breeding in a much greater number of ponds spread over a broad area. To maximize this effect, it may be possible to actually "improve" some ponds while making all others less suitable.

Thus, although eliminating suitable spawning sites would be impossible, concentrating oviposition might be feasible. Would such a change be of any use in ameliorating impact? I suggest that such a concentration of reproduction may help to control populations of invasive anurans for three reasons:

1) By setting up highly favorable breeding sites in areas close to roads, we can attract invasive anurans to sites where logistics facilitate capture and removal of breeding adults and their progeny. Indeed, the pond itself could become a self-contained trap if surrounded by an appropriately sized mesh fence with inward-facing funnels. This may be an effective method for large invasive anurans such as bullfrogs and cane toads. For example, the large size and low climbing ability of cane toads can restrain them within a fence that would be permeable to native anurans. Alternatively, smaller traps to capture adult toads, tadpoles or metamorphs could be deployed at such sites.
2) One major mechanism of impact involves mortality of native predators that attempt to ingest invasive anurans that are highly toxic (Phillips et al. 2003; Oakwood 2004). Spatial concentration of reproduction would tend to increase spatial heterogeneity in densities, especially of juvenile anurans that, because of their body size, may pose the greatest danger to small native predatory reptiles and mammals. Thus, predator populations in areas remote from optimal ponds may be less severely impacted than would otherwise be the case.
3) Eggs and tadpoles of most toads are highly toxic, which means that invasive toads often are relatively invulnerable to native predators (Crossland and Alford 1998;

> Crossland 2001), particularly in systems such as Australia, where there are no naturally occurring toads that have allowed predators to evolve resistance to toad toxins (Phillips et al. 2003). However, intraspecific competition is often intense, with many species of tadpoles rapidly devouring newly laid eggs, and strong competitive suppression of conspecific growth and size at metamorphosis (Hearnden 1991). For example, one study reported that survival of toad eggs fell from 70% when older cohorts were absent, to 5% when they were present (Hearnden 1991). Importantly, this cannibalism provided no detectable advantage to growth or survival of the older cohort. Growth rates, larval periods and size at metamorphosis of toad tadpoles were also impacted by the presence of older conspecific tadpoles (Hearnden 1991). Similar effects occur also at the metamorph stage via direct intraspecific predation on the shorelines of ponds (Hagman and Shine 2008b; Pizzatto and Shine 2008). Presumably the intensity of intraspecific effects such as cannibalism and competition will be greater if young toads are concentrated around a few ponds rather than widely dispersed around many (Crump 1986; Bayliss 1995).

Thus, simple and inexpensive modifications to ponds may well concentrate oviposition, thereby intensifying intraspecific competition, enhancing spatial heterogeneity in abundance, and exploiting density-dependent mechanisms to facilitate control of local populations of invasive anurans. Enhanced spatial heterogeneity in abundance presumably would tend to provide areas free of the invasive, where native anuran taxa can spawn without being impacted. More generally, the degree to which resources are clumped versus dispersed may be a critical determinant both of the success of invasive species, and of the magnitude of their impact on native taxa (Kiesecker et al. 2001). Anthropogenic disturbance frequently generates such clumping, and often exacerbates problems associated with invasive organisms (Petren and Case 1998; Kiesecker et al. 2001). Information on spawning-site selection by invasive anurans suggests that we may be able to take advantage of this sensitivity to resource clumping, by concentrating the spatial distribution of reproductive activity of the invasive organism and hence, intensifying density-dependent mechanisms for population control.

Other Potential Opportunities for Lineage-Specific Control Measures

As noted earlier, life history traits of invasive species may often be sufficiently different from those of native taxa to allow for lineage-specific control measures targeted at those traits. The larval alarm pheromones mentioned earlier in this chapter might offer one such opportunity. These alarm pheromones generally induce avoidance responses in other tadpoles of the same species (Hews 1988; Hoff et al. 1999; Hagman 2008; Hagman and Shine 2008a). Cross-reactions to alarm pheromones have been documented in a few cases. However, that has usually been between closely related species within the same genus, presumably reflecting homology (Hagman 2008). This pattern suggests specificity of these alarm pheromones, at least on the genus level (Hagman and Shine 2008c). Wassersug (1997) originally suggested that it might be possible to use larval alarm pheromones to control invasive anurans - an idea that I have tested on cane toads in Australia with encouraging results (Hagman and Shine 2008a, 2009a; Hagman 2010). For example, I found that cane toad tadpoles consistently fled from toad alarm pheromones (Hagman and Shine 2008a), whereas native Australian anurans did not avoid the same cues (Hagman and Shine 2008d, 2009b). Recurrent exposure to these pheromones also reduced size at metamorphosis (Hagman et al. 2009) and increased mortality of toad tadpoles in outdoor ponds (Hagman and Shine 2009a). The pheromone itself probably did not cause direct mortality in my trials. However, I suspect that the smaller sizes of pheromone-exposed toads rendered them more vulnerable to diseases, parasites, predators and desiccation than their larger siblings in the control groups (Hagman 2010). Whatever the case, these studies suggest that the pheromone has a stressful effect on cane toad tadpoles but not on tadpoles of native anurans, and that it therefore might be possible to use it for controlling toads specifically without impacting on native species (Hagman 2010).

The ability to influence tadpole behavior is the most obvious use for alarm pheromones (Wassersug 1997). For example, we could distribute pheromones in ponds to drive tadpoles towards a trap or to keep them away from favored microhabitats. That way we could disrupt thermoregulatory and foraging behaviors by driving tadpoles away from warm shallows with plentiful food resources and into cool and nutrient-poor areas of the pond. Another option is to use alarm pheromones to interfere with larval development and metamorphosis. Many tadpoles respond to environmental cues such as predation risk and competition with shifts in morphology or life history transitions (Chivers et al. 1999; Babbit 2001; Marquis et al. 2004; Relyea 2007). According to theory this strategy is a tradeoff between survival and fitness. For example, escaping a risky environment by sacrificing size for rapid development may increase an individual tadpole’s immediate survival (Wilbur and Collins 1973; Relyea 2007). In my study, cane toad tadpoles presumably perceived alarm pheromones as an indication of predation risk in the aquatic environment and responded by metamorphosing sooner and smaller (and hence were able to escape the water quicker) than their siblings in the control ponds (Hagman and Shine 2009a). However, small metamorphic size often affects later survival (as observed in my study) and reproductive success (Howard 1980; Berven 1981, 1982; Berven and Gill 1983; Smith 1987; Semlitsch et al. 1999; Gerhardt 1994; Altwegg and Reyer 2003; Relyea 2007). Larval alarm pheromones could thus potentially be used to manipulate developmental trajectories of invasive anuran larvae in such way that it lowers fitness and reduces viability. Distributing pheromones in the margins of a pond to drive invasive tadpoles to the center of it should advantage native tadpoles that inhabit the same pond for several reasons. First, native tadpoles would have access to more favorable areas (i.e. the warm shallows of the pond’s margins) that were free from the invaders. Second, spatial partitioning would decrease competition for resources (e.g. food and warm microhabitats) between native and invasive species. Indeed, concentrating the invaders in the center of the pond should instead increase intraspecific competition between the invaders. Third, if interspecific competition occurs native species should have a competitive edge over pheromone-stressed and weakened invaders.

In addition to breeding site selection and larval alarm pheromones, there should be many other traits that are suitable for lineage-specific conservation efforts. Traits that are associated with reproduction, development and communication may offer the best opportunities in this respect. For anurans these processes are typically linked to the aquatic environment. Researchers are limited only by their knowledge and ingenuity.

CONCLUSION

The ideas outlined above are largely speculative. However, some preliminary studies have been conducted with encouraging results (Hagman and Shine 2006; Hagman and Shine 2008a,c,d; Hagman and Shine 2009a,b,c; Hagman et al. 2009; Hagman 2010). In spite of extensive research in many fields there currently are no viable means of controlling invasive anurans, or of reducing their impact in foreign ecosystems. In addition to controlling invasive anurans, we need to conserve species that are endangered. In this chapter I have identified two aspects of anuran biology that potentially could be used for conservation efforts. First, many anurans are highly selective in their choice of spawning-sites, thus offering the potential that simple habitat manipulations could either impede or concentrate reproduction of invasive anurans. Reversing these manipulations may conversely encourage use by native anurans and help to conserve endangered species. Second, many tadpoles exhibit strong avoidance behavior in response to conspecific alarm pheromones. These chemicals are often specific in their activity and could potentially be used to disrupt fitness-related behaviors (e.g., thermoregulation, foraging) and to manipulate the developmental trajectories of invasive anurans in ways that reduces their viability. Thus, by careful habitat manipulations and use of alarm pheromones we could concentrate invasive anurans spatially and exploit density-dependent adverse ecological processes (e.g. cannibalism, competition, predation and shifting life history transitions) to reduce their numbers and (hence) impact in foreign ecosystems.

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Chapter 2

RECREATIONAL AND COMMERCIAL PONDS IN THE SOUTHEASTERN UNITED STATES: FACTORS INFLUENCING NUTRIENTS AND FISH PRODUCTION

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ABSTRACT

Recreational fishing is a popular pastime in the United States. Private stakeholders along with state and federal agency fishery managers are dedicated to increasing the productivity of their ponds to enhance this recreation. One of the procedures utilized for the attainment of maximum fish production is the application of inorganic fertilizers. In the southeastern United States fertilization is a widely accepted management tool. The purpose of fertilization is to increase phytoplankton production, which in turn results in an increase of zooplankton biomass and more food for fish by trophic cascade. The use of fertilizers to increase the production of fish in ponds has become widespread in recent years. It has been shown, however, that the physical characteristics and water chemistry of lakes also influence lake productivity. Fish production and condition in unfertilized ponds are inextricably linked to the amount of bioavailable nutrients in the water column. Additional variables such as sediment nutrients, benthic macro-invertebrate communities and macrophytes could play important roles in regulating the amount of available nutrients necessary to influence productivity at different trophic levels. While recreational ponds rely on nutrient availability through trophic cascade, fish production in commercial ponds depend on nutrients from supplemental food in the form of manufactured feed. Commercial catfish aquaculture takes place in earthen ponds where supplemental feed increases biomass for subsequent harvest. Production is often limited by low dissolved oxygen concentrations and nitrogen toxicity in the form of ammonia and nitrite accumulation in the system. The Mississippi River Alluvial Valley in the southeastern United States comprises nearly 65% of the total land devoted to catfish aquaculture in the United States. It is predicted that in the next two decades commercial catfish production will need to increase 5-fold to accommodate the human protein requirements. This increased need in production may prove difficult to accomplish in conventional earthen ponds. Today, new innovative strategies are taking aim at improving pond conditions and increasing production by enhancing dissolved oxygen concentrations and reducing harmful nitrogenous toxicity. The Split Pond System (SPS) is one new strategy which uses mass algal communities to assimilate harmful ammonia and increase dissolved oxygen concentrations through photosynthesis during the day. The SPS uses a low-speed water wheel which circulates pond water between a fish compartment and a waste treatment compartment. The water wheel enables the suspension of particulate matter in the water column facilitating nitrogen biogeochemical transformations. The production associated with a SPS is estimated between 20,000 and 30,000 pounds of catfish acre-1; 3-5 times greater than traditional earthen ponds. Nutrient management strategies in both recreational and commercial fish ponds are an essential tool in sustaining quality fish for both sport and economic value in the southeastern United States.

INTRODUCTION

In the southeastern United States, ponds are typically used for recreation such as angling, while other ponds are used for commercial production of seafood. Ponds used for recreational purposes are commonly managed with the application of fertilizers to enhance this recreational use. Commercial ponds in the southeastern United States comprise mostly of ponds committed to catfish farming. Most ponds in this region are termed embankment ponds, which are constructed by excavating a pond basin and using the fill for the levee or berm.

This chapter will discuss recreational fishing popularity, fish species and stocking rates, economic value, pond fertilization, and sediment nutrients and benthic-invertebrates. Additionally this chapter will examine the history of early aquaculture, physical pond features and formations of commercial ponds, the economic value and international competition, basic industry inefficiencies, and the future of commercial ponds.

1. RECREATIONAL FISHING POPULARITY NATIONWIDE AND IN THE SOUTHEASTERN UNITED STATES

Fishing is most likely the number one recreational pastime nationwide in the United States. In the 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation conducted by the U.S. Fish and Wildlife Service (USFWS), the U.S. Department of Interior (USDI), and the U.S. Department of Commerce (USDC) it was estimated that there were over 28 million anglers who fished on lakes, reservoirs, and ponds. This is a small decrease from the 1991 survey that estimated over 35.6 million anglers. It should be noted that the survey did not distinguish between lakes, reservoirs, or ponds.

Therefore, the total number of “pond only” anglers is unknown. The Great Lakes were the only freshwater locations omitted. The southeastern United States had an estimated 7.2 million licensed anglers in 2009 (Table 1), with the largest number of licensed anglers coming from Florida (~1.5 million) and the lowest coming from Mississippi (~367,000) (USDI 2009). The total expenditures, however, have nearly doubled nationwide since 1991 when they were approximately $24 billion compared to $42 billion in 2006. This will be further discussed in section 1.3. Although there has been a decrease in participation in the last 15 years, anglers still put an overwhelming demand on already over-utilized public waters.

The southeastern United States, however, has been blessed by its geographic landscape, which happens to be prime real estate for pond formation for both public and private uses. The southeastern United States is defined by the U.S. Fish and Wildlife Service (USFWS) as the states of Arkansas, Louisiana, Mississippi, Alabama, Georgia, Tennessee, Kentucky, North Carolina, South Carolina and Florida (USDI 2006). Hereafter, when the term *southeastern United States* is mentioned, it will subsequently include only the states listed above as defined by the USFWS.

Table 1. Estimated license sales for 2009 from the United States Fish and Wildlife Service for residents and non-residents for the southeastern United States

State	Paid License Holders	Resident Licenses, Tags, Permits and Stamps	Non-Resident Licenses, Tags, Permits and Stamps	Total License, Tages, Permits and Stamps	Gross Cost
Alabama	503,853	354,776	120,601	475,377	$7,342,421.15
Arkansas	671,266	527,580	245,570	773,150	$8,800,482.00
Florida	1,435,335	1,625,038	616,033	2,241,071	$25,499,799.00
Georgia	606,759	671,104	98,958	770,062	$7,254,190.00
Kentucky	593,805	519,125	109,494	628,619	$8,326,519.00
Louisiana	635,739	756,493	177,561	934,054	$8,769,569.00
Mississippi	366,301	378,660	61,962	440,622	$5,076,120.00
North Carolina	946,668	972,457	131,995	1,104,452	$19,424,526.00
South Carolina	505,616	491,311	109,859	601,170	$5,642,789.00
Tennessee	900,240	773,506	191,028	964,534	$17,409,442.00

1.1. Fish Species and Stocking Rates

Keeping the vast numbers of anglers satisfied in the southeast takes a lot of effort, as well as sufficient knowledge of how ponds function to create good fisheries for both public and private recreation. A pond owner faces many decisions when deciphering what kind of fishery they would like and what kind of fish to stock. An understanding of basic ecological principles relating to trophic relationships and pathways, as well as population dynamics, should be the basis for species recommendations and subsequent management techniques for the landowner (Flickinger et al. 1999). A widely recommended combination that provides sustainable fishing is largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and channel catfish (*Ictalurus punctatus*). The use of these species together, especially largemouth bass and bluegill (Swingle and Smith 1938), when properly managed, have consistent reproduction and create a beneficial predator-prey interaction that can be sustained without supplemental stocking. Channel catfish, however, usually have low (if any) reproductive success in ponds. Therefore, to keep a viable population present, supplemental stocking will need to take place. As previously discussed, the combination of the abovementioned species has proven successful, especially in the south. Other species, however, can also be used depending on your geographic locations. Fish species such as smallmouth bass (*Micropterus dolomieu*), pumpkinseed (*Lepomis gibbosus*), redear sunfish (*Lepomis microlophus*), crappie (*Pomoxis spp.*), northern pike (*Esox lucius*), walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), brown trout (*Salmo trutta*), rainbow trout (*Onchorynchus mykiss*), and brook trout (*Salvelinus fontinalis*) have all been stocked in ponds, with some having more success than others (Willis et al. 1990). Many stocking rates have been tried on a "trial-and-error" basis. The most successful rate in the south, however, is to stock 500 bluegill acre^{-1} in the fall while in the following spring to stock 50 largemouth bass acre^{-1}. The reason for the gap in stocking time is strategic. By the time the largemouth bass have been stocked in the spring, the bluegill should be spawning, or have spawned by then, providing ample forage for largemouth bass. Largemouth bass, which are typically the apex predator of most southeastern ponds, are the most sought after freshwater fish species by anglers in the United States as reported by the USDI (2006). Nearly 10 million anglers spent 161 million days pursuing largemouth bass. Panfish were a close second with roughly 7.5 million anglers and 101 million days fished (USDI 2006). Although the cost and time committed to providing a successful fishery may be high, the estimated revenue is impressive.

1.2. Economic Value

As previously mentioned, the number of anglers has decreased nationwide by nearly 8 million anglers in the last 15 years. The estimated expenditures, conversely, have increased nearly two fold during this time. This is a discerning trend for anglers, which is a result of the recent economic conditions. To make up for the yearly loss of anglers, states are prompted to increase license, tag, permit, and stamp fees for both residents and non-resident anglers. In 2009, the USFWS calculated a gross license cost by anglers to be approximately $605 million. Previously, Table 1 illustrated the breakdown by state license costs for the southeastern states. Consequently, Florida created the most revenue at roughly $25.5 million dollars in license sales, while Mississippi was the lowest with just over $5 million. This coincides with the number of license holders in each state. This data also includes monies created from special tags, permits, and stamps offered by participating states. In 2006, 30 million U.S. residents 16 years old and older enjoyed a variety of fishing opportunities throughout the United States. Anglers fished 517 million days and took 403 million fishing trips. They had $42 billion in fishing-related expenses during 2006. Fishing-related expenses could be defined as land leasing and land ownership, as well as magazine subscriptions, books, and club membership dues and contributions. Freshwater anglers were the majority of licensed anglers in the United States with nearly 25.4 million participants that fished 433 million days and took 337 million trips to freshwater destinations in 2006. Freshwater anglers spent $26.3 billion on freshwater fishing trips and equipment (USDI 2006). Equipment can be defined as fishing rods, reels, baits, and tackles, as well as marine expenses such as boats, motors, and boat accessories. The economic value of ponds, however, is hard to measure as there is no concrete data specifically for ponds.

1.3. Pond Density Nationwide and in the Southeast

Small impoundments are often constructed for purposes other than sport fish production (Flickinger et al. 1999). Their small sizes and vast numbers provide convenient angling opportunities for millions of people of all ages in the southeast. Ponds are an important recreational resource nationwide (Lopinot 1978). In this chapter, a recreational fishing pond will be defined as a small water body up to 40 ha in surface area (Willis et al. *In press*). Thus, small water bodies of all types including impoundments (hill ponds), excavated ponds or pits, pump-storage levee ponds, and bodies of natural origin (e.g., glacial lakes) will subsequently be included in the term *pond* (Willis and Neal *In press*). Subsequently, other small water bodies such as levee ponds and gravel pits, as well as ponds not necessarily used for recreational fishing, will be included when the term *pond* is used in the text. Pond densities nationwide are illustrated in Figure 1.

Development of new ponds and the loss of old ponds change pond abundances yearly (Willis and Neal *In press*). Table 2 illustrates the number of ponds, as well as other attributes including the total pond to state area ratios. Nationwide there are roughly 4.5 million natural and artificial ponds between 0.5 and 40 hectares. In 1950, however, there were roughly 1.6 million acres (0.6 million ha) of ponds; this increased to 2.5 million acres (1.0 million ha.) by 1970, which is a 56% increase in 20 years (Martin 1972). Today, there are just over 7.4 million acres (3.0 million ha.). It needs to be noted, however, that there may be discrepancies in the results as the two studies may have defined pond size differently. Within the ten states that represent the southeastern region of the continental U.S., there are nearly 1.1 million ponds present, which is the largest amount of any region.

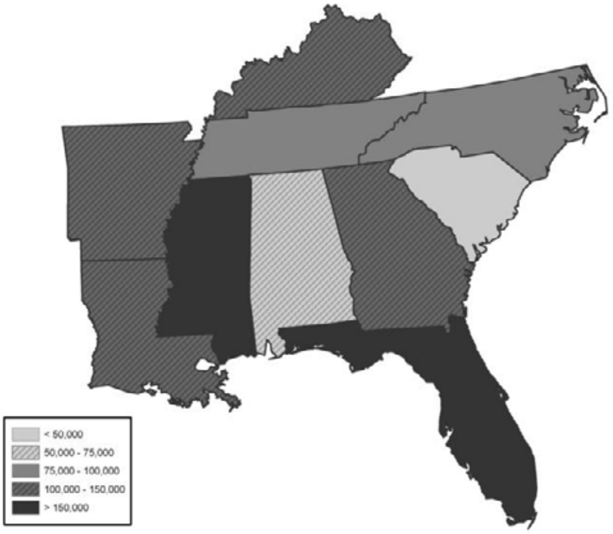

Figure 1: Distribution of pond resources (0.5 to 40 ha) in the southeastern U.S. Data were derived from the 1:24,000 scale U.S. Geological Survey National Hydrography Dataset. Modified from Willis and Neal *In* press.

Those 1.1 million ponds represent approximately 6.2% of the entire land area of the region, which is noteworthy when compared to other regions in the United States. Swingle

(1970) reported that the number of ponds in the U.S. increased from an estimated 20,000 in 1934 to over 2 million by 1965. Today in the U.S., there are an estimated 4.5 million ponds. This is more than double what Swingle found some 45 years ago, illustrating that either pond development has slowed down or the ponds built during Swingle's study have disappeared due to both anthropogenic and natural causes.

Table2. Pond resources (0.5 to 40 ha) of the southeastern U.S. by state. Data were derived from the 1:24,000 scale U.S. Geological Survey National Hydrography Dataset. Percent land area is pond area divided by state area, modified from (Willis and Neal *In* press)

State	Number of Ponds	Pond Area (Hectares)	State Area (Hectares)	Percent Land Area
Alabama	74,474	50,151	13,394,519	0.37%
Arkansas	127,714	63,255	13,704,573	0.46%
Florida	159,236	203,695	14,456,294	1.41%
Georgia	123,161	132,896	15,185,105	0.88%
Kentucky	139,733	43,530	10,442,831	0.42%
Louisiana	132,823	119,885	11,871,607	1.01%
Mississippi	160,237	77,719	12,333,411	0.63%
North Carolina	82,912	42,889	12,703,452	0.34%
South Carolina	40,874	34,665	7,994,713	0.43%
Tennessee	78,408	27,448	10,901,795	0.25%
Totals	1,119,572	796,133		

1.4. Pond Fertilization

Fertilization is a technique that has been observed by fisheries professionals for many years (Johnson et al., 1990). The implementation of fertilizer to enhance pond productivity is a widely accepted management tool in the southeastern United States. Private stakeholders along with state and federal agency fishery managers are dedicated to increasing the productivity of their lakes and ponds to enhance this recreation. One of the procedures for attaining maximum fish production is the application of inorganic fertilizers (Zeller 1953). The purpose of fertilization is to increase phytoplankton production, which in turn results in an increase of zooplankton biomass which means more food for fish through trophic cascade. Increasing production of fish in ponds with the use of fertilizers has become widespread over the years (Smith and Swingle 1940). In 1940, Smith and Swingle observed that the use of fertilizers to increase the production of fish in ponds had become widespread. Their findings in 1940 closely resembled the results from their study in 1938 when they compared inorganic to organic fertilizers. They found that the unfertilized system produced lower phytoplankton abundances when compared to the fertilized. On the basis of these and subsequent observations, fertilization was needed to be part of the equation to have a productive fishery. Inorganic fertilizer is the most common form of fertilizer used for fish production. There are four forms of fertilizer that are used regularly: granular, powdered, liquid, and time-release. Granular fertilizer is becoming more widespread as it is easy to apply and is cheaper than its liquid counterpart. Care must be taken, however, when applying granular fertilizer as you do not want to apply it in a way (broadcasting) that will rapidly sink to the bottom and be tied up by the soils instead of becoming available to the water column (Brunson et. al 1999). There are two ways to avoid this problem when dealing with granular fertilizer. The first is to build a platform at depth of 4-12 inches below the water surface. This will reduce the amount of interaction between the granules and the sediment. The alternative method, if a platform is not an option, is simply to slit the top of the bag and then to manually place the bag on the pond bottom. This will allow slow release of the nutrients via wave action, as well as reduce the interaction between the granules and pond bottom. Powder is more expensive than both liquid and granular; however, it is very easy to apply. Liquid fertilizer dissolves the most readily; however, caution should be used during application as it needs to be diluted. A common dilution ratio is 1 part fertilizer with 5-10 parts water. Time-release fertilizer is also the most expensive for landowners. Additionally, one application in the spring should be sufficient for the entire growing season. Table 3 suggests some common fertilization rates and applications for the southeast. One of the most important aspects of an effective management plan is nutrient application; however, it receives the least amount of research (Ashley and Stockner 2003).

The benefit of fertilizers for enhancing production in ponds is evident. The estimation for required nutrients for a pond fertilization program, however, depends on many variables such as substrate materials and antecedent water quality, as well as the type of fertilizer applied. In addition, fertilizer recommendations for one location may be unsuitable for another location, outlining the importance of knowing the natural potential productivity of the respective system. Therefore, the first step when considering potential ponds for nutrient enrichment is to determine the trophic status of each pond by examining seasonal concentrations of phosphorus and nitrogen as well as standing stock and abundance of phytoplankton, zooplankton, and fish (Ashley and Stockner 2003).

Table 3. Common fertilization types, forms and application rates for the southeastern United States. Rates could vary with geographic locations due to alkalinity levels and climatic conditions

Fertilizer Type	Formulation (N-P-K)	Application Rate
Granular:	20-20-5	40 pounds acre^{-1}
	15-15-15	50 pounds acre^{-1}
	0-46-0	4-8 pounds acre^{-1}
	0-20-0	8-16 pounds acre^{-1}
Powder:	12-52-4	2-8 pounds acre^{-1}
	12-49-6	2-8 pounds acre^{-1}
	10-52-0	2-8 pounds acre^{-1}
Liquid:	10-34-0	1 gallon acre^{-1}
	11-37-0	1 gallon acre^{-1}
	13-37-0	1 gallon acre^{-1}
Time-release:	10-52-0	25 pounds acre^{-1}
	14-14-14	75 pounds acre^{-1}

To achieve high survival and fast growth of fish in ponds, it is essential to develop and sustain desirable phytoplankton and zooplankton populations as the fish rely completely on naturally occurring foods (Kurten 1995). In order to stimulate phytoplankton production in hatchery ponds, phosphorus fertilizers are commonly used (Geiger1983a, 1983b; McCarty et al. 1986; Young and Flickinger 1989) because phosphorus is usually the first nutrient to limit phytoplankton growth in freshwater ecosystems (Moss 1980; Boyd 1990; Wetzel 1975). This is due to phosphorus being both heavily absorbed by sediment through opposite charges and easily assimilated by plants, which makes it unavailable to the rest of the water column. It is still debated whether the primary control is by resources (bottom up forces) or predators (top down forces) (Power 1992). According to the bottom up view, organisms on each trophic level are food limited. For instance, if there is too little phosphorus in the pond water column, it will not stimulate enough phytoplankton production, which will hinder zooplankton production (Kurten 1995). The top down view holds that only the apex predator or any organisms at the top of the food chain are food limited (Bowlby and Roff 1986). The top down view also ensures that fish, as primary consumers, are the main influence on the process of the system.

1.5. Sediment Nutrients and Benthic Invertebrates Interactions in Ponds

The emphasis on aquatic insects and their habitats has increased in recent decades (Merritt and Cummins 1984). In much of the aquaculture literature, however, sediment and benthic macro-invertebrates are mentioned only in passing. This is somewhat surprising as the potential importance of soils in pond fertility has been known for some time (Pershall and Mortimer 1939; Mortimer 1949; White 1986). Pond productivity is directly dependent on the natural productivity of the sediment. Sediment organic matter, for instance, is a key component of any aquatic ecosystem, and any variation in its abundance and composition has important effects on many of the processes that occur within the system (Batjes 1996). Benthic macro-invertebrates also influence ponds through bioturbation. Bioturbation increases exchange rates and solubility of nutrients naturally occurring in the system as well as from fertilization applications (White 1986). Benthic macro-invertebrates can influence lake and fish productivity in other ways. Benthic macro-invertebrates may release growth substances into the water which could promote algae growth in the pond, additionally, they could compete directly with young benthic feeding fishes for resources. As mentioned earlier, the implementation of inorganic fertilizers is commonly used to enhance fish production. Studies have shown, however, that the biomass of insects may also be increased by additions of inorganic phosphorus and nitrogen through increases in autotrophic production (Quamme and Slaney 2003). An increase in insect biomass provides more prey for fish, thus making insects a high priority in recreational fishing ponds. Invertebrates are affected both indirectly and directly by many physiochemical factors. The nature of the substrate, for instance, is probably the most important physical variable that could determine the diversity and density of invertebrates as well as any taxon specific differences in the aquatic ecosystem (Voshell 2002). Nutrients such as phosphorus and nitrogen can have both positive and negative impacts on invertebrates. If nutrient concentrations are too high, eutrophication could take place which could disturb the balance of the aquatic environment proving detrimental to invertebrate abundance. Under appropriate densities, however, nutrients can positively affect invertebrates. Nitrogen and phosphorus augmentation can increase biomass of benthic algae (Bothwell 1989) and microbial growth (Peterson et al. 1993, Hullar and Vestal 1988), providing food for many aquatic insect grazers (Lamberti and Moore 1984); thus invertebrate prey density usually increases with plant density (Schramm et al. 1987). While it is known that recreational ponds rely on nutrient availability through trophic cascade, fish production in commercial ponds depends on nutrients from supplemental food in the form of manufactured feed.

2. COMMERCIAL PONDS

2.1. Early Aquaculture in the United States

Commercial aquaculture is an important economic commodity worldwide. Countries around the globe have been farming fish for nearly 4,000 years. Aquaculture is a relatively new industry in the United States establishing roots approximately 200 years ago.

In the 1700s fishing stocks were considered by most to be plentiful, available for all harvest regimes. As the 19th century approached, concerns over the health of wild populations in the form of overharvesting and dam construction were mounting. During this time fisheries in the Exeter River in New Hampshire were being dismantled. Striped bass and sturgeon populations were declining as a result of overfishing, while alewife spawning grounds were affected by dam construction and ultimately destroyed by 1790 (Bowen 1970). In 1871, legislation was passed which created the U.S. Fish and Fisheries Commission. Spencer Baird who worked as secretary at the Smithsonian Institution was named the first Commissioner (Stickney 1996). The purpose of this commission was to provide a recreational enhancement to existing domestic fisheries. Stocking of fish facilitated this need, and thus recreational aquaculture programs were brought about in the United States.

It was not until many years later that commercial production really began to catch on in the United States. In the 1950s an oceanographer by the name of John Ryther estimated the harvestable amount of seafood from the world’s oceans at 100 million tons. Today, we know this number is closer to 85 million tons and because of commercial fishing laws, many countries have formed fishery management groups designed to place strict quotas on catches, and in some cases shut down commercial fishing altogether (Stickney 2009). An alternative to wild caught seafood is farm raised fish which can be produced either on the land in ponds, or raised captively in nets and cages in existing water bodies.

In the United States, much of the aquaculture for commercial production is done in ponds. The most common pond form is the embankment or earthen type. The basic formation of earthen ponds requires on site soil material to create the pond basin. Fill removed from the pond basin is used to construct the berm or levee surrounding the pond. Once this is complete, water can be added and fish may be stocked.

In the United States, earthen ponds are most often used for commercial production of channel catfish, which spend the majority of their life stages in ponds. Commercial catfish farming began in the 1960s after less successful attention was given to the culture of buffalo, bass, crappie and trout (Lee 1981). Commercial catfish farming began in Arkansas, just west of the Mississippi River. As the industry developed, much of the farming was being done in Mississippi. With support from local colleges and universities, towns and cities, catfish farming became a way of life in Mississippi. By 1980, over 27,000 acres in ponds were installed in Mississippi. Arkansas ranked second with just over 10,000 acres in pond production (Lee 1981). This area of land near the Mississippi River is referred to as the Mississippi River Alluvial Valley, or the Delta. The soil in this region is rich for growing grain crops and comprises of very fine clay particles, a necessity for water retention in ponds. The Delta was the perfect setting for any potential catfish farmer. The long periods of warm temperatures yielded optimum growth rates for catfish, water was only a well pump away, and a very low water table with good clean water, free of pesticides and chemicals was readily available for the aqaculturalist. Perhaps the most important feature was the close proximity of fish farms to the processing plants. As catfish farming intensified through the 1980s, processing plants were made available to keep up with the incoming product (Lee 1981). The grains raised on the land were used to feed the catfish in the ponds. The various agribusinesses supported one another as they were interconnected in a web of economic dependence.

2.2. Physical Pond Features

As previously mentioned, embankment or earthen ponds are the most common type of pond used in commercial aquaculture (Steeby et al. 2004). Embankment ponds are typically square to rectangular shaped ponds with levee roads serving as boundaries between ponds. Grading the pond sides to a ratio of 3:1 ensures limited erosion of pond walls. The pond bottom is stripped of all brush and trees, and flattened to aid in harvesting. A typical catfish farmer would strategically place an arrangement of ponds together in a way that would optimize well placement and water pumping, draining, and harvesting (Figure 2).

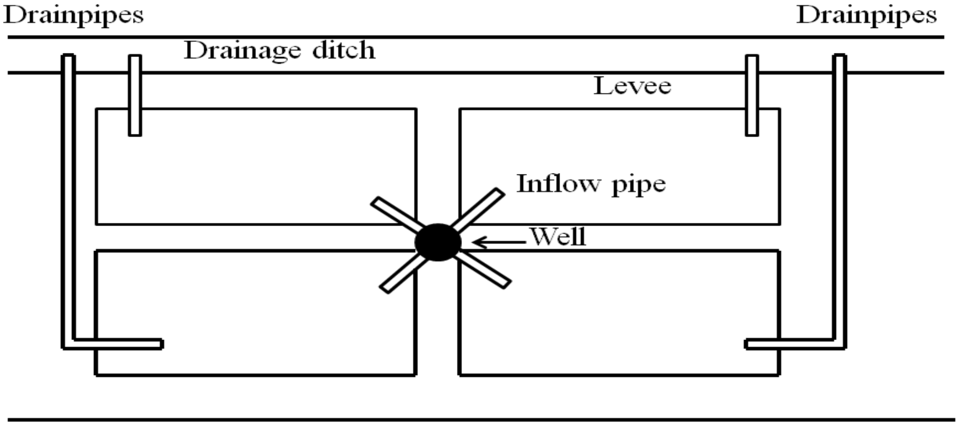

Figure 2. Layout of a typical levee-type catfish pond modified from Steeby and Avery 2002.

Pond soils play a vital role in the appropriate function of aquaculture ponds. During construction the pond bottom is often compacted to reduce permeability; this is one reason why site selection is important when considering building ponds (Munsiri et al. 1995). Over time, natural degradation of embankment levees occurs. Erosion and scouring of levees and banks result from wind/wave action and, to a lesser degree, rainfall. As ponds age, erosion limits the ability for farm vehicles to safely pass on levee roads, and in addition, the resulting sedimentation into the aquaculture pond creates difficult conditions for harvesting (Steeby et al. 2004). Furthermore, Steeby et al. (2004) mention that the rate of sedimentation into aquaculture ponds is highest during the first year of production, and recommend planting Bermuda grass (*Cynodon dactylon*) on the slopes of pond banks to assist with stabilization.

Pond sediments also play a role in nutrient cycling. In the case of catfish aquaculture, feed is added daily throughout the growing season where approximately 75% is lost to the pond system (Boyd and Tucker 1995). Pond soils may be classified as a nutrient sink in commercial ponds until the carrying capacity of the sediment is reached. These eutrophic conditions result in deterioration of water quality and anaerobic conditions at the pond bottom. The development of anoxic conditions at the sediment-water interface reduces production and limits the potential for culture intensification (Avnimelech and Ritvo 2003).

The organic matter associated with feed enters the system and eventually, through the process of detrital rain, becomes a substrate for microbial communities living on the pond bottom. Over time, these nutrients and organic material breakdown and form a sludge on the bottom known as a flocculent layer. Throughout many growing seasons, this sludge material accumulates, which in turn reduces pond volume. Avnimelech and Ritvo (2003) described a way to control sedimentation in fish ponds. Embankment ponds were built in a manner which westerly winds provided surface water and current flow from west to east. A trench was installed on the up-wind side of the pond bottom with a drag line. The water currents directed suspended sediment westward in a fashion that enable it to get intercepted by the trench, thus delaying the processes of sedimentation (Avnimelech and Ritvo 2003).

2.3. Economic Value and Competition

Catfish represent a very large economic commodity to the southeastern United States. In the state of Mississippi, the industry's economic factor totals $1 billion annually, including the creation of jobs, the support other local agribusinesses, and the revenue of sold catfish. Given this fact, it is surprising that the commercial catfish industry has the largest trade deficit of any agricultural enterprise in America. Today, this $9 billion annual trade deficit is overpowering catfish farmers.

International competition with Vietnam and China started to noticeably affect the national production post 2004 (Figure 3). Imports in the form of pangasid and channel catfishes as well as tilapia from these two countries have driven the demand for U.S. farmed catfish downward. Catfish farmers, scientists, and economists alike, are asking the question, where is the bottom?

One potential reason for the high demand of these imports is simply due to their low cost and their successful marketability; that is they look appetizing. So why does the catfish farmer simply not lower the price of their goods in order to better compete with foreign imports? The answer to this seemingly simple problem is actually quite complex. The catfish farmer is selling their product at the absolute cheapest price they can afford. Approximately 50% of the aquaculturalists costs is in the form of feed. In the early 2000s as alternative fuel exploration was under way, corn sources for catfish feed were becoming more expensive as corn was being sold for ethanol use.

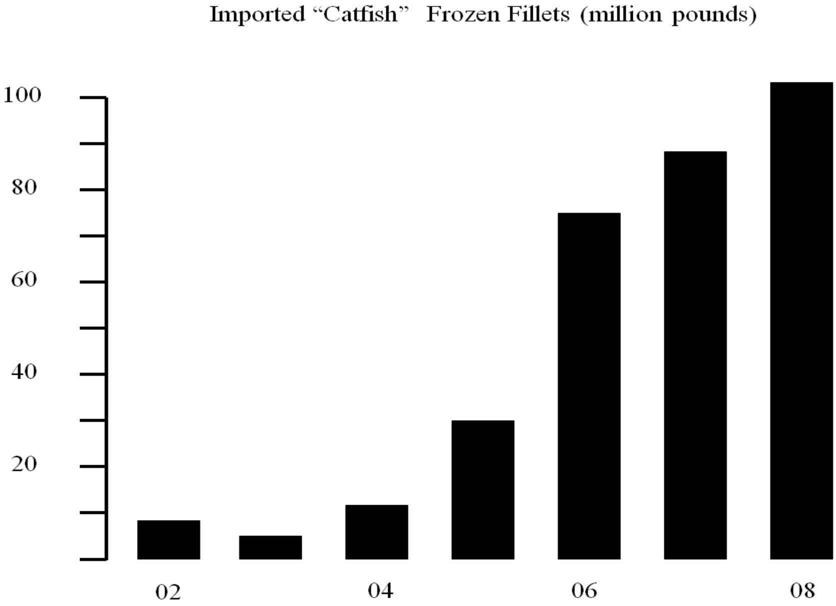

Figure 3. Temporal trends in imported pangasid and channel catfish.

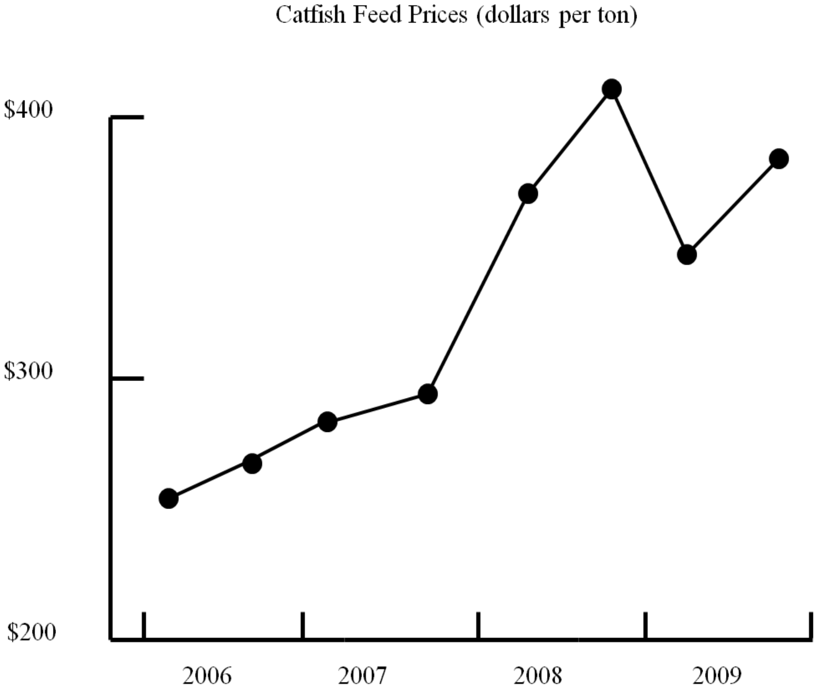

Figure 4. Temporal trends in catfish feed prices.

Grain prices increased dramatically in a few short years putting even more stress on the domestic catfish industry (Figure 4). At this point in time, some farmers began to knock down their levees and pull their ponds out of fish production, using them instead for row crop production. The culminations of all these events are thought to have led to where the industry is today.

2.4. Industry Inefficiencies

Basic industry inefficiencies such as overcoming low dissolved oxygen concentrations and increasing waste treatment in ponds needs to be addressed. By improving basic inefficiencies catfish will be subjected to less stress resulting in improved catfish health and higher yields for the farmer. Solutions for improving dissolved oxygen concentrations in catfish ponds began in the 1980s. Prior to the 1980s commercial catfish aquaculture was adequate, meeting the demand of the consumer. Farmers would build their ponds, add fingerlings, and watch them grow-out to market size, then of course sell them. The catfish farmer, remember, is an agriculturist. It should be the objective of the farmer to increase the production of food per unit area of land above the level that would be produced under natural conditions (Lee 1981). The 1980s provided an increase in production that permanently altered the industry. The paddle-wheel aerator was utilized as a way to supplement dissolved oxygen to ponds, especially during the summer. Dissolved oxygen below 1.0 mg L^{-1} will lead to fish mortality and crop loss. The paddle-wheel aerator was designed to be placed in the pond and agitate the water (usually by spinning), increasing the amount of dissolved oxygen in that particular area of the pond. The metabolic processes of catfish, in this case, the conversion of food energy to fillet meat, depends on a number of environmental conditions to be within optimum ranges where, either above or below a certain environmental variable's range, growth is suppressed. Even with paddle-wheel aeration, total oxygen demand in earthen ponds is difficult to reach (Hargreaves and Tucker 2003). Oxygen produced by photosynthesis during the day is consumed at night by respiring phytoplankton and catfish, resulting in a water respiration rate of about 1.0 mg O_2 L^{-1} hr^{-1} (Steeby 2002). This is not to say paddle-wheel aerators are not effective. Electric paddle-wheel aerators, for example, are powered by 7.5 to 11.3 kW (10-15 hp) electric motors, can provide standard aeration efficiency (SAE) values of 2 to 2.5 kg O_2 kW^{-1} hr^{-1}, and are considered the most efficient type of aerating system on the market (Boyd 1998; Tucker and Hargreaves 2004).

Aquaculture ponds are closed systems, designed to house fish until they reach optimum size at which point they are harvested. Aquaculture ponds therefore retain the feed not consumed by the cultured species. Commercial catfish feed contains between 25 – 36% crude proteins, or about 4 – 6% organic nitrogen (Lovell 1989). Roughly 25% of the feed is recovered in fish tissues at harvest; therefore, close to 75% of feed is lost to the pond system (Boyd and Tucker 1995). Feed is the main input of nitrogen in catfish aquaculture. Ammonia is the main waste product excreted by catfish and can take the form of ionized ammonium (NH_4^+) or un-ionized ammonia (NH_3). Ammonia is produced from catabolism of dietary proteins, mainly in the liver. Ammonia may be harmful to fish health if allowed to accumulate, so it is excreted across the gill epithelium and into the water column (Hargreaves and Kucuk 2001). When ammonia enters the water column a number of nitrogen biogeochemical processes can occur given specific water quality conditions. Nitrite is the other toxic form of nitrogen in fish ponds. Nitrite is the intermediate product released in both nitrification and denitrification and can build up in pond water following episodes of elevated ammonia levels. Certain bacteria which oxidize nitrite to nitrate may lag behind bacteria that oxidize ammonia. In short, over three times as much nitrite must be oxidized to support an equivalent microbial growth that is derived from ammonia oxidation (Tucker and Hargreaves 2004). Understanding nitrogen biogeochemical processes in aquaculture ponds is important for maintaining the health of the species of interest. Improving the rate of removal for certain toxic forms of nitrogen compounds should improve somatic growth of cultured species.

2.5. The Future of Commercial Catfish Ponds

As the human population continues to grow, the demand for seafood to meet that growth is expected. From 1980 – 2000 the U.S. catfish industry demonstrated positive stable growth. Today, we are witnessing the flip side of the same coin. So what happened? The stable years showed times of great economic prosperity, feed was cheaply available, marketing campaigns were strong, and the diet of Americans contained a lot of fish. Today, high energy prices are driving up operational costs for the farmer. Additionally, high feed costs as a result of increased grain prices, as well as continued competition with foreign imports are reducing profits.

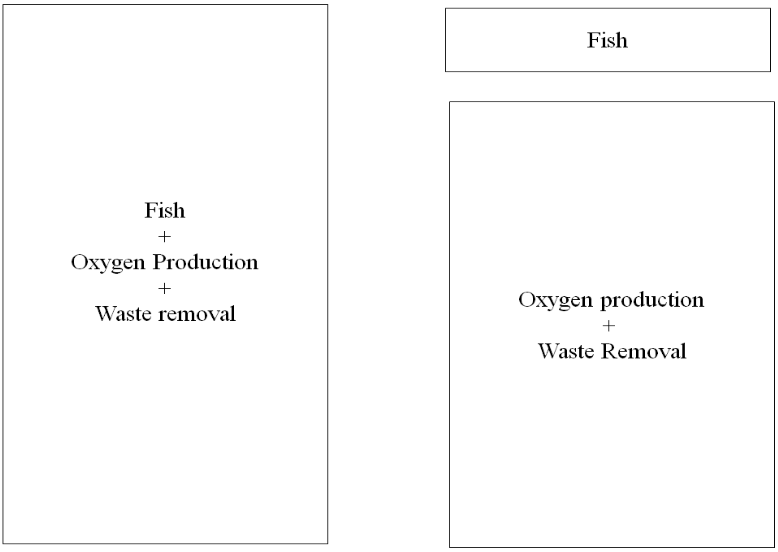

Figure 5. Side-by-side comparison of two different variety of commercial catfish production; traditional earthen pond (left) and split pond (right).

A new pond design which is working to improve industry inefficiencies and increase domestic production is the split pond system. The split pond system physically separates a culture compartment and a waste treatment compartment. The split pond design is set up to confine the culture species on one side of the pond by installing an earthen dam structure to an existing pond, new pond, or a pond which has come back into production. A low speed paddle-wheel provides circulation between the culture compartment and waste treatment compartment, while simultaneously restricting catfish passage to the waste treatment compartment (Figure 5). The smaller fish compartment in the split pond could prove to be more efficient when compared to typical earthen grow-out ponds.

Daily operation of a 10 acre grow-out pond is difficult. Feeding in such a large area can have its effects on certain fish in the pond, especially if they are far away from the feeder and must swim long distances to get food. Treating disease in these large rectangular ponds can also be challenging.

Confining the fish to a small compartment makes daily activities like feeding, disease treatment and control, and harvesting easier. Preliminary data from the split pond system suggests that it has a high waste treatment capacity when compared to traditional earthen ponds. Toxic nitrogenous compounds are remediated in the split pond system through the mass algal communities produced in the pond. Phytoplankton may assimilate harmful ammonia and also increase dissolved oxygen concentrations through photosynthesis during the day. The paddle- wheel enables the suspension of particulate matter in the water column facilitating nitrogen biogeochemical transformations. This means that ammonia and nitrite compounds may effectively leave the system before they are allowed to accumulate in the water column and adversely affect the catfish crop. Additionally, dissolved oxygen in the new split pond system is, on average, at higher concentrations throughout the water column when compared to traditional ponds. Increased dissolved oxygen levels throughout the pond indicate an increase in the availability of vertical habitat within the pond (Figure 6). The production associated with a split pond system is estimated between 20,000 and 30,000 pounds of catfish per acre, 2-3 times greater than traditional earthen ponds.

Current research is underway to determine precisely the dynamics of waste treatment processes in this split pond system. Further understanding will help lead to future developments in commercial catfish aquaculture to increase waste treatment capacity and production.

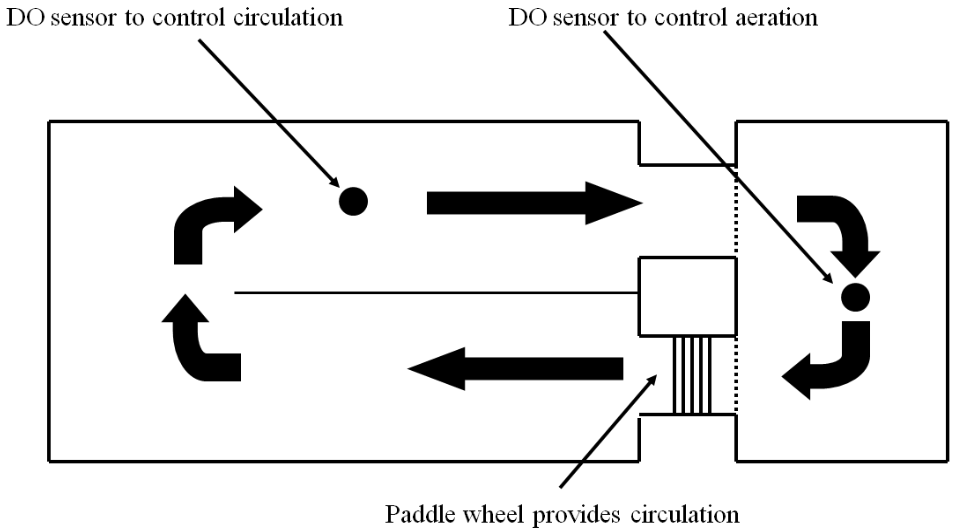

Figure 6. A diagram of water flow through the split pond. As oxygen flows between the two sides, two dissolved oxygen sensors control when the paddle wheel and aerators engage.

Nutrient management strategies in both commercial and recreational fish ponds are an essential tool in sustaining quality fish for both sport and economic value in the southeastern United States.

3. SYNOPSIS

The two most common uses of ponds in the southeastern United States are recreational fishing and commercial aquaculture. Recreational fishing is a popular pastime in the United States. Private stakeholders along with state and federal agency fishery managers are dedicated to increasing the productivity of their lakes and ponds to enhance this recreation. One of the procedures utilized for the attainment of maximum fish production is the application of inorganic fertilizers. In the southeastern United States fertilization is a widely accepted management tool. The purpose of fertilization is to increase phytoplankton production, which in turn results in an increase of zooplankton biomass and more food for fish by trophic cascade. The use of fertilizers to increase the production of fish in ponds has become widespread in recent years. However, it has been shown that the physical characteristics and water chemistry of lakes also influence lake productivity. Fish production and condition in unfertilized ponds are inextricably linked to the amount of bioavailiable nutrients in the water column. Additional variables such as sediment nutrients, benthic macro-invertebrate communities, and macrophytes could play important roles in regulating the amount of available nutrients necessary to influence productivity at different trophic levels. While recreational ponds rely on nutrient availability through trophic cascade, fish production in commercial ponds depend on nutrients from supplemental food in the form of manufactured feed. Commercial catfish aquaculture takes place in earthen ponds where supplemental feed increases biomass for subsequent harvest. Production is often limited by low dissolved oxygen concentrations and nitrogen toxicity in the form of ammonia and nitrite accumulation in the system. The Mississippi River Alluvial Valley in the southeastern United States comprises nearly 65% of the total land devoted to catfish aquaculture in the United States.

Today, new innovative strategies are taking aim at improving pond conditions and increasing production by enhancing dissolved oxygen concentrations and improving harmful nitrogenous toxicity. The Split Pond System is one new strategy which uses mass algal communities to assimilate harmful ammonia and to increase dissolved oxygen concentrations through photosynthesis during the day. The SPS uses a low-speed water wheel which circulates pond water between a fish compartment and a waste treatment compartment. The water wheel enables the suspension of particulate matter in the water column facilitating nitrogen biogeochemical transformations. The production associated with a SPS is estimated between 20,000 and 30,000 pounds of catfish acre^{-1}, 3-5 times greater than traditional earthen ponds. Nutrient management strategies in both recreational and commercial fish ponds are an essential tool in sustaining quality fish for both sport and economic value in the southeastern United States.

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Chapter 3

OPTIMUM SIZE OF NON-CONVECTIVE ZONE OF SALT GRADIENT SOLAR POND

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NOMENCLATURE

$a0....a6$	Constants defined by Hull (1980)
C_N	Pond operating parameter (% salinity/^{0}C)
C_p	Heat capacity of liquid in pond (kJ/kg- ^{0}C)
D	Salt molecular diffusivity
h	Radiation attenuation function for pond's liquid
H_b	Coefficient of heat transfer between STZ liquid and bottom
Hw	Coefficient of heat transfer between STZ liquid and sides
$I_{in(l1+xm)}$	Incoming radiation flux at interface of NCZ and STZ
I_x	Solar radiation flux at depth x
I_0	Radiation flux incident at pond surface
I_{l2}	Radiation flux incident at NCZ-STZ interface
I_L	Radiation flux absorbed by pond bottom (W/m^2)
I_{STZ}	Radiation energy absorbed in STZ (W/m^2)
I_T	Net radiation flux available at depth x
J	Component flux for salt molecular diffusion
K	Thermal conductivity of liquid in pond (W/m-^{0}C)
K_g	Thermal conductivity of soil (W/m-^{0}C)
l_1	Thickness of UCZ (m)

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l_2	Depth from surface to the interface of NCZ-STZ (m)
l_3	thickness of STZ
l_c	Depth from surface to the additional interface of UCZ-NCZ (m)
L	Depth of pond (m)
NCZ	Non-convective zone
q_c	Convective heat losses from UCZ to surface (W/m^2)
q_e	Evaporative heat losses from UCZ to surface (W/m^2)
q_r	Radiative heat losses from UCZ to surface (W/m^2)
Q_{LOAD}	Heat extraction rate (W/m^2)
Q_{LOSS}	Loss of heat through bottom and sides (W/m^2)
R	Bottom reflectivity
S	Salinity expressed in % by weight
$s_0 \ldots s_5$	Constants defined by Hull
SGSP	Salt Gradient Solar Pond
STZ	Storage zone
t	Symbol used for denoting time
T	Symbol used for denoting temperature
T_{amb}	Ambient temperature (^{0}C)
T_b	Temperature of bottom (^{0}C)
T_{STZ}	STZ temperature (^{0}C)
T_{UCZ}	Temperature of UCZ (^{0}C)
Δt	Time difference for iteration
ΔT	Temperature difference between UCZ and STZ (^{0}C)
UCZ	Upper convective zone
x	Depth (m)
Δx	Symbol for sub-layer thickness in NCZ
x_g	A depth of soil below bottom of pond (m)
x_M	Optimum thickness of NCZ (Husain et al 2003)
x_{Mobs}	Observed optimum thickness of NCZ (Husain et al 2003)
x_{m}	Optimum thickness of NCZ (Kooi 1979)
x_n	Thickness of NCZ
$f(\beta)$	Universal function defined by Hull
$g(\alpha)$	Universal function defined by Hull
$G(\alpha)$	Universal function defined by Hull
$M(\beta)$	Universal function defined by Hull
ρ	Density of liquid in pond (kg/m^3)
τ^*	Transmissivity-absorptivity product defined by Kooi.

INTRODUCTION

Salt gradient solar ponds have history over a century. Kalecsinsky (1902) first reported a pond like phenomenon is Hungarian lakes. Since then researchers have explored various aspects of ponds. Weinberger (1964) first developed analytical solution of pond's equations. This made it possible to design ponds for commercial applications. The first finite difference based computer simulation of pond was presented by Hull (1980). It was based up on the iterative approach proposed by Tybout (1966). Tabor has contributed significantly for commercial use of pond especially in Israel. The country has an ambitious plan of meeting complete electricity demand by ponds only by the year 2020 (Amnon Einav 2004). This shows that with the rising energy demand coupled with the severe environmental concerns of traditional fossil fuel energy; solar ponds are emerging as cost effective, environmental friendly viable technology for twenty first century.

The thermal performance of SGSP is principally governed by its NCZ size. The present article aims to propose a complete and rational design of NCZ. It proposes analytical approach for selection of NCZ size considering thermal and salt gradient stability aspects.

When a SGSP is started, it is filled with saline water in layers. Initially the entire depth of liquid is at ambient temperature. As the time descends, solar radiation penetrates through the liquid content of pond and the pond warms up. The initial warming may take several months depending up on pond's vertical dimensions and meteorological conditions. This initial warming is termed as 'maturation of pond' (Husain et al 2003). After initial warm-up pond temperature (temperature of STZ as well as NCZ temperature profile function) does not remain constant, because it is a function of meteorological parameters which themselves are not constant. The meteorological parameters are subjected to cyclic variations. Hence pond temperature also oscillates within certain range. This phase of working of pond is termed as 'mature phase'. As such a pond never acquires a true thermal steady state.

The NCZ size has principal role in heat retrieval by the pond. It should be such that in the maturation phase pond warms up rapidly. Later, during mature phase, it should provide maximum heat collection in STZ. Over and above to this, the NCZ salinity gradient must remain stable during both these phases. Kooi (1979) has given optimum size of NCZ (x_m) for 'steady state', i. e. considering constant STZ temperature after initial warm up. Husain et al (2003) have extended the concept given by Kooi for oscillating pond temperature. They have also given NCZ size (x_M) for maturation phase. As x_M is significantly lower than x_m they proposed that while starting a pond the NCZ size should be x_M and later should be increased to x_m.

The above-mentioned NCZ sizes are derived considering only thermal performance aspect of the pond. The NCZ consists of layers of varying salt concentration that are vital for the warm-up of pond. Heating of pond subjects NCZ layers to convection. This tends to destabilize the layer-gradient. Convection can be restricted by maintaining a desired ratio of temperature gradient and density gradient throughout the NCZ thickness (Zangrando 1991). Again there is a restraint. The solubility of salt is limited. Therefore the highest value of salt concentration and so the density of layer for a given size of NCZ is limited. Therefore in order to maintain a desired level of density gradient, NCZ size must be limited. Thus the size of NCZ is governed by two criteria: thermal performance, and salt gradient stability.

DESIGN STRUCTURE OF SALT GRADIENT SOLAR POND

A salt gradient solar pond is a large body of saline water. Its lateral dimensions are generally considered as infinite (Hull 1980). Hence 'side wall effects' can be ignored in the analysis of such ponds. This condition simulates to the practical size working ponds.

However, there exist small-size laboratory-scale ponds too in which lateral dimensions are essentially finite. Analysis of such pond requires wall effects also to be incorporated (Jaefarzadeh 2004). The depth of pond consists of three zones: upper convective zone (UCZ) at top, non-convective at middle and storage zone (STZ) at bottom. Figure 1 describes the three zones of a SGSP. Each of these zones has their own important contribution in the working of a pond.

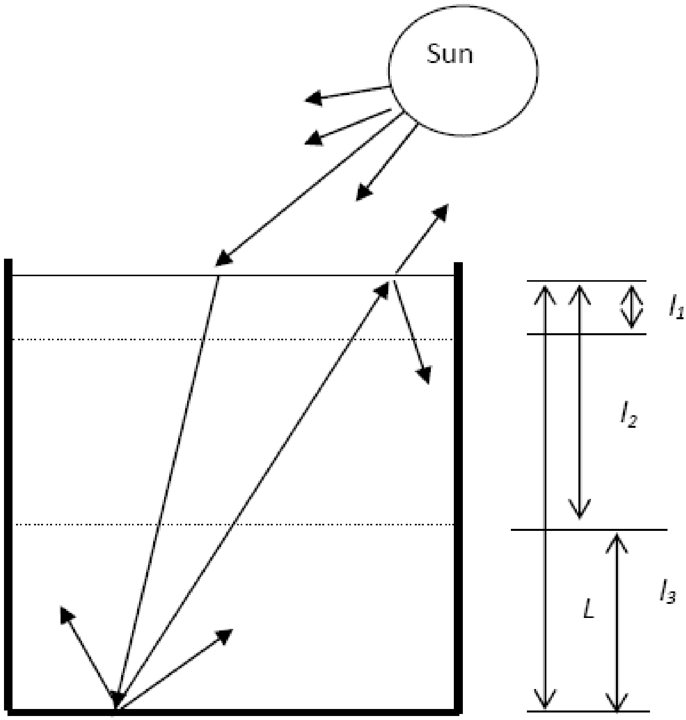

Figure 1. Schematic diagram of a salt gradient solar pond showing the radiation path way.

Upper convective zone: its role is to preclude the wind and rain born turbulences to penetrate down up to NCZ, where vertical mixing is not allowable. Its thickness (vertical size) is decided considering the local meteorology. The UCZ absorbs a significant fraction of incoming solar radiation. However it does not contribute directly to the heat collection of pond. It is subjected to wind born mixing and looses heat to the atmosphere by convection, evaporation and radiation (Joshi and Kishore 1984)). Sum total effect of all these keeps the UCZ temperature in close proximities of ambient temperature (Weinberger 1964).

Non-convective zone: it acts as an insulating lid over the storage zone. It consists of layers of salts concentrations varying from highest at lower interface to the lowest at top interface. This creates a downward increasing density gradient in it. Solar radiation passing through the liquid content of NCZ gets attenuated thereby imparting heat to it. The liquid content of NCZ gets warmed up. Warmed liquids loose most of their heat by convection. When a lower layer of liquid gets heated, it becomes lighter. Hence it moves towards the surface.

However in case of NCZ there is an artificially created density gradient in which density increases downward. This density differential does not allow lower layer to move up. Thereby it prohibits convection. The lower layers can lose their heat in upward direction only by conduction which is a slow process. Hence in course of time NCZ develops a downward increasing thermal gradient.

It must be noted that the salt concentration gradient of NCZ is inherently instable. Salt has a tendency to diffuse toward low concentration. Hence salt flux moves upward thereby destabilizing the gradient layers. Therefore the gradient zone requires continuous maintenance. This is done by removing dilute salt solution from UCZ and adding concentrated salt solution in STZ. The artificially created salinity profile is a straight line in the beginning. During the working lifespan of pond, the profile will remain straight provided if the UCZ and STZ salinities are maintained constant. However else, due to salt molecular diffusion the profile may take a parabolic shape (Zangrando 1991).

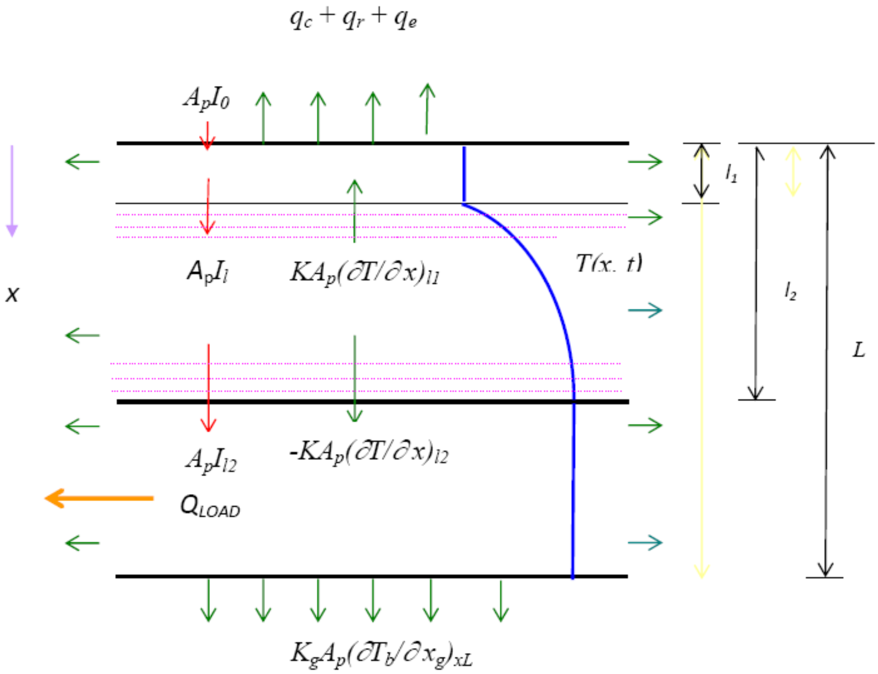

Figure 2.Schematic diagram of SGSP showing the energy balance.

Storage zone: its role is to store the heat. It is the lowest zone having uniform and highest salt concentration. Mixing is not restricted here. It warms up due to absorption of solar radiation. It loses heat upward at the NCZ interface through conduction. It also loses heat towards sides of pond and bottom. When its temperature reaches to the desired value, heat is extracted out of it through heat exchangers. Its thickness decides its bulk heat storage capacity and consequently the highest temperature acquired by it.

Figure 2 shows the complete heat balance of SGSP.

OPTIMUM NCZ SIZE CONSIDERING THERMAL PERFORMANCE ASPECT

Analysis for optimum size of NCZ for rapid Warm-Up (Determination of x_M)

The Heat balance of storage zone is given as follows:

$$\rho C_p (L - l_2)\, \partial T/\partial t = -K\, \partial T/\partial x - Q_{LOSS} - Q_{LOAD} + I_{STZ} \quad (1)$$

Where L and l_2 are depths of pond and depth of NCZ-STZ interface; Q_{LOSS} the heat loss through sides and bottom, Q_{LOAD} the heat extraction rate and I_{STZ} the radiation energy absorbed in STZ. K, ρ, Cp and T denote respectively conductivity, density specific heat and temperature of salt solution. Terms from LHS to RHS sequentially denote the change in heat content of STZ with time, conductive heat flow towards NCZ, loss of heat through sides and bottom, rate of heat extraction and radiation energy absorbed in the STZ.

Initially when the pond is filled with liquid to start, its entire content is at ambient temperature. The STZ temperature, after certain duration of warm up can be estimated by solving equation (1). Now few simplifications are made in eq. (1) and it is rewritten as:

$$\rho C_p (L - l_2)\, (T_{STZ} - T_{amb}) /\Delta t = -K[(T_{STZ} + T_{amb})/2 - T_{amb}]/(x_n) - Q_{LOSS} - Q_{LOAD} + I_{STZ} \quad (2)$$

where x_n denotes NCZ size. Equation (2) in this form deals with the overall heat exchange for the period Δt, in which, the initial temperature of STZ is increased from T_{amb} to T_{STZ}. The term $-K[(T_{STZ} + T_{amb})/2 - T_{amb}]/(x_n)$ accounts for the conductive heat loss from STZ to surface, through NCZ, assuming a linear temperature profile. In true sense this loss follows a parabolic pattern. The assumption of linear temperature profile is an over estimation of losses (Srinivasan and Guha 1987). Still it is considered for simplicity. The loss is calculated on the basis of an average of the starting and the final temperatures of pond's warm-up in the period Δt. This assumption is justified as follows: the STZ will slowly warm-up. Due to this assumption there will be an over estimation of conductive losses in the beginning and an under estimation later on, which will compensate out each other.

Rewriting (2) as

$$(T_{STZ} - T_{amb}) /\Delta t = \{-K\, T_m / x_n - Q_{LOSS} - Q_{LOAD} + I_{STZ}\}/\rho C_p (L - l_2) \quad (3)$$

where $T_m = (T_{STZ} + T_{amb})/2 - T_{amb}$.

Solution of eq. (3) requires estimation of Q_{LOSS} and I_{STZ}. Q_{LOSS} can be estimated by the coefficients given by Hull et al (1984). Theses coefficients are presented in table no. 1. Q_{LOSS} can also be estimated by considering convective heat transfer between liquid and solid surface (STZ liquid and bottom/side wall) and subsequent conductive heat flow in the soil as shown in eq. (4)

$$Q_{LOSS} = H_g(T_{STZ} - T_b) + H_w(T_{STZ} - T_w) \quad (4)$$

where H_g and H_w denote the coefficients of heat exchange between STZ liquid and bottom, and STZ liquid and sidewalls respectively, T_b and T_w the bottom and sidewall temperatures.

Table 1. A_p and P_r denote area and periphery of the pond respectively

Insulation condition	Coefficient C_1	Coefficient C_2	$Q_{LOSS} =$
Sides insulated, only bottom losses are considered	$C_1 = 0.99 \times K_g(T_{STZ} - T_{SINK})/D_w$	$C2 = 1.37 \times K_g(T_{STZ} - T_{SINK})$	$(C_1A_p + C_2P_r)/A_p$
Losses from bottom as well as sides are considered, side walls are vertical.	$C_1 = 0.9 \times K_g(T_{STZ} - T_{SINK})/D_w$	$C2 = 0.9 \times K_g(T_{STZ} - T_{SINK})$	$(C_1A_p + C_2P_r)/A_p$
Losses from bottom as well as sides are considered, side walls are sloping.	$C_1 = 0.9545 \times K_g(T_{STZ} - T_{SINK})/D_w$	$C2 = 1.01 \times K_g(T_{STZ} - T_{SINK})$	$(C_1A_p + C_2P_r)/A_p$

Estimation of I_{STZ}, i.e. the net radiation flux absorbed in the STZ is done by considering multiple reflections phenomena (Hull 1982). The radiation energy incident at the surface of pond is partly reflected back into the air and remaining penetrates in. As this radiation flux propagates in water, it imparts heat to it and gets attenuated. It reaches the bottom of pond. If the bottom is black, it gets absorbed completely. If the bottom is reflective, it gets partly absorbed and remainder is reflected diffusively and propagates towards the surface. At surface, a part of it is passes through the interface and gets lost in air. Remainder gets specularly reflected back inwards. It further propagates towards the bottom and the process goes on till the radiation energy is vanished. Hull (1982) has given expressions for estimation of net radiation flux at a depth considering multiple reflection phenomena. Using these expressions, I_{STZ} is estimated. The methodology is described in detail in Appendix I.

Thus I_{STZ} and Q_{LOSS} are estimated and substituted in eq. (3).

During initial warm up, heat is generally not extracted from the pond. Heat extraction starts after maturation when the STZ temperature has reached a desired value. Hence Q_{LOAD} should actually be accounted accordingly.

On the right hand side of equation (3), x_n is a variable. A larger value of it shall reduce conductive losses towards UCZ and ambient, but will also cause lesser radiation flux reaching STZ. A smaller value of x_n will cause vice-versa. Hence there is a possibility to optimize the x_n that will cause the quickest warm-up of the pond. According to eq. (3), for maximum heat collection during warm-up period, $T_{STZ} - T_{amb}$ must be a maximum for a given value of Δt. That is, the temperature in STZ should attain a maximum value in a given time. Or, the time required, Δt, to attain a desired T_{STZ} should be a minimum. Such a pond shall be an efficient one during maturation (warm-up) phase. Equation (3) is differentiated with respect to x_n and equated to zero to find its maxima i.e. x_M.

$$d/dx_n(-KT_m/x_n - Q_{LOSS} - Q_{LOAD} + I_{STZ})/\rho C_p(L - l_2) = 0. \quad (5)$$

Term Q_{LOAD} shall vanish during differentiation. Solution of eq. (5) gives the optimum NCZ thickness i.e. x_M. Numerical solution of equation (5) is explained in Appendix-I.

It must be noted that this optimum size of NCZ has been determined considering only thermal performance aspect. Shall this size of NCZ ensure the gradient zone stability also, is investigated in the later sections.

Analysis for Optimum Size of NCZ for Maximum Heat Retrieval after Warm Up (Determination of x_m)

Kooi (1979,) has given the expression for efficiency of black bottom pond doing steady state analysis. The analysis considers that after initial warm up, pond acquires a 'steady state'. Kooi (1981) extended the concept for reflective bottom pond also. Kooi's equation to determine the optimum size of NCZ (x_m):

$$\int_{l_1}^{l_{1+xm}} (I_T)\mathrm{d}x - x_m\, I_{(l1+xm)} = K\Delta T/I_0 \qquad (6)$$

where l_1 denotes UCZ thickness; $l_1 + x_m$ the depth of NCZ –STZ interface from surface; I_T the net radiation flux available at depth x; $I_{(l1+xm)}$ the radiation flux at NCZ – STZ interface; I_0 the radiation incident just within pond surface and ΔT temperature difference between STZ and UCZ liquid.

At this thickness of NCZ (x_m) the pond retrieves maximum heat at constant T_{STZ}. Kooi (1979; 1981) has given an expression to estimate I_T considering only incoming and bottom reflected radiations. I_T can be more accurately estimated considering multiple reflection phenomenon (Hull 1982). Solution of eq. (6) to determine x_m is explained in Appendix-I.

EFFECT OF OPTIMUM NCZ SIZE ON THERMAL PERFORMANCE OF SGSP

In order to demonstrate the effect of optimum NCZ size on overall thermal performance of SGSP, long term thermal performance analysis of SGSP is done below. It is done by solving one dimensional parabolic equation governing heat flow in the NCZ. The equation is given as:

$$\rho\, C_p\partial T/\partial t = K\, \partial^2 T/\partial x^2 - \mathrm{d}I/\mathrm{d}x \qquad (7)$$

That is, the rate of change of heat content of a finite thickness sub-layer in NCZ is equal to the algebraic sum of radiation flux absorbed ($\mathrm{d}I/\mathrm{d}x$) and the heat conducted out of it ($K\, \partial^2T/\partial x^{2)}$. Equation (7) is solved numerically using Crank –Nicholsen's method (Husain et al 2002). It requires two boundary conditions. They are heat balance of STZ given by eq. (1) and the same of UCZ as given below:

$$\rho C p l_1 \, \mathrm{d}T/\mathrm{d}t = K\partial T/\partial x + I_{UCZ} - 1/A_p \, (q_c + q_e + q_r) \tag{8}$$

where A_p is the area of pond; I_{UCZ} the radiation energy absorbed in the UCZ; q_c, q_e and q_r are heat lost to atmosphere through convection, evaporation and radiation respectively. For simplicity UCZ temperature can be taken as equal to ambient temperature.

$$T_{UCZ} = T_{amb} \tag{9}$$

The initial condition used is

$$T(x, 0) = T_{amb} \tag{10}$$

That is the entire content of pond initially is at ambient temperature.

Solution of eq. (7) is obtained using conditions (1), (9) and (10). A computer simulation model is developed for it.

Input Data for Simulation Model

The simulation of model of SGSP predicts the STZ temperature as well as NCZ temperature profile for given time. thermal performance The effect of NCZ size on thermal performance of pond is demonstrated using various sizes of NCZ for a pond having sizes A pond with lateral dimensions 20m x 20m is considered. STZ and UCZ sizes are taken as 2.0 m and 0.2 m respectively. Pond solutal properties are considered as constant because their variation does not have any significant impact on thermal performance of pond (Hull 1980). The meteorological data for city of Jalgaon (21.05N, 75.57E) is used. It is obtained from Mani et al (1982). Figure 3 shows the variation of warm-up time with NCZ size.

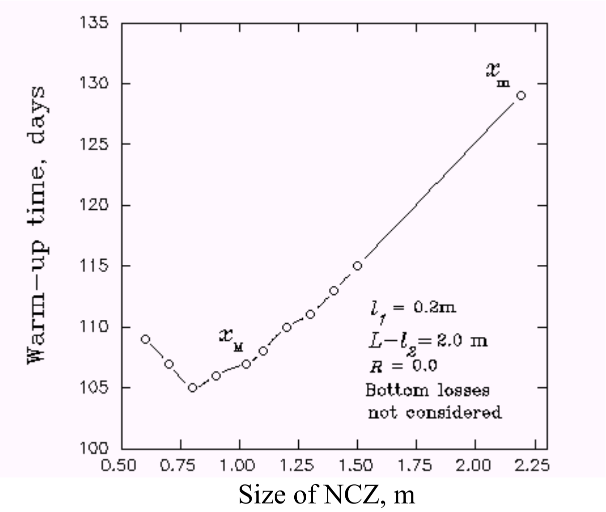

Figure 3. Effect of NCZ size on warm-up time of the pond. Meteorological data for city of Jalgaon are considered. Bottom is insulated. (Husain et al 2003).

Available daily average radiation data is converted to hourly data by the method of Collares-Pereira and Rabl (Duffie and Beckman 1981). Starting day of pond's operation is taken as first January. x_M and x_m are calculated using eq. (5) and (6). This requires mean of the solar radiation as well as ambient temperature from the day of starting of the pond to the maturation of pond. By trial this time is estimated to be four months. Hence average of solar radiation and ambient temperature from January to April is used in eq. (5) and (6).

It can be seen that there is a strong influence of NCZ size on the warm-up period of pond. The optimum size as calculated by (5) provides a substantial saving in warm-up time, of the order of weeks. Further it can be seen that the actual optimum size (x_{Mobs}) that causes the fastest warm-up is around 20% less than the calculated optimum size, i.e. x_M. The deviation may be attributed to the assumption of linear temperature profile to estimate the conductive heat losses through NCZ, which is an over estimation.

In the case described above, the bottom is considered as insulated and black (non-reflective). Similar analysis with various degrees of bottom reflectivity shows that the impact is more substantial when reflectivity is lower (Husain et al 2003). Similar effect is also observed when bottom is non-insulated. In case of non-insulated bottom, when the required NCZ size less than x_{Mobs} is used, the required warm up time increases very sharply. Another peculiar phenomenon is observed in case of non-insulated bottom- the expression (5) shows a discontinuity at lower reflectivity values. That is, expression (5) fails to give any value of x_M at low reflectivity values. Figure 4 shows this phenomenon.

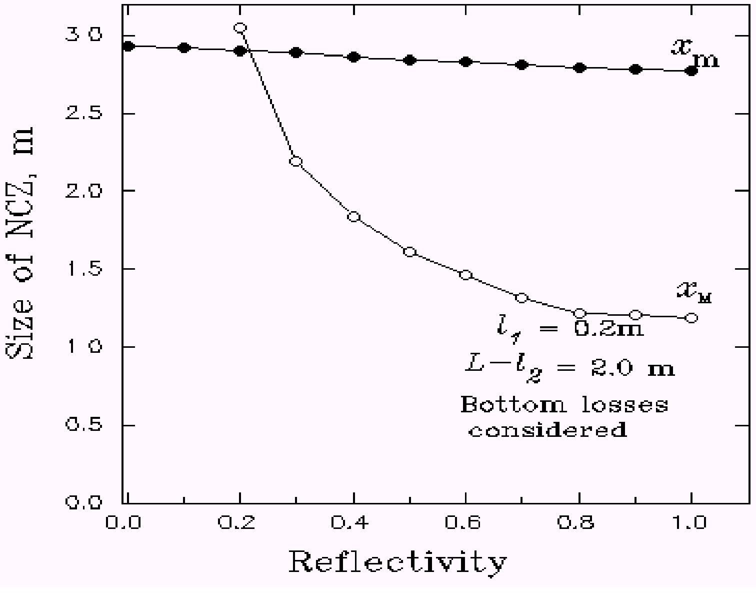

Figure 4. Variation of optimum size of NCZ with bottom reflectivity. Bottom is not insulated. A discontinuity of the function (5) can be seen as the values for x_M are not available for lower reflectivity. (Husain et al 2003).

The reflectivity value below which the discontinuity phenomenon is observed is a function of meteorological parameters, pond's vertical dimensions and temperature of STZ.

When eq. (5) fails to give x_M at a given reflectivity, it is recommended to use the x_M value available at the nearest reflectivity for optimum thermal performance of the pond.

In the overall thermal performance of pond, apart from warm-up time, heat retrieved thereafter is also an important concern. Figures 5 – 7 demonstrate the effect of NCZ size on this aspect.

Here, when STZ temperature reaches 90^{0}C, heat extraction is started at such a rate so that the STZ temperature remains constant.

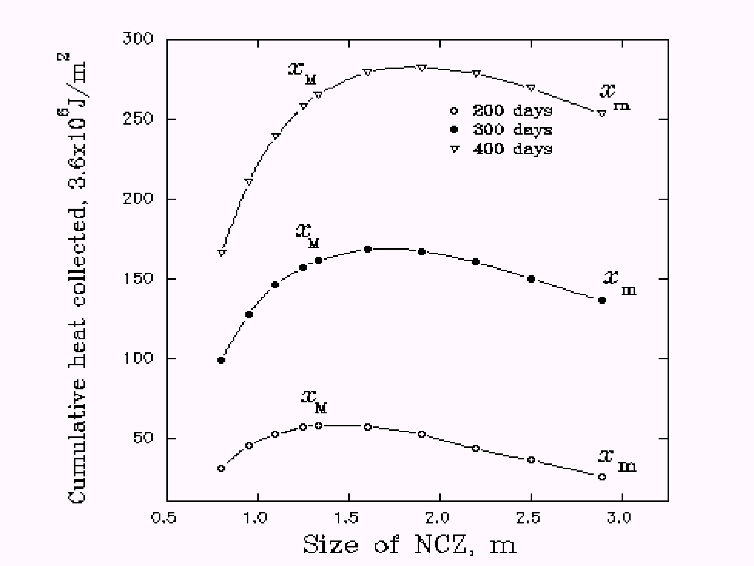

Figure 5. Effect of NCZ size on cumulative heat collection. (Husain et al 2003).

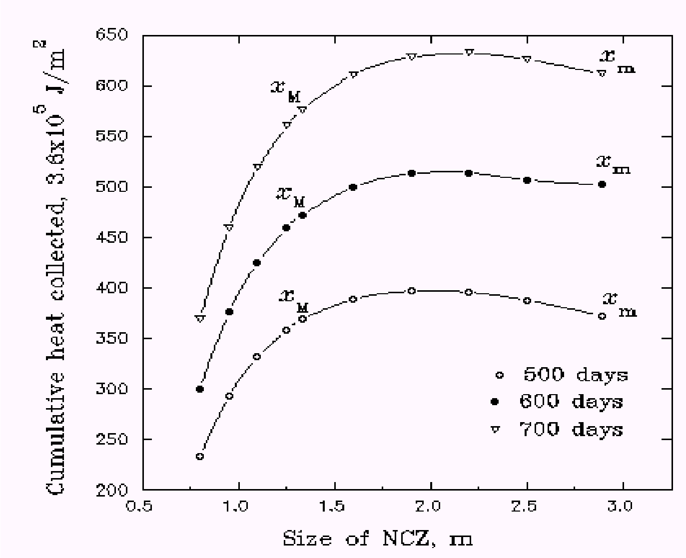

Figure 6. Effect of NCZ size on cumulative heat collection. (Husain et al 2003).

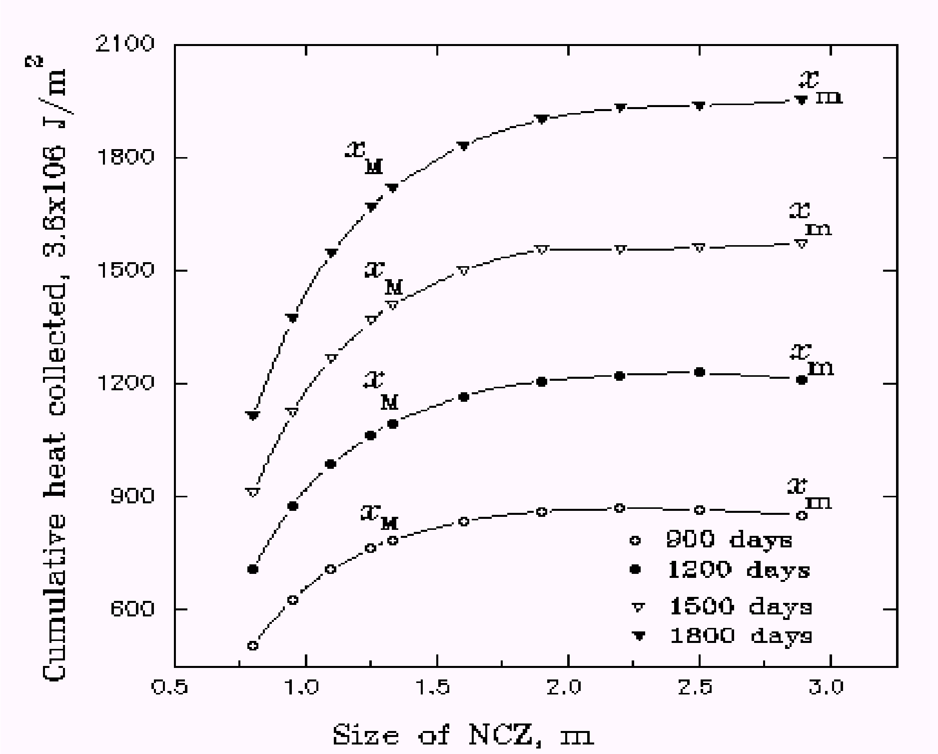

Figure 7. Effect of NCZ size on cumulative heat collection. (Husain et al 2003).

Figure 5 - 7 show the cumulative heat retrieved by the ponds in long terms with various NCZ sizes. Input data is same as described above. The results are is split on three figures for better elaboration.

It can be seen that during initial days of heating a pond with NCZ size close to x_M collects maximum heat. At later stage higher NCZ size results into more heat collection. After very long period pond having NCZ size close to x_m collects maximum heat. Figure 7 further shows that even at the end of 1800 days, pond with NCZ sizes up to 60% less than x_m collect heat that is not much less than that of x_m. It can be further seen that NCZ size up to 20-25% higher than the x_{Mobs}, does not increase the warm-up time significantly while collected cumulative heat that is not significantly less than that of x_m. These points are of practical consideration for pond design and operation. Over sizing NCZ makes the construction of pond costlier. Hence optimization of size is an important economic aspect.

In view of the foregoing discussion, a different approach of operating the pond is suggested. When a pond is started, its NCZ size should be taken as x_{Mobs}. After maturation it should be raised to x_m. Its impact on long-term thermal performance pond is analyzed. Figure 8 compares the cumulative heat collected by three ponds. In pond P_1, NCZ size is taken as x_{Mobs} while in P_2 it is x_m. in pond P_3, NCZ size is initially taken as x_{Mobs} and is raised to x_m after initial warm up. It can be seen that the thermal performance of Pond-P_3 is the most desirable.

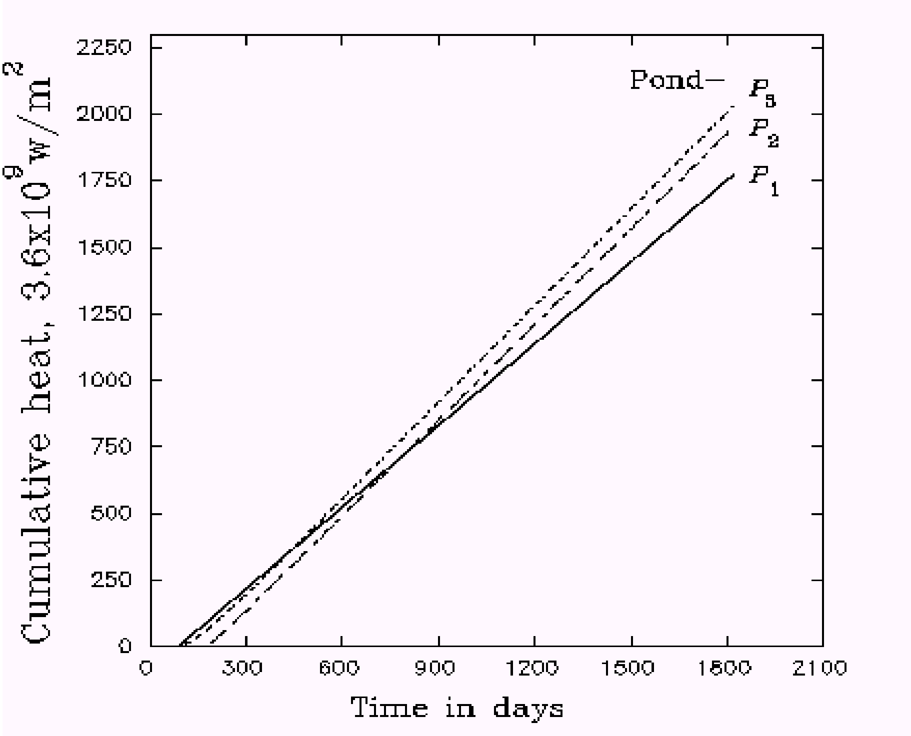

Figure 8. Comparative thermal performance of Pond-P_1, P_2 and P_3. UCZ and STZ sizes are 0.2 m and 1 m respectively; $R = 0.3$, bottom is insulated, meteorological conditions of Jalgaon city are considered, x_{Mobs} and x_m are calculated as 0.95m and 2.9m. In case of P_3, initially NCZ size is taken as x_{Mobs} (0.95m) and after maturation (83 days), it is increased to x_m.

The analysis done above is solely considering the thermal performance aspect. The stability aspect of the gradient zone is not accounted here. The proposed size of NCZ should be checked from stability criterion also and tampered accordingly.

APPLYING GRADIENT ZONE STABILITY CRITERION TO THE NCZ SIZES

Zangrando (1991) has defined the pond operating parameter C_N as:

$$C_N = (\mathrm{d}S/\mathrm{d}x)/(\mathrm{d}T/\mathrm{d}x) = \mathrm{d}S/\mathrm{d}T \qquad (11)$$

where S is the salinity in % (kg of salt per kg of solution) and T is temperature in ^{0}C; at depth x in NCZ. Term dS/dx represents salinity gradient while dT/dx represents temperature gradient. The parameter C_N (% salinity/^{0}C) is used to examine the stability of gradient zone. It should be it within range $0.4 \leq C_N \leq 0.8$ for 30 mm span from interfaces and $0.1 \leq C_N \leq 0.2$ for the rest intermediate part of NCZ to ensure gradient zone stability against thermal convections.

Amongst various salts used for creating salinity in SGSP, sodium chloride is the most common one. It has the maximum solubility as 26% which can be maintained in STZ. In UCZ, the generally maintained salinity is 2%. With these values dS/dx shall be equal to (26 –

2)/ (size of NCZ). If the temperature profile of NCZ is known, criterion given by eq. (11) can be applied at any depth of NCZ and its stability can be determined. The criterion should be applied at various stages of warm up of the pond. it is obvious that with smaller size of NCZ, gradient value (dS/dx) shall be higher. Hence smaller NCZ sizes shall be more resistant to the thermal convection born destabilization. However this may prompt to excessive salt diffusion. In fact the present discussion aims to size up NCZ such that pond's thermal performance is optimum yet the gradient zone is stable against thermal convection born de-stability.

Now, let us apply the criterion given by eq. (11) to a pond. Consider a pond with following dimensions: UCZ = 0.2 m, STZ = 2.0 m; bottom is black; bottom and sides are insulated. Meteorological conditions for city of Jalgaon (21.05 N, 75.57 E) are considered. Let 90^0C be the temperature desired in STZ. Using eq. (5) and (6), x_M and x_m are obtained as 1.13 m and 1.8m respectively. Thus x_{Mobs} is $0.8x_M = 0.9$ m. Using this input data in simulation model temperature profiles for NCZ are generated for long period of warm up. In order to maintain the STZ temperature near to 90^0C, heat is extracted from pond at a rate of 40 W/m^2, after 100 days of starting. The values of C_N, for all these profiles, are calculated by eq (11) at each sub-layer thickness of NCZ (Δx) = 0.5 cm. It is assumed that the straight line nature of salinity profile is maintained during the entire working lifespan of pond. For parabolic shape salinity profile also analysis is done and presented in Appendix II.

It is observed that during the initial warm up for pond, C_N value remains within permissible range for the entire NCZ thickness. However as the NCZ temperature rises up, the C_N value goes beyond permissible range, especially near the UCZ-NCZ interface. This indicates 'destabilization' of NCZ.

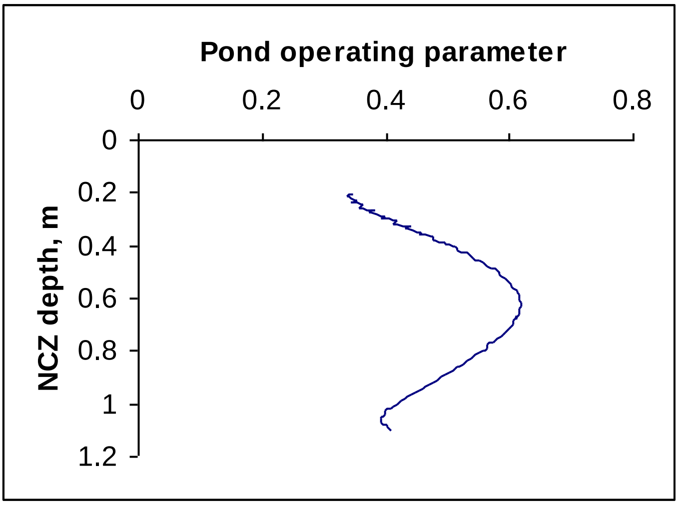

Figure 9. Values of C_N along the depth of NCZ at 60^{TH} day of warm up; NCZ size = 0.9m (x_{Mobs}), $T_{STZ} = 58^0$ C.

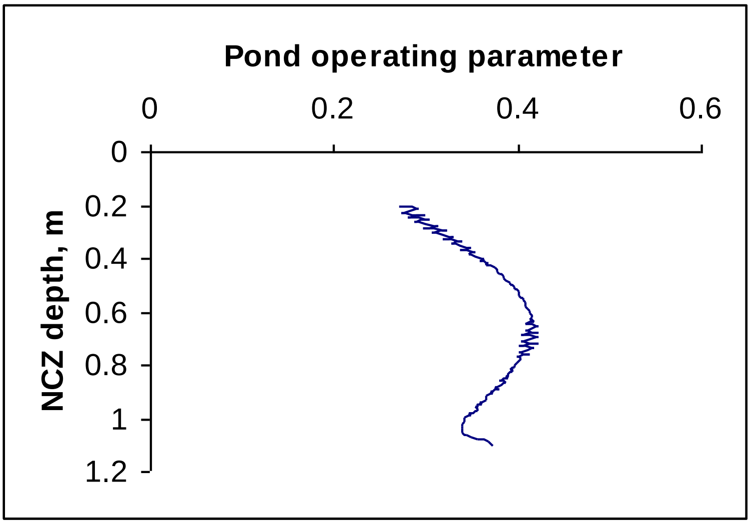

Figure 10. Values of CN along the depth of NCZ at 90TH day of warm up; NCZ size = 0.9m (x_{Mobs}).

Figures from 9 to 11 present the values of C_N calculated for the pond at various stages of its warm up. It can be seen that at 60TH day, the destabilization has just begun at UCZ-NCZ interface. At 90TH day and 120TH day, the destabilization has become prominent. Figure 10 and 11 are based upon the assumption that the pond will keep on warming at the same pace even after the set up of destabilization.

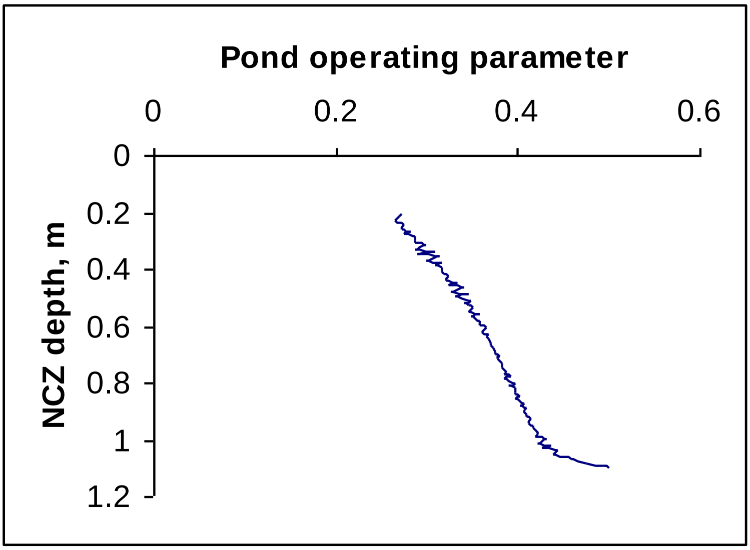

Figure 11. Values of CN along the depth of NCZ at 120TH day of warm up; NCZ size = 0.9m (x_{Mobs}).

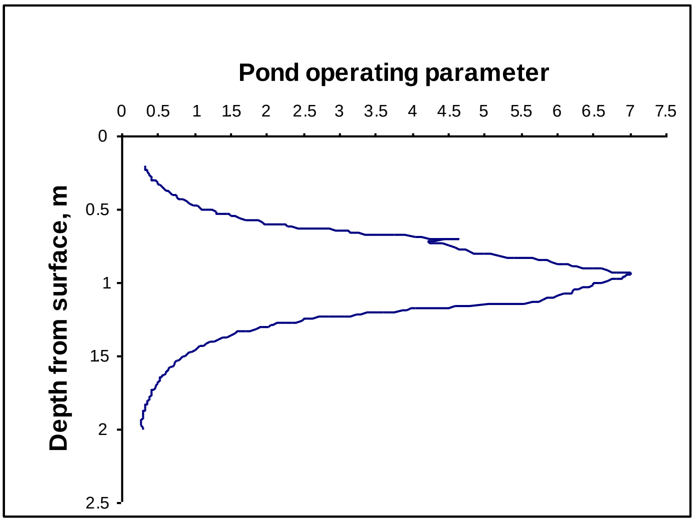

Figure 12. Stability of NCZ (C_N) along pond depth at 60^{TH} day. NCZ size = 1.8m (x_m), $T_{STZ} = 44^0$ C.

Similar analysis done with varying NCZ sizes shows that with the increased size of NCZ, destabilization takes place at even lower temperature. Figure 12shows the C_N values, at 60^{TH} day with NCZ size as x_m where destabilization can be seen at both the interfaces of NCZ. Compare it with the figure 9; in case of NCZ as x_{Mobs}, the STZ temperature has reached to 58^0C while with NCZ size as x_m, it is at 44^0C.

It is clear that with the NCZ sizes as x_{Mobs} or x_m, the pond will not acquire the desired T_{STZ} as 90^0C due to destabilization of NCZ.

At smaller NCZ sizes the observations are as follows: with $0.9x_{Mobs}$ and 0.8 x_{Mobs} sizes, at 60 days of warm the C_N values near UCZ-NCZ interface falls in unsafe range. With $0.7x_{Mobs}$, at 30 days only C_N values goes unsafe at both the interfaces. With $0.6x_{Mobs}$, C_N values falls in unsafe range after 90 days. With $0.5x_{Mobs}$, C_N values are within safe range throughout the warm up, but the temperature acquired by STZ at 400 days is 69.6^0C only.

Two important conclusions can be drawn from the preceding discussion: firstly, the pond having NCZ size as determined by eq. (5) or (6) will never acquire the desired high temperature and will get destabilized during warm up. At what temperature of STZ the destabilization shall initiate is a function of pond's vertical dimensions and meteorological parameters. Secondly, at UCZ-NCZ interface, a very high value of dS/dx is required. However, keeping very high dS/dx will limit the size of NCZ to impractically small, because the solubility of NaCl (or any other salt used) is limited.

The forgoing discussion implies that the UCZ-NCZ interface is most prone to thermal convection born instability. That is, it has a salinity gradient requirement higher than the rest of the part of NCZ. Considering this an innovative design of SGSP is suggested in subsequent section.

AN INNOVATIVE DESIGN WITH ADDITIONAL NCZ

Let us consider a pond having an additional NCZ between the UCZ and conventional NCZ. This additional NCZ shall have higher salinity gradient. It will be of thickness around 50 mm. In fact higher salinity gradient is required up to 30 mm depth below UCZ-NCZ interface (Hull et al 1989). However, 50 mm size is taken here for better safety and practical considerations. Such a pond is schematically shown in Figure 13.

Now, for the pond with NCZ size as x_{Mobs}, the salinity gradient required in the proposed additional NCZ can be determined as follows:

dS/dT= S at UCZ-NCZ conventional interface– S at additional interface (50 mm below)

T at conventional UCZ-NCZ interface- T at interface (50 mm below)

(12)

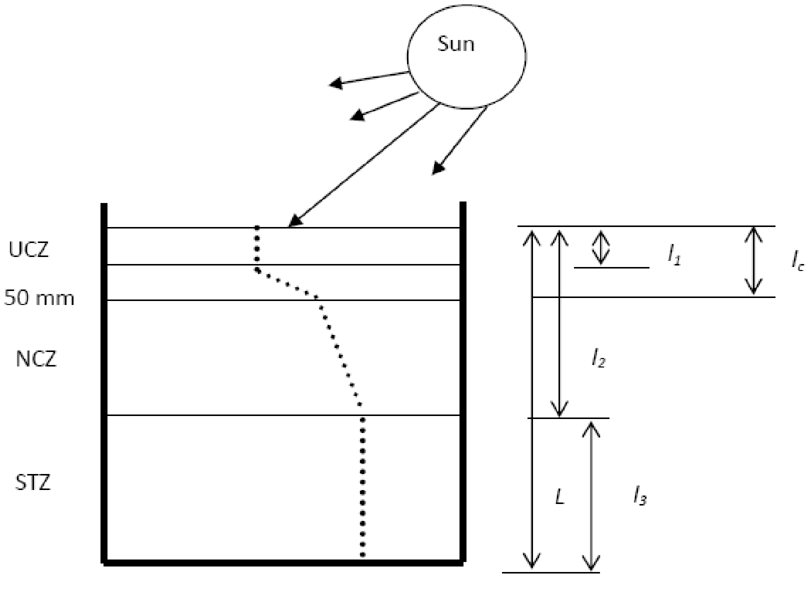

Figure 13. Schematic diagram of a salt gradient solar pond showing the proposed additional interface and salinity profile. *In the figure, 50 mm dimension has been exaggerated for visibility.*

Simulation analysis for warm up of the pond shows after 400 days, the temperature at 50 mm below UCZ-NCZ interface is 21.14^{0}C. Ambient temperature at 400 days for the selected location (Jalgaon) is 20.6 ^{0}C. Substituting this is in eq. (12):

$$C_N = dS/dT = (2 - S)/\,(20.6 - 21.14) \qquad (13)$$

where salinity at the top of interface is considered as 2%.

Now, from stability criterion dS/dT required at 50 mm below interface is 0.4 percent salinity per ^{0}C. Hence

$$0.4 = (2 - S)/\,(20.6 - 21.14) \qquad (14)$$

Solving which, $S = 2.216\%$, which is the salinity required at 50 mm below the UCZ-NCZ interface. Thus in NCZ, for top 50 mm, the salinity will vary from 2% to 2.216%, and for the rest of the part it will be 2.216% to 26%. The C_N values for such a pond after 400 days of warm up is presented in Figure 14. It can be seen that the C_N values are within safe limits for the entire NCZ depth.

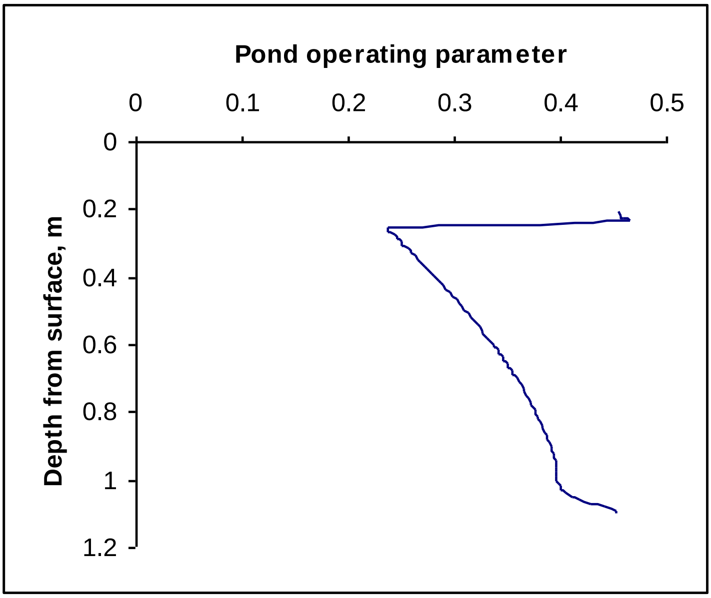

Figure 14. Stability of NCZ (C_N) along pond depth at 400^{TH} day. UCZ size = 0.2m, NCZ size = x_{Mobs}, with proposed additional interface. $T_{STZ} = 89^0C$.

APPENDIX I

Numerical solution of equation (5) is elaborated here.

$$d/dx_n(-KT_m/x_n - Q_{LOSS} + I_{STZ})/\rho C_p(L - l_2) = 0. \tag{15}$$

It requires estimation of I_{STZ}. It is done by Hull's method. Hull's expression to estimate net available radiation flux at a depth in water is given as

$$I_x = I_{xin} + I_L R \{f(\beta) - g(\alpha)\}/\{1 - R f(\beta_L)\} \tag{16}$$

where I_x, I_{xin} and I_L denote respectively the net radiation flux resulting due to multiple reflections at depth x, incident radiation flux at the same depth, and the radiation flux incident at pond's bottom. R is the reflectivity of bottom. $f(\beta)$ and $g(\alpha)$ are universal functions defined by Hull (1982). I_{xin} is estimated by the correlation given by Rabl and Nielsen (1975), which is a four part exponential function.

$$I_{xin} = I_0 \overset{4}{\Sigma} \sigma_i\, e^{-\mu i\, x \sec\theta'}$$

$i = 1$

(17)

where I_0 is the radiation flux available at surface within the pond and θ' is its penetration angle. The coefficients σ and μ, which correspond to specific wave lengths in the solar spectrum, are given as:

$\sigma_1 = 0.237$, $\mu_1 = 0.032$ m^{-1} ; $\sigma_2 = 0.193$, $\mu_2 = 0.45$ m^{-1};

$\sigma_3 = 0.167$, $\mu_3 = 3.0$ m^{-1}; $\sigma_4 = 0.179$, $\mu_4 = 35.0$ m^{-1}.

Universal functions $f(\beta)$ and $g(\alpha)$ are defined as follows:

$$f(\beta) = (a_1 + a_2\beta + a_3\beta^2 + a_4\beta^3 + a_5\beta^4 + a_6\beta^5)\ e^{-a0\beta} \qquad (18)$$

and

$$g(\alpha) = \int_0^{\pi/2} (1 - \alpha)e^{-\alpha} - \alpha^2 (\lambda + \ln \alpha - \alpha + \alpha^2/2.2! - \alpha^3/3/3! + \ldots)$$

(19)

where $\alpha = \mu(L - x)$, $\beta = \mu\ (L + x)$ and $\lambda = 0.5772157\ldots$. Constants $a_0 \ldots a_6$ are given by Hull as $a_0 = 3.2503$, $a_1 = 0.471952$, $a_2 = 0.230947$, $a_3 = 0.88894$, $a_5 = 0.420595$, $a_6 = -0.022282$.

When the bottom of the pond is insulated, the I_{STZ} can be obtained by substituting $x = l_1 + x_n$ in (5):

$$I_{STZ} = I_{in(l1+xn)} + I_L\ R\ \{f(\beta) - g(\alpha)\}/\{1 - R\ f(\beta_L)\} \qquad (20)$$

However, in case of non-insulated bottom I_{STZ} is obtained by subtracting the part absorbed by bottom:

$$I_{STZ} = I_{in(l1+xn)} + I_L\ R\ \{f(\beta) - g(\alpha)\}/\{1 - R\ f(\beta_L)\} - (1 - R)I_L \qquad (21)$$

The solution of (5):

$$\Phi(x) = Dx_n\{-K(T_m/ (l_1 + x_n) - Q_{LOSS} + I_{STZ}\}/\rho C_p\, l_3 = 0. \qquad (22)$$

where, symbol D denotes the operator d/dx.

$\rho C_p\ l_3$ is a constant term it will be cancelled. Recalling that the sizes of UCZ, NCZ and STZ are respectively l_1,x_n and l_3. the overall depth $L = l_1 + x_n + l_3$, is also a function of x_n.

Solution of (21) is done by Newton-Raphson method. Accordingly, a trial value of x_i, is taken. The next improved value is obtained as

$$x_{i+1} = x_i - \Phi(x_i)/\ \Phi'(x_i) \qquad (23)$$

Figure 3 shows the variation of warm-up time with NCZ size.

where $\Phi'(x_i)$ is the first order derivative of $\Phi(x_i)$. The process is repeated until the following condition is satisfied

$$|x_{i+1} - x_i| \leq \text{a permissible error, taken as 1cm} \qquad (24)$$

In practice, x_M cannot be maintained up to an accuracy of 1cm. However 1 cm is taken as accuracy limit for analysis.

Case (1) when bottom is insulated, i.e. $Q_{LOSS} = 0$

$$KT_m / (x_n + l_1)^2 + D\,(I_{STZ}) = 0. \qquad (25)$$

Evaluation of $D\,I_{STZ}$ is done as

$$D\,I_{STZ} = D\,I_{in(l1+xn)} + D\{I_L\,R\,(f\beta - g\alpha)/(1 - R\,f\beta_L)\}$$

Where $f(\beta)$ and $g(\alpha)$ are written as $f\beta$ and $g\alpha$ respectively for simplicity. Now,

$$D\,I_{STZ} = D\,I_{in(l1+xn)} + R\{(DI_L)(f\beta - g\alpha)/(1 - R\,f\beta_L) + I_L[(1 - R\,f\beta_L)\,D\,f\beta +$$

$$(f\beta - g\alpha)R\,Df(_L]/(1 - R\,f(_L)^2\} \qquad (26)$$

where $\beta = \mu(L + l_1 + x_n)$

The various terms in (25) are evaluated as below.

Referring (16),

$$D\,I_{in(l1+xn)} = -I_0\sigma\,\mu\ \mathrm{e}^{-\mu(l1+\,xn)\sec\theta'}$$

Let θ' be taken as 0^0.

$D\,I_L$ is evaluated by substituting L in place of $l_1 + x_n$

Again,

$$D\,f\beta = \mathrm{e}^{-a0\mu\beta}\,[2a_2\mu + 4a_3\mu^2\beta + 6a_4\mu^3\beta^2 + 8a_5\mu^4\beta^3 + 10a_6\mu^5\beta^4\,] - 2a_0(\mathrm{e}^{-a0\mu\beta}[a_1 + a_2\mu\beta + a_3\mu^2\beta^2 + a_4\mu^3\beta^3 + a_5\mu^4\beta^4 + a_6\mu^5\beta^5]$$

Because $\alpha = \mu[L - (l_1 + x_n)] = \mu\, l_3$, $g\alpha$ is a constant. Hence $Dg\alpha = 0$.

$$\beta_L = \mu(L + L) = 2\mu L.$$

$$D\beta_L = \mathrm{e}^{-2a0\mu L}\,[2a_2\mu + 8a_3\mu^2L + 24a_4\mu^3L^2 + 64a_5\mu^4L^3 + 160a_6\mu^5L^4] - 2a_0(\mathrm{e}^{-2a0(L}[a_1 + 2a_2(L + 4a_3\mu^2L^2 + 8a_4\mu^3L^3 + 16a_5\mu^4L^4 + 32a_6\mu^5L^5]$$

All these terms are evaluated for all the four values of μ and substituted in (26) which is finally substituted into (25).

For solving (23), $\Phi'(x)$ is evaluated as

$$\Phi'(x) = -2KT_m/(x_n + l_1)^3 + D^2 I_{STZ} = 0. \qquad (27)$$

This requires evaluation of $D^2 I_{STZ}$. It is done as below.

$$D^2 I_{STZ} = D^2 I_{in(l1+xn)} + R\{(D^2 I_L)(f\beta - g\alpha)/(1 - R f\beta_L) + (DI_L)D[(f\beta - g\alpha)/(1 - R f\beta_L)] + Rf\beta_L (Df\beta + (f\beta - g\alpha)[D(Rf\beta_L)](DI_L)/(1 - R f\beta_L)^2 + I_L D[(1 - R f\beta_L)D f\beta + (f\beta - g\alpha)R Df\beta_L]/ (1 - R f\beta_L)^2\}$$

$D^2 I_{in(l1+xn)}$ is equal to $\sigma\mu^2 \mathrm{e}^{-\mu(l1+xn)}$
Substituting L in place of $l_1 + x_n$, $D^2 I_L$ is evaluated.
Now,

$$D^2 I_{\mathrm{STZ}} = D^2 I_{\mathrm{in}(l1+xn)} + R\{(D^2 I_L)(f\beta - g\alpha)/(1 - R f\beta_L) + (DI_L)D(f\beta - g\alpha)/(1 - R f\beta_L) + Rf\beta_L (Df\beta) + (f\beta - g\alpha)(R Df\beta_L)DI_L/(1 - R f\beta_L)^2 + I_L (TR1)\}$$

where $TR1$ is $= \{(1 - R f\beta_L)^2 D[(1 - R f\beta_L)D f\beta + (f(- g\alpha)RD f\beta_L] + [2(1 - R f\beta_L) R D f\beta_L] [(1 - R f\beta_L)D f\beta + (f\beta - g\alpha)RD f\beta_L]\}/(1 - R f\beta_L)^4$

or,

$$TR1 = \{(1 - R f\beta_L)^2 [-R Df\beta_L D f\beta + (1 - R f\beta_L)D^2 f\beta + (DR f\beta_L)(D f\beta) + (f\beta - g\alpha)R D^2 f\beta_L] + 2(1 - R f\beta_L) RD f\beta_L [(1 - R f\beta_L)D f\beta + (f\beta - g\alpha)RDf\beta_L]\} /(1 - R f\beta_L)^4$$

Evaluation of these expression requires evaluation of D^2 $f($ and D^2 $f(_{\mathrm{L}}$. These are evaluated as

$$D^2 f\beta = -2a_0\mu\, \mathrm{e}^{-a0\mu\beta} [2a_2\mu + 4a_3\mu^2\beta + 6a_4\mu^3\beta^2 + 8a_5\mu^4\beta^3 + 10a_6\mu^5\beta^4] +$$

$$\mathrm{e}^{-a0\mu\beta} [8a_3\mu^2 + 24a_4\mu^3\beta + 48a_5\mu^4\beta^2 + 80a_6\mu^5\beta^3] + 4a_0^2\mu^2 \mathrm{e}^{-a0\mu\beta} [a_1 + a_2\mu\beta + a_3\mu^2\beta^2 + a_4\mu^3\beta^3 + a_5\mu^4\beta^4 + a_6\mu^5\beta^5] - 2a_0(\mathrm{e}^{-a0(\mu\beta}(2a_2\mu + 4a_3\mu^2\beta + 6a_4\mu^3\beta^2 + 8a_5\mu^4\beta^3 + 10a_6\mu^5\beta^4]$$

$$D^2\beta_L = -2a_0\mu\, \mathrm{e}^{-2a0\mu L} [2a_2\mu + 8a_3\mu^2 L + 24a_4\mu^3 L^2 + 64a_5\mu^4 L^3 + 160a_6\mu^5 L^4] + \mathrm{e}^{-2a0\mu L}$$

$$[8a_3\mu^2 + 48a_4\mu^3 L + 192a_5\mu^4 L^2 + 64a_6\mu^5 L^3] + 4a_0^2\mu^2 \mathrm{e}^{-2a0\mu L} [a_1 + 2a_2(L +$$

$$4a_3\mu^2 L^2 + 8a_4\mu^3 L^3 + 16a_5\mu^4 L^4 + 32a_6\mu^5 L^5] - 2a_0\mu\mathrm{e}^{-2a0\mu L}[2a_2(+ 8a_3\mu^2 L +$$

$$24a_4\mu^3 L^2 + 64a_5\mu^4 L^3 + 160a_6\mu^5 L^4]$$

In computer program, all these terms are evaluated by writing function subroutines.
All these terms are used in eq. (22) and eq. (5) is solved to obtain x_M is evaluated.

Case (2) when bottom is not insulated.

In this case the expression for I_{STZ} will become as

$$I_{STZ} = I_{inl2} + \{I_L\, R\, (f\beta - g\alpha)/(1 - R\, f\beta_L) - (1 - R)I_L \tag{28}$$

Hence, while evaluating $D\, I_{STZ}$ and $D^2 I_{STZ}$, the additional term $D[(1 - R)I_L]$ and $D^2[(1 - R)I_L]$ will appear in the corresponding expressions. Equation (20) will become now

$$\Phi(x) = KT_m/\, (x_n + l_1)^2 + D\, I_{STZ} - D\, Q_{LOSS} = 0. \tag{29}$$

and

$$\Phi'(x) = -2KT_m/\, (x_n + l_1)^3 + D^2\, (I_{STZ}) - D^2 Q_{LOSS} = 0.$$

Q_{LOSS} is given as

$$Q_{LOSS} = H_b(T_{STZ} - T_b) + H_w(T_{STZ} - T_w) + (1 - R)I_L \tag{30}$$

and $D\, Q_{LOSS} = D[(1 - R)I_L]$. Similarly $D^2[(Q_{LOSS})] = D^2[(1 - R)I_L]$.

H_b and H_w denote the coefficient of heat exchange between bottom and STZ liquid, and walls and STZ liquid respectively.

Determination of x_m:

For determination of x_m, eq. (6) is solved as follows

$$\int_{l_1}^{(l_{1+}x_m)} (I_x)\mathrm{d}x - x_m\, I_{(l1+xm)} = K\Delta T/I_0 \tag{6}$$

where the first term in eq. is the transmissivity-absoptivity product as defined by Kooi (1979; 1981). Let it be denoted by τ^*.

$$\psi(x) = \tau^* x_m - x_m\, I_{(l1+xm)} - K\Delta T/I_0 = 0 \tag{31}$$

Solution of eq. (31) is done by Newton-Raphson method. This requires evaluation of $\psi'(x)$.

$$\psi'(x) = \tau^* + x_m\, D\tau^* - x_m\, DI_{(l1+xm)} - I_{(l1+xm)} = 0 \tag{32}$$

Hull (1982) has given following expression for τ^*.

$$\tau^* = [I_0/(\mu x_m)]\{\cos\theta'\, [h(\gamma_1) - h(\gamma_d)] + [R\, h(\gamma_L)/(1 - Rf\beta_L)]\, [M((_{l1+xm}) + G((_{l1+xm}) - M(\beta_1) - G(\alpha_1)]\} \tag{33}$$

where

$h(\gamma) = \mathrm{e}^{-\gamma}$, $\gamma_1 = \mu l_1 \sec\theta'$, $\gamma_{l2} = \mu(l_1 + x_m)\sec\theta'$, $\gamma_L = \mu L \sec\theta'$

$\cos\theta'$ is taken as unity, i.e. vertically incident radiation flux is considered.

$\beta_1 = \mu(l_1 + L)$, $\beta_{l2} = \mu[(L + (l_1 + x_m)]$, $\beta_L = 2\mu L$,

$\alpha_1 = \mu(L - l_1)$, $\alpha_{l2} = \mu[L - (l_1 + x_m)]$.

M and *G* are the functions given by Hull.

$M(\beta) = s_5[1 - (1 + s_1\beta + s_2\beta^2 + s_3\beta^3 + s_4\beta^4)\,\mathrm{e}^{-s0\beta}]$

where

$s_0 = 2.46352$, $s_1 = 0.322274$, $s_2 = 0.519885$, $s_3 = -0.114534$, $s_4 = 0.087752$, $s_5 = 0.2189$.

$G(\alpha) = \alpha\mathrm{e}^{-\alpha} - \alpha^2[\lambda/3 + (\ln\alpha)/3 - 1/9 - \alpha/4 + \alpha^2/(5.2.2!) - \alpha^3/(6.3.3!) + \ldots]$

Evaluation of eq. (27) requires evaluation of $D\,\tau^*$. It is done as below.

$D\tau^* = -I_0/(\mu x_m^2)]\{ [h(\gamma_1) - h(\gamma_d)] + [R\,h(\gamma_L)/(1 - Rf\beta_L)]\,[M(\beta_{l1+xm}) + G(\alpha_{l1+xm}) -$
$M(\beta_1) - G(\alpha_1)]\} + I_0/(\mu x_m)]\{ [Dh(\gamma_1) - Dh(\gamma_{l1+xm})] + [R\,h(\gamma_L)/(1 - Rf\beta_L)][$

$DM(\beta_{l1+xm}) + DG(\alpha_{l1+xm}) - DM(\beta_1) - DG(\alpha_1)] + [M(\beta_{l1+xm}) + G(\alpha_{l1+xm}) -$

$M(\beta_1) - G(\alpha_1)]\,[(1 - Rf\beta_L)\,RDh(\gamma_L) + R^2\,h(\gamma_L)\,D\,f(\beta_L)]/\,(1 - Rf\beta_L)^2\}$

The above-mentioned expression requires evaluation of few derivatives, which is done as under.

$Dh(\gamma_1) = -\mu\mathrm{e}^{-\mu l1}$

$Dh(\gamma_{l2}) = -\mu\mathrm{e}^{-\mu(l1+xm)}$

$Dh(\gamma_L) = -\mu\mathrm{e}^{-\mu L}$

$DM(\beta_1) = s_5 s_0 \mu\mathrm{e}^{-s0\beta 1}[1 + s_1\beta_1 + s_2\beta_1^2 + s_3\beta_1^3 + s_4\beta_1^4] - s_5\mathrm{e}\text{-}^{s0\beta 1}[s_1 + 2s_2\mu + 3s_3\mu\beta_1^2 +$

$4s_4\beta_1^3]$

$D\,M(\beta_{l2}) = 2s_5 s_0(\mathrm{e}^{-s0\beta d}[1 + s_1\beta_{l2} + s_2\beta_{l2}^2 + s_3\beta_{l2}^3 + s_4\beta_{l2}^4] - s_5\mathrm{e}\text{-}^{s0\beta d}[s_1 + 4s_2(+$

$6s_3\mu\beta_{l2}^2 + 8s_4\mu\beta_d^3]$

$$D\,G(\alpha_1) = e^{-\alpha}\mu - \mu\alpha e^{-\alpha} -3\alpha^2\mu[\lambda/3 + (\ln\alpha)/3 - 1/9 - \alpha/4 + \alpha^2/5/2/2! - \alpha^3/6.3.3! + \ldots]$$

$$D\,G(\alpha_d) = 0.$$

Computer programming is used for evaluation of these expressions.

APPENDIX II.
ANALYSIS FOR NON-LINEAR SALINITY PROFILE

The salinity profile of NCZ remains straight subjected to following conditions (Zangrando 1991):

1. The UCZ and STZ are of infinite lateral dimensions.
2. Salinity of UCZ and STZ are maintained constant.

However due to deficient maintenance, the salinity gradient takes a shape defined by equation (334 and (35) (Turner 1973):

$$-\$(x)\mathrm{d}S/\mathrm{d}x = J \qquad (34)$$

$$\$ = (0.58 + 0.03\,T + 0.0002\,T^2 + 0.001\,S^2) \times 10^{-9} \qquad (35)$$

where $\$$ salt molecular density, J is component flux for salt which is constant for a fixed shape of profile. Equations (33) and (34) can be solved together to determine the shape of salinity profile. At UCZ-NCZ interface, S = 2% and T = ambient temperature. dS/dx is a constant because salinity profile is a function of S^2 (parabolic). Substituting these conditions in equation (34) and (35) respectively, J is obtained in terms of dS/dx. Further at any depth of NCZ, T is known from simulation results. Hence S, as a function of depth can be calculated and shape of salinity profile is determined.

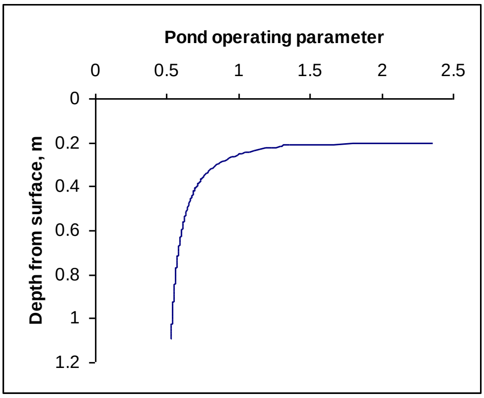

Figure 15. Stability of NCZ (C_N) along pond depth at 400^{TH} day. UCZ size = 0.2m, NCZ size = x_m, parabolic salinity profile is considered. $T_{STZ} = 89^0$ C.

This way, for NCZ depth as x_{Mobs}, dS/dT (= C_N) is calculated at 400 days of warm-up. The results are shown in figure 14. It can be seen that the C_N values for the entire depth of NCZ are within safe range. However this requires a downward increasing salinity in NCZ reaching to 60% at NCZ-STZ interface. This is a hypothetical case, because the solubility of NaCl is limited to 26%. According to figure 14, 26% salinity is required just at 17.5 cm below UCZ-NCZ interface. This means, to restrict the NCZ size to 17.5 cm only. Hence it is strongly desirable to maintain the conditions for the straight salinity profile. Of course if a salt with 60% solubility is found or synthesized, parabolic profile may be permitted.

CONCLUSIONS

The basic objective of present discussion is to develop a rational analytical insight for judicious selection of NCZ size considering optimum thermal performance as well as stability aspects. The optimum NCZ size can be obtained from eq. (5) considering purely thermal aspect. However before actually using it in pond design, it must be checked using pond operating parameter criterion. If needed, it must be modified or tampered accordingly. Obviously the NCZ size thus obtained shall not be optimum from thermal performance point of view. The proposed design of SGSP with additional NCZ permits to use x_{Mobs} for NCZ yet ensures gradient zone stability. Feasibility of this proposed technique needs to be established experimentally by future researchers.

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Chapter 4

A DYNAMIC PERSPECTIVE OF SHALLOW LAKES OF ARID PATAGONIA AS HABITAT FOR WATERBIRDS

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ABSTRACT

In arid regions, where water availability imposes significant constraints on many species, shallow lakes and ponds have a particularly important ecological role. Meanwhile, these aquatic environments have been listed among the most threatened habitats of the world. With an area of over 6.000.000 km^2, the Patagonian steppe is one of the largest arid extensions of South America. Running intermittently along the steppe, a system of basaltic plateaus or mesetas, holding thousands of lakes and ponds, provides primary habitat for numerous species, including a rich waterbird community and numerous endemism. We characterized the array of shallow lakes of the Strobel meseta, analyzing their dynamics along temporal and spatial gradients. Using multivariate analyses, based on limnological, topographic, and geographic variables of 32 water bodies, we identified four lake types: large unvegetated, large vegetated, turbid, and ponds. Based on 114 bird censuses we evaluated the relative importance of each lake type as waterbird habitat. Ponds hold the highest density of waterbirds and, together with large vegetated lakes, the highest number of species. Using satellite images corresponding to periods with contrasting precipitation, we analyzed the hydrologic dynamic by lake type and by location throughout the meseta. Whereas most lakes, including large ones, are concentrated on the west side of the meseta, above 900m of elevation, ponds are distributed throughout the whole area, but are less stable from a dynamic point of view. The total area covered with water on the meseta is strongly affected by seasonal and inter-annual changes in precipitation. During dry periods, most ponds, and particularly those located at lower altitudes, undergo a drastic reduction in water level or even dry out. Variations in water level impinge on the limnological configuration of lakes and ponds, particularly on the emergence of macrophytes, a key habitat attribute for most species of waterbird. Given this strong dependency of hydrology and habitat provision on precipitation, temperature, and wind, meseta shallow lakes and the communities they sustain appear particularly vulnerable to climate change.

INTRODUCTION

There is a growing concern about the loss of diversity due to aquatic ecosystems degradation at global scale, as well as increasing attempts to mitigate such effects. (Williams, 1999; Sala *et al.*, 2000; Abell, 2002; Brönmark and Hansson, 2002). Numerous aquatic ecosystems suffer substantial impacts and dramatic biodiversity loses caused by land uses, and biotic exchanges (Sala *et al.*, 2000). Projections based on the concomitant effects of such variables of impact and climate change on these environments are alarming, due to the accumulative character and potential interaction of such effects (Brinson y Malvárez 2002). Research carried out during the last two decades indicate that the decline in biodiversity in continental aquatic environments is faster than in terrestrial ecosystems (Sala *et al.*, 2000; Saunders *et al.*, 2002).

In South America, continental water is largely found situated in tropical and subtropical regions, contrasting with temperate regions, where water is scarce and locally found, in discrete areas disseminated throughout large geographic extensions. Continental water constitutes a key resource in arid regions, where its availability to species and human activities is restricted (Williams, 1999; Schwinning and Sala, 2004). However, judging by the little attention that aquatic systems of arid regions have received from the scientific community, their ecological importance has not been truly appreciated (Williams, 1999). For instance, most studies about aquatic ecosystems in Patagonia were referred to the Andean district, which concentrates the bulk of freshwater of this region.

The Patagonian steppe represents approximately 21% of the Argentinean territory, covering more than 610.000 km^2. This region receives less than 300 mm of annual precipitations, representing one of the most arid surfaces of Argentina (Cabrera 1976). Throughout this extensive territory freshwater is mostly confined to few rivers of Andean origin that flow across the region, such as the Río Negro, Chubut and Santa Cruz Rivers, and several sizable lakes such as the Colhué Huapi and Musters (414 y 810 km^2 respectively) in Chubut Province, and the Cardiel lake (460 km^2) in Santa Cruz Province. On the other hand, an extensive system of basaltic plateaus (mesetas), rich in permanent and temporal shallow lakes, covers intermittently the Patagonian steppe along its latitudinal axis, representing collectively an important freshwater reservoir. These basaltic beds of quaternary origin (Panza and Franchi 2002) hold numerous natural craters, which accumulate water from precipitation and snow melting, forming complex shallow lake systems with a broad diversity of sizes, configurations and limnological characteristics. These conglomerates of lakes constitute the prime habitat for a rich diversity of organisms, including several endemic vertebrates and invertebrates (Canevari et al. 1988; Menu Marque et al. 2000; Perrotti et al. 2005; Ortubay et al. 2006).

The basaltic mesetas of Patagonia have been widely recognized for their importance as biodiversity reservoir and listed among priority areas for waterbird conservation (Canevari, 1998; Scott and Carbonell, 1986). To date, there are increasing concerns about the potential effects derived from human activities associated to aquaculture and climate change over the aquatic communities of this region (Canevari, 1998; Peroti et.al, 2005). Besides, both disturbance sources have been proposed as potential drivers for the decline of the Hooded grebe (*Podiceps gallardoi*), an endemic and threatened waterbird, restricted geographically to these basaltic mesetas (BirdLife International, 2009).

Waterbirds have an important ecological role in basaltic mesetas as abundant vertebrates, top predators, and prominent herbivores. Waterbirds are particularly sensitive to changes in limnological characteristics of lakes (Weller 1999; Ortubay *et al.* 2006), being good indicators of the health of aquatic systems.

The large environment variation in basaltic mesetas of Patagonia located along geographic, topographic and climatic gradients, presents an excellent opportunity to assess the role and dynamics of aquatic systems in arid regions, evaluating their importance at a regional scale.

Based on an extensive survey of lakes, we characterized the aquatic system of the Lake Strobel meseta -one of the largest and representative basaltic mesetas of Patagonia- considering limnological and topographic characteristics. We classified lakes and analyzed their distribution, along temporal, geographic and precipitation gradients. We characterized the waterbird assemblage of the Lake Strobel meseta, evaluating the importance of particular lake types as waterbird habitat. Additionally, we assessed habitat preferences of the Hooded grebe, and analyzed the potential effects of lake turnover in response to hydrological shifts on habitat provision for this species.

STUDY AREA

The Strobel meseta is located on the northwest of the Santa Cruz Province (Argentina). It has an extension of 2500 km^2, representing 9 % of the area of the basaltic mesetas of this province (Figure 1). The meseta is made up by a bed of alkaline basalt with a thickness of up to 50m, originated by tectonic activity during the Tertiary and Quaternary Periods (Panza y Franchi 2002). The basaltic bed is spotted by over a thousand natural depressions that collect water from ice and snow accumulated during winter, generating a conspicuous lake system (Pereyra *et al.* 2002). Most water bodies are strictly endorheic, while few of them are temporary connected. The topography of the meseta is relatively uniform, with a mild slope towards the northwest, with a height of 1200 m.a.s.l on the west and 700 m.a.s.l on the east (Figure 3). This region is characterized by their extreme climatic conditions, with temperatures below -19°C during winter, and a large contrast in photoperiod between seasons. All lakes remain frozen from early autumn to late spring. The high incidence of wind storms during the whole year generates a continuous mixing of water layers, preventing the formation of a thermocline. Even deep lakes (up to 16 m depth) can be considered as shallow from a hydrodynamic point of view (Lancelotti, 2009). There is a large variation among lakes in macrophyte cover (dominated by *Myriophyllum elatinoides*, locally called ‘vinagrilla’), from turbid lakes devoid of them to lakes totally covered by a dense carpet of vinagrilla (Lancelotti *et al*, 2009).

More than 20 species of waterbirds inhabit the Strobel meseta, including several endemic and threatened species (Scott and Carbonell, 1986: Lancelotti *et al*, in press). The area has been recognized as the most important reproductive habitat for the Hooded Grebe (*Podiceps gallardoi*), categorized as “endangered” (BirdLife International, 2009), and is also inhabited by the near threatened Magellanic plover (*Pluvianellus Socialis*), the Chilean Flamingo (*Phoenicopterus chilensis*), and several endemic waterbirds (Scott and Carbonell, 1986; Imberti, 2005). Based on censuses on 119 lakes of the Strobel meseta Scott y Carbonell (1986) estimated a total population of more than 200,000 waterbirds, including 3,100 Hooded grebes for the whole meseta.

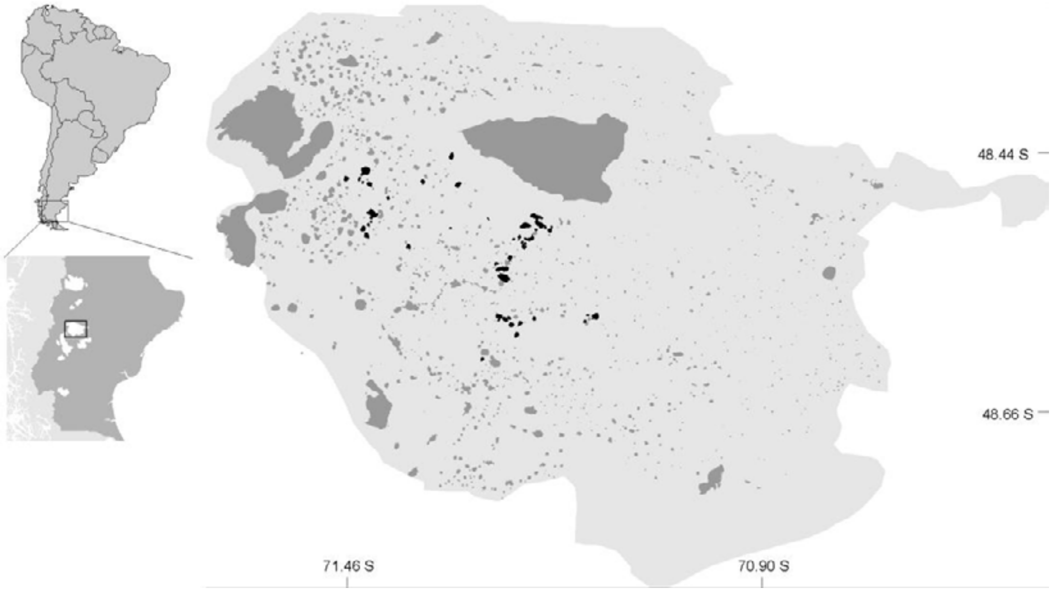

Figure 1. Satellite image of the Strobel Meseta (Landsat 7-etm) processed to mask land and highlight water bodies (in grey) and surveyed lakes for lake classification (in black). Inserted map is Santa Cruz Province (Argentina), basaltic mesetas were highlighted (grey) and black rectangle identifies the Lake Strobel meseta.

METHODS

Field Data Collection

We measured 10 limnological variables on 32 lakes and ponds (Table 1) to generate a characterization and classification of the water bodies of the Lake Strobel meseta. In order to encompass the wide environmental diversity characteristic of this region, lakes selected covered a wide range of limnological characteristics, geographic extension, size and configurations. Six surveys were conducted on the Lake Strobel meseta: two in late spring (2004, 2005), two in summer (2005, 2006), and two in early fall (2005, 2006).

Table 1. Variables measured in 32 lakes of Lake Strobel Meseta: conductivity (cond), pH, emergent macrophytes (cover), and submerged macrophytes (subm), lake area (area), total suspended solids (solids), total suspended organic matter (organic), maximum depth (h-max), maximum axis length (A-max) and maximum axis in the east-west direction (west). For lakes surveyed more than twice the mean value of all measurements for each single variable was used. Lake types: LU (Large unvegetated lakes), LV (Large vegetated lakes), SV (Shallow vegetated lakes), T (Turbid lakes)

		Primary variables					Secondary variables				
Lake	Type	cond	pH	cover	subm	area	solids	organic	h-max	A_max	West
		(us)		%	%	(ha)	(mg L^{1})	(mg L^{1})	(m)	(m)	(m)
Herradura	LV	201	9.3	20	50	16.8	0.0041	0.0037	9	610	413
Martinez_4	LV	285.5	9.2	50	30	16.85	0.0055	0.0038	12	614	452
Potrero	LU	380	9.16	1	1	78.5	0.0044	0.0044	15	1653	983
Satelital_7	SV	164.3	8.6	3	97	5.13	0.0065	0.0047	0.75	368	294
Alvarez_7	LU	190.2	8.4	5	5	59.95	0.0073	0.0056	8	1091	818
Potrerito	SV	501	9.11	40	60	6.25	0.0075	0.0056	1.5	320	253
Ocho	LV	129.4	8.12	65	20	23.04	0.0100	0.0060	8.6	925	921
Rodriguez_19	LU	227	8.58	0	0	18.37	0.0177	0.0094	5	566	451
Puesto	SV	980	10.42	40	40	4.33	0.0160	0.0100	1.3	313	303
Vega	SV	535	10.02	40	60	9.21	0.0240	0.0128	2	477	328
Rodriguez_16	LU	142.4	8.4	5	5	47.23	0.0197	0.0130	5	1126	1024
Cardielito	T	7370	10.7	0	0	26.99	0.0366	0.0162	3.6	701	590
Campamento	LU	81.6	8.4	1	3	42.83	0.0260	0.0205	16	1310	1193
Oliva	T	4542	9.14	0	0	8.86	0.0531	0.0306	1.5	480	321
Alvarez_9	LU	268.2	8.4	0	0	18.34	0.0643	0.0521	8	581	505

Table 1 (Continued)

		Primary variables					Secondary variables				
Lake	Type	cond	pH	cover	subm	area	solids	organic	h-max	A_max	West
		(us)		%	%	(ha)	(mg L^{1})	(mg L^{1})	(m)	(m)	(m)
Martinez_2	T	9930	10	0	0	13.98	0.1300	0.0600	1.5	625	407
Grabados	T	6510	9.99	0	0	7.01	0.6380	0.2560	0.3	326	282
Loggers	SV	1125	8.88	40	60	3.48	1.3040	0.3720	1.5	293	264
Independent lake subset											
Alvarez_10	LU	177.2	8.7	5	10	17.3					
Alvarez_101	SV	612.0	10.4	10	90	5.0					
Alvarez_103	SV	612.0	10.4	10	90	4.5					
Casco	SU	2602.0	9.8	0	100	21.2					
Chanchos	LU	75.9	9.6	0	1	60.4					
Compuerta	SV	155.5	10.0	70	30	4.7					
Gallaretas	SV	971.0	9.1	55	42	3.6					
Martinez_29	T	3135.0	9.8	0	0	9.1					
Martinez_3	T	2280.0	10.1	0	0	15.8					
Patos	SV	454.5	9.7	30	70	7.4					
Rodriguez_18	LU	170.8	8.8	0	0	7.6					
Rrodriguez_20	LU	60.3	8.0	1	0	18.3					
Rodriguez_51	LU	161.8	8.4	0	0	17.0					
Rodriguez_8	LU	83.8	9.5	0	0	7.4					

We measured in situ lake depth, conductivity, pH, temperature, and total dissolved oxygen. We collected water samples using a VanDorm bottle to estimate total suspended solid and organic matter. Macrophyte cover (emergent and submerged) was estimated visually. Lake area, maximum axis (great linear axial dimension), and the axis in the direction of predominant winds (west–east axis) were calculated from satellite images (Landsat 7 ETM) of the area using Erdas Imagine software (version 8.5) (for further information about the specific methods see Lancelotti et al 2009).

Lake Classification

We used multivariate analyses to reduce the large environmental variability observed on the field to a discrete number of lake types with similar characteristics, and to identify the most relevant variables for the lake classification. First, we carried out a principal component analysis (PCA; Manly 1994) based on a subset of 18 lakes of the 32 surveyed lakes. Variables included on the analysis were morphometric (lake area, maximum depth, maximum axis, west–east axis), physical-chemical (water conductivity, pH, total suspended solids and particulate suspended organic matter) and biological (macrophytes cover) (Table 1). We used the average value of these variables for lakes surveyed more than once. We plotted the two first component axes of the PCA and visually identified four lake types based on their spatial aggregation (see Results).

Subsequently, a forward stepwise discriminant analysis (DA; Manly 1994) was performed for the same subset of lakes to validate the inclusion of individual lakes to the groups resulting from the PCA, and to explore the contribution of individual variables in reducing inter-group variance. We evaluated the performance of the reduced model (including only the explanatory variables) to reassign an independent subset of 15 lakes to the previously defined groups (for further details see Lancelotti et al 2009). Statistical analyses were carried out using the software STATISTICA (version 6.0).

Spatial and Temporal Variation

We analyzed a Landsat 7 etm satellite image (scene 230/ row 94) acquired on April 5 of 2005 to evaluate, at regional scale, the availability and geographic distribution of each lake type identified on the multivariate analysis. We carried out image classification analyses to remotely estimate the primary variables emerging from the multivariate analyzes for each single lake present on the satellite image. The process consisted on three steps:

1. A mask was generated to eliminate all pixels corresponding to ground, based on the spectral signature of each pixel of the image. We defined a threshold value of 20 for the digital number (DN) of reflectance corresponding to the band 5 (medium infrared spectra 1.55-1.75μm) to differentiate water (including macrophytes, values lower than 20 DN) and ground (values higher than 20 DN).
2. Based on field and satellite images observations, we defined four cover categories: open water, corresponding to clear water free of macrophytes; turbid water, emergent macrophytes, and submerged macrophytes. In the field we recorded the percent of

lake area covered by these categories for 18 lakes. The area corresponding to each category was identified on the satellite images to define a collection of training areas to be used on a pixel by pixel classificatory process (ERDAS, 1997). Based on their spectral characteristics all pixels of the Lake Strobel area were classified on one of these *a priori* defined cover categories. We used a supervised classification method (ERDAS, 1997), including the satellite bands corresponding to the visible spectra (red, 0.63-0.69μm; green, 0.52-0.6μm; and blue, 0.45-0.52μm) and the near and medium infrared (0.75-0.9μm and 1.55-1.75μm, respectively). We visually evaluated the spectral classification accuracy by overlapping the classified pixels and surveyed areas on the original image. The image was processed and classified using Erdas Image software (version 8.5).

3. We exported the image resulting from the supervised classification to ArcView software (version 3.2) in order to calculate the area corresponding to each class at the level of individual lakes. Finally, the data were exported to R software (V2.2.1, R Development Core Team, 2009) to classify each individual lake in one of the four lake types identified on the multivariate analysis, based on their values of size, macrophytes cover, and turbidity. We followed the dichotomy criteria showed below:

- Turbid lakes: more than 70% of area covered with turbid water
- Large vegetated lakes: larger than 5ha and emergent macrophytes covering 30-80% of lake area
- Large unvegetated lakes: larger than 5ha and emergent macrophytes covering less than 5% of lake area
- Ponds: smaller than 9 ha and emergent macrophytes covering more than 90 % of lake area

We evaluated the lake type classification accuracy by means of the Kappa index based on a confusion matrix (Conglaton, 1991), contrasting the classes obtained from the satellite image classification and those emerging from multivariate analyzes based on field measurements.

We evaluated temporal variations in lake availability and lake characteristics by comparing satellite images corresponding to periods with contrasting precipitations. Analyses were based on three Landsat 7 satellite images free of clouds of the Lake Strobel meseta region: December 5, 1999; February 15, 2003 and April 5, 2005 with 132mm, 190mm, and 217mm of accumulated precipitations respectively. Precipitations were estimated as the sum of the accumulated precipitations during 365 days previous to the image capture date. Data of precipitation were acquired from a meteorological station at Gobernador Gregores (48º47’S, 70 º10’W) located at 50 km from the Lake Strobel meseta. Images were processed following the classification protocol mentioned above. The image of February–2003 corresponds to an unusually wet year, therefore we considered them as the potential capacity of the meseta as water reservoir (base scene). We compared this scene with those corresponding to dry and regular years (December 1999 and April 2005, respectively; target scenes). We recorded the number of lakes that changed their configuration between the base and target scenes.

Waterbird Habitat Suitability

We carried out 114 waterbird censuses on 59 lakes. All individuals were identified to the species level, based on a field identification guide (Narosky and Yzurieta, 1987). Waterbirds were observed using a 10x 50x binocular and 25 x telescopes. Lakes were grouped in the four lake types identified by the multivariate analysis. The number of species, density of waterbirds, and waterbird abundance for each individual lake were calculated as a measure of habitat suitability. Total waterbird abundance was calculated as the sum of the individuals of all species (excluding the hooded grebe, which was analyzed separately). Finally, total waterbird abundance, mean waterbird density (individuals ha^{-1}) and mean number of species for each lake type were summarized. For lakes surveyed more than twice the mean values of waterbird species and their abundances were used. Bird species number and density were compared across lake type by means of one-way ANOVA. Statistical analyses were carried out using the software STATISTICA (version 6.0).

RESULTS

Lake Characterization

The shallow lakes of the Strobel meseta present a wide environmental diversity, characterized by different combinations of morphology, macrophyte cover, and physicochemical characteristics, which in addition present an ample range of values (Table 1). Over the wide range of lake sizes (1.85 – 78.6ha), turbid and clear water lakes presents the most extreme values of percent of macrophytes cover (0 - 100%), conductivity (11.7 – 10600*us*), and organic and inorganic suspended matter (0.004 – 0.372mg/l and 0.004 – 0.372mg/l, respectively). While all deep lakes are relatively clear, medium and shallower lakes are represented by both, turbid and clear types.

The principal components analysis, based on 10 variables and 18 lakes showed a clear lake arrangement. Lakes were grouped on four classes, considering the two first principal components (defined by ellipses on Figure 2, Table 1). Lakes with high conductivity (>2000µs) and characterized by turbid water (Secchi <0.5 m) conformed a lake type clearly differentiated (turbid lakes, T), which includes a wide spectrum of lake sizes (9 – 27 ha.) and low depth (<3 m). The other three groups are clear water lakes, differentiated mainly by the combination of size and percent macrophytes cover. Ponds (P) are small to medium size and shallow lakes (<9 ha y deep <2 m), which present most of their surface covered by macrophytes. The two remaining groups comprised the largest lakes (>7 ha, 3-16 m deep) which could present ample zones covered by macrophytes (large vegetated lakes, LV, 15-30% of emergent macrophytes) and sparsely vegetated (large unvegetated lakes, LU, <15% of emergent macrophytes).

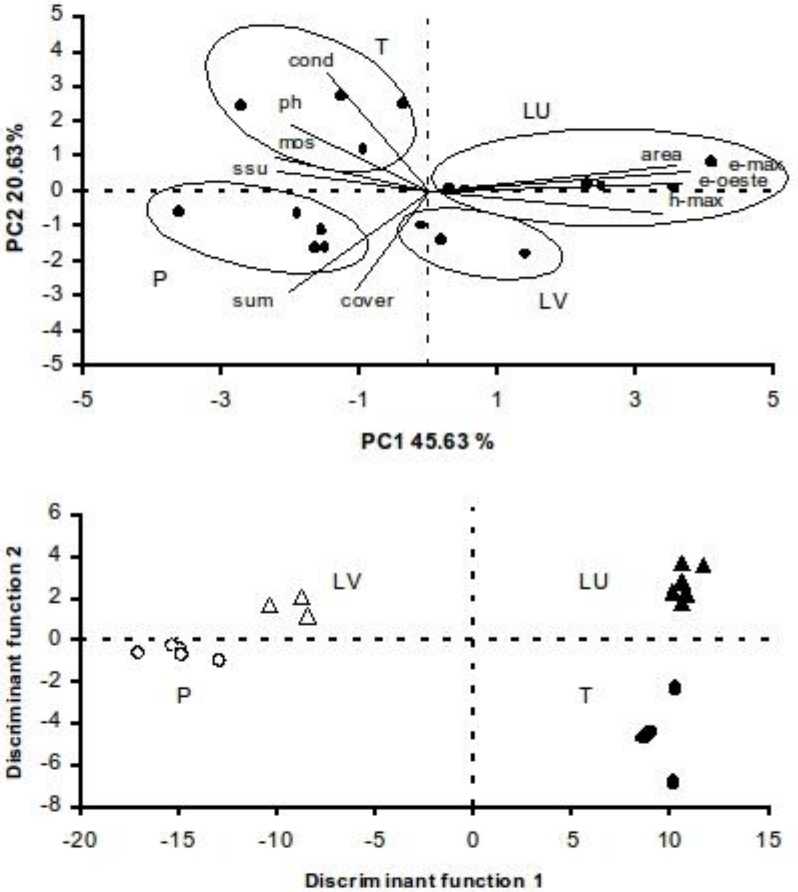

Figure 2. Lake classification based on the Principal Component and Discriminant Analyses. Upper panel correspond to ordination of lakes for the two first components (PC) which explained over 65 % of data dispersion, solid lines represent the individual weight of variables (see codes in Table 1). Ovals enclose proposed groups: LU (Large unvegetated lakes), LV (Large vegetated lakes), SV (Shallow vegetated lakes), T (Turbid lakes). Bottom panel shows the relative position of lake groups LU (black triangles), LV (open triangles), SU (black circles) and SV (open circles).

Based on the discriminant analysis (DA, Figure 2) all 18 lakes were correctly assigned to the previously defined groups. The percent of macrophytes cover explained much of the observed variability. Meanwhile, conductivity, pH, depth, and lake area contributed moderately. Finally, we used a simplified model including the variables percent of emergent and submerged macrophytes, conductivity, and pH, all of them with significant effect on the classification ($p<0.05$, primary variables). Additionally, the variable "area" was included in the model because its measurement based on satellite images is simple and its incorporation improves the overall classificatory capacity of the model. The resultant model was validated with an independent subset of 15 lakes. Each one of these lakes was *a priori* assigned to one of the four defined groups. The DA based on this model reassigned correctly all 15 lakes to the previously defined groups.

Spatial and Temporal Variations

The spectral classification of the satellite images provided very good results, classifying pixels in agreement with the classes of cover observed in the field. Based on the spectral classification of the images, all lakes of the meseta were assigned to one of the four general lake types. The classification had a high precision, reassigning more than 90% of surveyed lakes (30 of 33) to the classes defined by multivariate analyses (kappa index = 0.87). The misclassifications corresponded to two large unvegetated lakes and one pond, which were classified as large vegetated lakes. This result was expected because large vegetated lakes represent an intermediate configuration between the other two groups, which are mostly defined by macrophyte cover and lake area.

More than 47% of the whole water area of the meseta was represented by large unvegetated lakes, which accounted for less than 15% of the total number of lakes. On the other hand, ponds were the most numerous (50% of the total), but represented only about 10% of the total water surface of the meseta for the analyzed scene. Large vegetated lakes represented 17% of total number or lakes, with more than 1700 ha, while turbid lakes represented 20% of the total area of the meseta. The geographic distribution of lake types is heterogeneous (Figure 3). A clear gradient of lake distribution was observed on the East-West direction, where the isocline of 90 m.a.s.l represents an apparent limit for the distribution of large lakes, both vegetated and unvegetated. Ponds and turbid lakes clearly predominate east of this line, in the range of 700-900 m.a.s.l.

Results emerged from the analysis of satellite images showed high temporal variability in lake availability and considerable changes on configurations (Table 2).

Table 2. Temporal variations in lake configuration. Values correspond to lakes that shifted their configuration between a wet year (February 2003) and a dry and medium precipitation year, December 1999 and April 2005 respectively (target scenes). Diagonal numbers (bold) correspond to lakes that kept their configuration between scenes. The "dried" column refers to the balance in lake number, where negative signs correspond to lakes presents in the wet scene and absents in target scene, and positive numbers correspond to the partition of single lakes on two or more smaller lakes

			December 1999 (dry year)					
	Type	Area wet year (ha)	LU	LV	P	T	Dried	Dried area %
February 2003 (wet year)	LU	4067	102	2	15	31	3	26.1
	LV	916	5	5	15	7	-17	66.6
	P	3212	11	6	175	38	-693	75.8
	T	2221	5	0	6	72	-126	56.2
			April 2005 (regular year)					
	LU	4067	89	45	4	16	7	11.5
	LV	916	5	31	13	4	4	21.4
	P	3212	21	72	401	63	-366	46.4
	T	2221	10	4	11	89	-95	28.0

The scene corresponding to February of 2003 represents the wettest period in our records, considered here as the potential capacity of the meseta in terms of water reservoir (base scene). Variations on lake availability between this scene and the driest year analyzed (December 2009) strongly depend on lake type. As compared to the base scene, over 75%, 66% and 56% of the water area in ponds, large vegetated and turbid respectively, dried out during the dry year, whereas more than 70% of the area in large unvegetated lakes remained. Ponds represent the extreme of instability from a hydrological point of view, since even in regular years their represents partially their potential capacity of water storage. Close to 50% of ponds recorded in the base scene were absent in April of 2005 (regular precipitations), whereas all other lakes types preserved more than 75% of their water area.

Whereas ponds showed the highest hydrological variations, large vegetated lakes suffered the largest changes in configuration. Of the 49 large vegetated lakes recorded in the base scene only 5 (10.2 %) conserved their original configuration in December 2009.

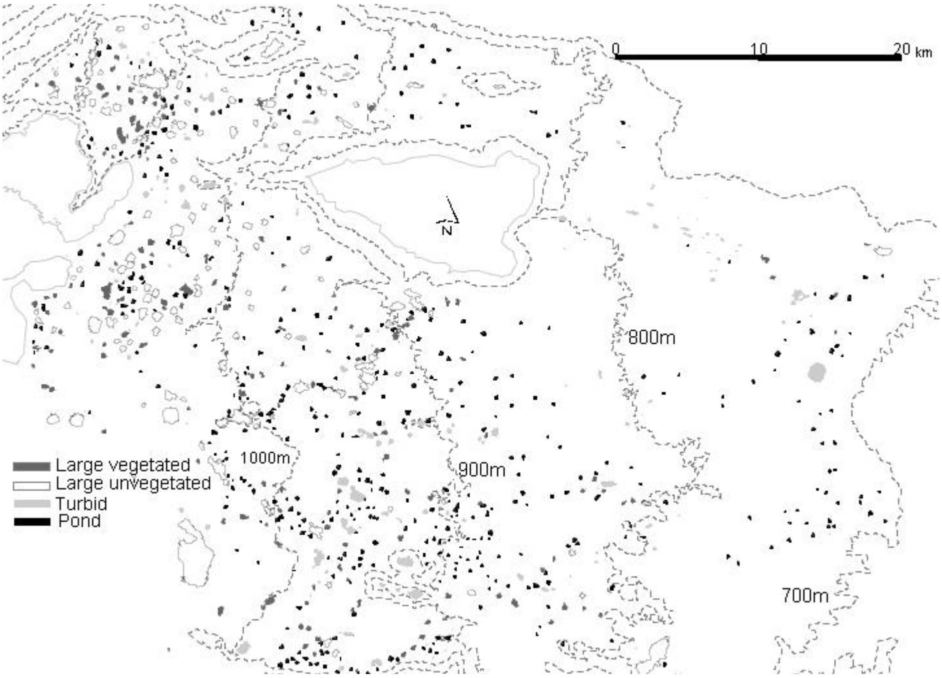

Figure 3. Geographic distribution by lake type. Lakes were classified on four categories based on their limnological characteristics. Variables included on the classification were estimated using satellite image analyzes.

As expected, most LV lakes (30.6%) changed their configuration to ponds, which essentially are smaller than the first, with most of their area covered by macrophytes. But more than 21% of large vegetated lakes changed their configuration to turbid, which represents a strong shift because turbid lakes do not have macrophytes. Large unvegetated lakes represent the most stable type. Variations in water area were smaller than 12% and 27% during the regular and dry years respectively. Additionally, most LU lakes keep their configuration during dry and regular years, 69% and 60% respectively. During the dry year most LU lakes changed their configuration to Turbid (21%), while during regular year most lakes changed to Large vegetated lakes (30%) and few of them to Turbid (10%).

Waterbird Habitat Suitability

We recorded 18 waterbird species in the meseta, represented by five families and six orders (Table 3). The family Anatidae was the best represented in the study area with more than 12 species, and 86% of individual waterbirds counted (20614 individuals). The Black–necked Swan, the Chiloe Wigeon (*Anas sibilatrix*) and the Red Shoveler (*Anas platalea*) were the most abundant and widespread species, occupying over 50 of the surveyed lakes in the first and second study years, respectively. Grebes (Podicipedidae) were the second family in importance, representing 8% of the total number of waterbirds counted.

Table 3. Relative frequency (RF) for each waterbird species observed in the Lake Strobel Meseta during the 2004–05 and 2005–06 study periods

Common name	Scientific name	2004-05	2005-06
Podicipedidae			
White–tufted Grebe	*Rollandia rolland*	0.01	0.14
Silvery Grebe	*Podiceps occipitalis*	4.45	7.69
Hooded Grebe	*Podiceps gallardoi*	1.58	2.74
Phoenicopteridae			
Chilean Flamingo	*Phoenicopterus chilensis*	1.21	1.51
Anatidae			
Andean Duck	*Oxyura ferruginea*	0.01	0
Lake Duck	*Oxyura vittata*	0.10	0.01
Flying Steamerduck	*Tachyeres patachonicus*	2.02	2.16
Rosy–billed Pochard	*Netta peposaca*	0.21	0.18
Chiloe Wigeon	*Anas sibilatrix*	16.50	17.81
Yellow-billed Pintail	*Anas georgica*	7.19	1.10
Red Shoveler	*Anas platalea*	17.51	32.05
Crested Duck	*Anas specularioides*	2.38	1.94
Speckled Teal	*Anas flavirostris*	0.42	4.91
Coscoroba Swan	*Coscoroba coscoroba*	3.43	0.76
Black–necked Swan	*Cygnus melancoryphus*	33.27	21.34
Upland Goose	*Chloephaga picta*	3.43	3.06
Rallidae			
White–winged Coot	*Fulica leucoptera*	5.69	2.59
Scolopacidae			
Wilson's Phalarope	*Phalaropus tricolor*	0.59	0

Contrasting abundances of waterbird were observed between lake types (Figure 4). While large unvegetated lakes represented more than 50% of the surveyed area, these lakes accounted for less than 5% of the waterbirds recorded. Ponds, on the other hand, represented less than 10% of the area surveyed but accounted for more than 35% of the waterbirds counted. These differences are clearly reflected on mean bird density, which was 35 times higher in ponds than in large unvegetated lakes.

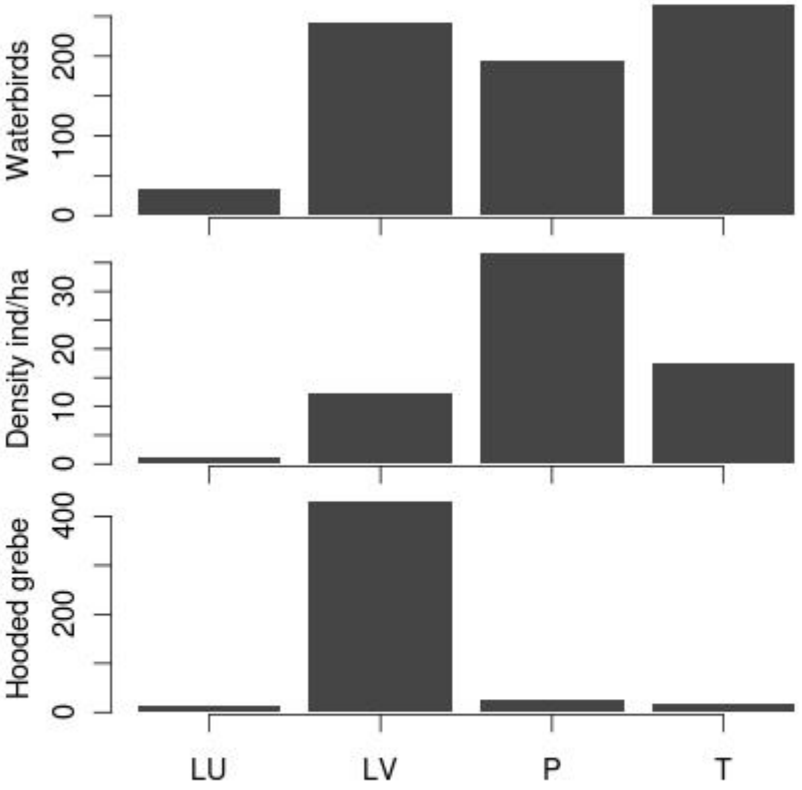

Figure 4. Use of lakes by waterbirds on the Lake Strobel Meseta. Upper panel: mean number of waterbirds recorded by lake type. Middle panel: mean density of waterbird estimated (ind/ha) by lake type. Lower panel: total Hooded grebes recorded by lake type. Surveys were carried out during spring, summer and fall from 2004-2006.

Turbid and large vegetated lakes presented similar waterbird densities (around 12 and 17 individuals ha-1, respectively), which represented nearly half of the abundances recorded in ponds. The mean number of waterbird species was significantly higher in large vegetated lakes, ponds, and turbid lakes than in large unvegetated lakes ($p<0.001$). Turbid lakes presented a significantly lower number of species than large unvegetated lakes and ponds ($p<0.001$). The highest waterbird densities were found in ponds and the lowest values in large unvegetated lakes, both significantly different from all other lake types ($p<0.001$). Large vegetated and turbid lakes presented similar waterbird densities ($p>0.05$).

CONCLUSION

The aquatic system of the Lake Strobel Meseta represents an important water reservoir in a region characterized by the extreme aridity. This system presents an outstanding environmental diversity, including a wide spectrum of lake configurations with contrasting limnological characteristics. The lake configurations are determined by a combination of variables related with size, shape, physical-chemical characteristics and macrophytes cover. These variables have been largely documented as important drivers in aquatic communities, highlighting their primary role on the distribution and abundance of species (Carpenter 1988; Jeppesen *et al.* 1997 a, b; Scheffer 1998).

The ample diversity of lakes is revealed through multiple variables, which are distributed in a continuum along the environmental gradient of the meseta. Using multivariate analysis this gradient was partitioned in discrete lake types with similar configurations: 1) turbid lakes, characterized by high conductivity, medium values of lake area and depth, and devoid of macrophytes, 2) ponds, which are represented mainly by small lakes usually completely covered by macrophytes, 3) large unvegetated lakes, included the largest lakes, mostly deep and only a small percent of the area covered by macrophytes, and 4) large vegetated lakes, which present a combination of open water and areas covered by macrophytes.

The weather in the Lake Strobel region is extreme and highly variable. Time series of precipitation show periodic alternations of extremely dry and wet periods. Additionally, wind storms are frequent, increasing water evaporation and preventing the thermal stratification of lakes (Lancelotti, 2009). These properties, together with the geographic location of lakes and the topography of the meseta, generate a hydrological dynamics highly fluctuating, resulting in substantial variations in lake availability and profound changes in lake configuration across space and time. Lakes and lake sizes are not homogeneously distributed over the meseta. Most lakes, including large ones, are concentrated on the west, above 900 m.a.s.l., arranged along a gradient of altitude and precipitation.

As expected, ponds are the most unstable from a hydrological point of view, whereas large unvegetated lakes are the most stable. Large vegetated lakes represent an intermediate configuration, fluctuate between the other two types depending on the weather conditions. Turbid lakes, which presented the extreme values of conductivity and suspended organic and inorganic matter, represent a distinctive group. While all other lake types could shift to a turbid state in dry years, a set of turbid lakes kept their configuration over all weather conditions. In fact, 86% of lakes that were turbid during the dry period kept that configuration in the wet period. This result suggests that factors other than water level could be responsible of the turbid state of a lake. The biological components of turbid lakes are also particular, characterized by high concentrations of chlorophyl, and pelagic communities dominated by calanoid copepods, absent from other lake types (Lancelotti, 2009). The turbid lake configueration may be determined by the geologic or ecological history of the particular basin.

Changes in limnological characteristics of lakes, driven by climatic fluctuations, could have strong effects on community assemblages (Williams 1997; Fernández-Aláez *et al.* 1999; Gyllstrom *et al.* 2005). For example, substantial changes on water level could affect the optical characteristics of water (e.g. increasing the turbidity), salinity, pH, and nutrient concentration, preventing or reducing the development of macophytes (Weisner *et al.* 1997;

Medina-Sánchez *et al.* 1999; Rooney y Kalff 2000). Additionally such alterations could promote substantial changes in the relative importance of key species during wet and dry periods (Williams, 1997; Medina-Sánchez *et al.* 1999; Nurminen y Horppila 2002), resulting even in ecological shifts, widely documented for shallow lakes (Scheffer 1998 , Carpenter, 2003). These changes are schematically represented by two extreme situations: 1) A macrophyte dominance state, with clear water and relatively low concentrations of suspended organic matter, and 2) A turbid water state, with high levels of organic matter, dominance of phytoplankton, and absence of macrophytes (Jeppesen *et al.* 1997b; Scheffer 1998; Beisner *et al.* 2003; Jackson 2003). Such state changes could have different causes, some related to human interventions (nutrient addition, species introduction) and some to natural events (climatic shifts) (Scheffer 1998). Generally, both conditions represent equilibrium states between which shallow lakes fluctuate, but could also become irreversible states (Scheffer 1998; Carpenter 2003).

While the climatic conditions represent a constraint for much organisms, this region congregate high number of waterbirds, winch inhabit the basaltic mesetas from early spring to early autumn, for feeding, reproducing or as steady step during their migrations. Besides, the basaltic mesetas of Patagonia have been highlighted for their importance for an wide diversity of fauna (Cei 1971; Cei 1980; Scott y Carbonell 1986; Canevari *et al.* 1998), where the waterbird community, which include at least three threatened species, represents the most characteristic component (Fjeldsa 1986; Scott y Carbonell 1986; Canevari *et al.* 1998). Additionally, the Lake Strobel meseta in particular has been identified as the most important reproductive area for the Hooded grebe (Beltran *et al.* 1992; Johnson 1997; Imberti 2005).

The highest waterbird densities were recorded on ponds and large vegetated lakes, both lake types with similar species number. On the other hand, large unvegetated lakes comparatively held lower bird populations and fewer species. Hooded grebe was strongly associated to particular environments, which present specific habitat characteristics (large vegetated lakes): medium size lakes partially covered by macrophytes surrounded by open water areas. These habitat requirements have been quantitatively evaluated using generalized linear models, showing that Hooded grebe presence is strongly related to particular combinations of these variables (Lancelotti *et al*, 2010).

We evaluated average habitat preferences for the waterbirds. But it is apparent that, abundances fluctuate substantially between seasons. Also, frequent day to day movements occur between neighboring lakes (Lancelotti *et al*, 2009). Such movements are facilitated by the high density of lakes, separated by relatively short distances (there are 60km between most distantly located lakes), and the density of lakes in the meseta provide an ample supply of stepping stones for migrating birds. Therefore, waterbirds can move around with low energetic costs in response to changes in environmental conditions (e.g. water level or food availability). Consequently, the array of lakes in the Strobel meseta constitutes an exceptional environmental mosaic, providing waterbirds with an ample availability and diversity of habitats. The persistence of several waterbird species in the region may well depend of the aquatic network rather than on individual lakes, as has been observed in other regions with similar characteristics (Skagen y Knopf 1994).

Lake areas and configurations suffer deep changes in response to shifts in precipitation, ultimately affecting the geographic distribution and abundance of waterbirds. Recent population studies focused on the Hooded grebe found substantial reductions in reproductive output during dry years (2008-2009), probably as a consequence of inadequate habitat conditions caused by the absence of emerged macrophytes (Imberti, personal communication, Lancelotti unpublished data). Climate change will affect precipitation, wind intensity, and temperature, all variables that are expected to have strong effects over the dynamic and health of aquatic ecosystems in the region. Species such as the Hooded Grebe, adapted and restricted to these extreme environments with highly specific habitat requirements (Fjeldsa, 1986, Lancelotti *et.al* 2010), could be strongly affected by such changes.

Lakes of basaltic mesetas of Patagonia constitute complex and highly dynamic aquatic ecosystems. Challenges for future research include projecting changes in habitat quality and availability under potential scenarios of climate change, evaluating the consequences for regional aquatic communities.

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Chapter 5

PHYTOPLANKTON FROM SUBTROPICAL PONDS: GROWTH PARAMETERS, CARBOHYDRATE PRODUCTION, AND POLYSACCHARIDE COMPOSITION OF THREE CHLOROPHYTES

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ABSTRACT

Microalgae are found in multiple environments as a result of the diversity of their morphological and physiological adaptations, including the production of a large variety of polysaccharides. This chapter describes the growth parameters as well as the patterns of carbohydrate accumulation and release of three green phytoplanktonic strains isolated from different subtropical ponds. A preliminary characterization of the polysaccharides produced by these strains was also carried out in order to identify potential bioactive compounds. *Chlamydomonas* sp. (Chlamydophyceae), *Ankistrodesmus* sp. (Chlorophyceae), and *Onychonema* sp. (Zygnematophyceae) were isolated by micromanipulation and several washes under the microscope. Microalgae were isolated from subtropical ponds smaller than 10,000 m^2, which are found throughout the landscape of the Carreiros campus of the Federal University of Rio Grande. These ponds are located in southernmost areas of Brazil and have different trophic statuses, which range from oligotrophic to hypereutrophic. Experiments were carried out with batch cultures until stationary growth was reached. Samples were collected at 48 and 72-hour intervals to monitor cell growth (direct counts using a microscope), particulate and extracellular dissolved total carbohydrates (phenol-sulfuric), and polysaccharide

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composition (High Performance Ion Chromatography with Amperometric Detection - HPIC-PAD). *Chlamydomonas* sp. exhibited the fastest growth rate (0.8 div per day), followed by *Ankistrodesmus* sp. and *Onychonema* sp. (0.3 and 0.1 div day^{-1}, respectively). Only *Onychonema* sp. had a senescent growth phase after 33 days of cultivation. Particulate carbohydrate accumulation occurred simultaneously with growth, except in *Onychonema* sp., which accumulated particulate carbohydrates during the stationary growth phase. Extracellular dissolved carbohydrates were released continuously during the experiment even after stationary growth was reached. Polysaccharide analysis by HPIC-PAD revealed the presence of arabinose associated with galactose in *Chlamydomonas* sp., and significant levels of uronic acid in *Ankistrodesmus* sp. and fucose in *Onychonema* sp. Polysaccharides with these characteristics are similar to the pectins produced by vascular plants and the fucoidans produced by brown algae, which are associated with antitumoral, anti-inflammatory, immunostimulatory, and other biological activities. On the other hand, the high content of uronic acid-containing polysaccharides can potentially form complex metals and might be used in biotechnology applications.

Keywords: Bioprospection, growth, phytoplankton, ponds, polysaccharides.

INTRODUCTION

Phytoplankton is a diversified ecological compartment, which includes components from nine phyla of eukaryotic and two phyla of prokaryotic photoautotrophic organisms. They represent the basis of the food chain that sustains more than 70% of the biomass in the world and constitute an important resource for biotechnology (Day *et al.,* 1999). In general, phytoplankton is composed of photosynthetic microorganisms adapted to live partially or continuously in open waters (Reynolds, 2006). They include both primitive and more recent eukaryotic lineages such as euglenophytes and chlorophytes, respectively (Keeling, 2004), configuring a definition that is much more functional than phylogenetic. This diversity of lineages, shapes, and physiological mechanisms enable the phytoplanktonic species to produce a great variety of biochemical compounds with potential biotechnology applications in the food, cosmetic and pharmaceutical industries as well as in clean energy production (Olaizola, 2003).

Among the phytoplankton metabolites, polysaccharides are significant both quantitatively and qualitatively. They represent 40% to 90% of the organic compounds produced by these organisms and exhibit a wide range of compositions and molecular weights (Myklestad, 1995). All phytoplanktonic species produce both intra- and extracellular polysaccharides (Paulsen and Vieira, 1994). Intracellular polysaccharides play mainly storage and structural roles. Storage polysaccharides are usually composed of homogeneous glucans such as starch and its variations in cyanobacteria and red algae, in addition to chrysolaminarin from heterokont algae (Percival, 1979). Structural polysaccharides are also largely homogenous, especially the cell wall constituents such as xylans, mannans, rhamnans (Carlberg and Percival, 1977) and several glycoproteins (Morita *et al.*, 1999). Cell wall polysaccharide composition is an important characteristic of the phylum, class and order definitions for algae (Hoek, 1995).

Extracellular polysaccharides (EPS) may also be very significant and vary from 5 to 90% of the total photoassimilated carbon (Lewin, 1956). EPS could be homogeneous compounds, such as fucans, mannans, and arabinogalactans, or very heterogeneous compounds with five or more different monosaccharides (Paulsen and Vieira, 1994; Giroldo and Vieira, 2002; Giroldo and Vieira, 2005; Vieira *et al.*, 2006, 2008; Kiemle *et al.*, 2007). EPS have been less studied than structural and storage polysaccharides with regard to their composition and structure and their biological functions (Giroldo *et al.*, 2007). There are not enough studies on phytoplanktonic EPS characterization to determine if their composition could be a species-specific characteristic (Myklestad, 1995).

Several biological and ecological functions have been proposed for the excretion of polysaccharides by microalgae, such as resistance to desiccation, protection against predation, biofilm establishment for periphytic species, reduction of cell density to improve floatation in a planktonic environment and cooperative association with bacterioplankton (Hutchinson, 1967; Porter, 1973; Brook, 1981; Reynolds, 2006; Decho, 1990; Grossart *et al.*, 2005, Domozych *et al.,* 2007, Giroldo *et al*., 2007). EPS-release by phytoplankton is influenced by environmental factors, such as irradiance and nutrient availability (Myklestad, 1995). In general, the EPS excretion rate is increased under conditions of nutrient depletion coupled with saturating irradiance due to an excess of photoassimilated carbon (Fogg, 1983). Under such conditions, photosynthesis remains active and the photoassimilated carbon cannot be used for growth because of the nutritional deficiency. This situation generates excess of carbon that is deviated to polysaccharide excretion (Giroldo and Vieira, 2005). This mechanism also works as a resource to protect the photosynthetic apparatus against the excessive entry of electrons from photosynthesis (Smith and Underwood, 2000).

In addition to the roles played by phytoplanktonic polysaccharides, biological activity has been shown for many of these compounds (Olaizola, 2003). The wide variety of fractions with different molecular weights and compositions produced by all phytoplanktonic species indicates the broad possibility of prospecting for bioactive compounds. Among the phytoplanktonic polysaccharides that could potentially have biological activity, fucans, arabinans, arabinogalactans and rhamnogalacturans could be highlighted (Paulsen, 2001; Cumashi *et al.,* 2007).

Fucans are fucose-rich polysaccharides that have been shown to be related to a wide spectrum of biological activities, including anticoagulant, anti-inflammatory, antiviral, antitumoral, anti-metastatic and immunostimulatory effects (Cumashi *et al*., 2007). The main sources of these compounds are brown algae, especially Laminariales and Fucales, which produce fucoidans, polysaccharides with high proportions of fucose and sulfate. Many microalgae species produce potentially bioactive fucans, but tests to demonstrate the bioactivity of the compounds are rare. *Cryptomonas obovata*, *Cryptomonas tetrapyrenoidosa* (Cryptophyceae), *Thalassiosira duostra* (Bacillariophyceae), and *Staurastrum orbiculare* (Zygnematophyceae) are examples of microalgae that produce fucose-rich polysaccharides with potential bioactivities that are currently unexploited (Giroldo and Vieira, 2002, Giroldo *et al*., 2003, Giroldo *et al*., 2005a e b).

Arabinans, arabinogalactans and rhamnogalacturans are frequently associated with pectins, which are glycoproteins with a wide variety of compositions (Paulsen, 2001). Neutral pectins, such as arabinans and arabinogalactans, and acid pectins, such as rhamnogalacturans, have anti-inflammatory and immunostimulatory activities. These compounds are common in vascular and medicinal plants and are one of the main focuses of pharmacognosy (Paulsen, 2001). Many microalgae species, especially those close to the vascular plants, have pectins in their cell walls (Domozych *et al*., 2007). Also, some green microalgae (e.g., Volvocales and Chlamydomonadales) have cell wall and extracellular polysaccharides that are similar to pectins (Halmann, 2006). The immunostimulatory activity of *Chlorella* (Chlorococcales) is related to the presence of polysaccharides rich in arabinose, galactose and galacturonic acid (Kralovec *et al*., 2007). Although few studies have focused on the production of these compounds by microalgae, the compositions of both the cell wall and the extracellular polysaccharides of green algae indicate that this group is a promising for the prospecting of bioactive substances.

This chapter intends to demonstrate the production of both particulate and extracellular dissolved polysaccharides and their relationships with the growth parameters of three chlorophytes isolated from the plankton of subtropical ponds. The growth rates, chlorophyll a content, and absolute and relative carbohydrate production were determined, in addition to the preliminary characterization of the polysaccharide composition in order to demonstrate the biotechnological potential of the pond's biodiversity. The phytoplankton community of the ponds is a promising genetic patrimony, and bioprospecting has emerged as a valuable tool for discovering new substances of human interest.

MATERIAL AND METHODS

Organisms and Culture Conditions

The phytoplanktonic strains studied in this chapter were isolated from three ponds located on the grounds of the Carreiros Campus of Federal University of Rio Grande (FURG). They are small and shallow with a superficial area between 5,000 and 10,000 m^2, a maximum depth between 1.5 and 3.0 m, and have different trophic conditions. *Chlamydomonas* sp. (Chlamydophyceae) was isolated from Polegar pond (32°04'40"S, 52°10'07"W), *Ankistrodesmus* sp. (Chlorophyceae) from Bigua's Pond (32°04'26"S, 52°09'57"W) and *Onychonema* (Zygnematophyceae) from Sport Center pond (32°04'18"S, 52°09'56"W). They were isolated by micropipette under the microscope after several washes with 1:10 diluted WC medium (Guillard and Lorenzen, 1972). The cultures have been maintained in the freshwater microalgae culture collection of the Biological Sciences Institute, Federal University of Rio Grande (*Chlamydomonas* sp., FURGCH007; *Ankistrodesmus* sp., FURGCH004; *Onychonema* sp., FURGZY009). The cultures were kept under a 10 h:14 h dark:light cycle of 80 μmol photons m^{-2} s^{-1} in an incubator (FANEM) under controlled temperature (20°C ± 1°C). The WC culture medium (Guillard and Lorenzen 1972) was adjusted to WC/2 and contained half of the phosphate and nitrogen concentration.

Experiments

Figure 1 shows the experimental design used in this chapter. A 20-mL aliquot of a 150 mL exponentially growing culture (10^6 cell mL^{-1}) of each phytoplanktonic species was used to inoculate 1-L Erlenmeyer flasks containing 600 mL of WC/2 culture medium (triplicate). The cultures were manually homogenized twice a day. The addition of pH buffer was not required because preliminary tests indicated only slight variations in the pH during a 30-day period (pH 7 ± 0.5). A 30-mL sample was removed from each 1-L Erlenmeyer flask at 48/72-h intervals in order to determine the growth by direct counts using a microscope (Olympus CX21, Tokyo, Japan). We also determined the particulate and extracellular dissolved total carbohydrate production and provided a preliminary characterization of both carbohydrate fractions.

Sub-samples (4 mL) were stored in lugol in order to perform cell counts in an improved Neubauer hemocytometer chamber (Brand, Wertheim, Germany). Growth rates (μ) and doubling times were estimated according to Fogg (1975). The remaining 26 mL was filtered through 0.6-μm pore size glass fiber filters (GF/3 Macherey-Nagel, Düren, Germany). The filter was used to determine the particulate carbohydrate content according to Myklestad and Haug (1972). The filtrate was used to determine the total dissolved extracellular carbohydrate content by the phenol-sulfuric assay (Dubois *et al.,* 1956).

The preliminarily composition analysis of particulate and extracellular dissolved carbohydrates was performed by high performance ion chromatography coupled to pulse amperometric detection (HPIC-PAD). For that purpose, 1.5 mL was sampled from each 1-L Erlenmeyer flask at the end of the stationary growth phase. These samples were centrifuged for 5 minutes at 10,000 rpm and the extracellular dissolved carbohydrate composition was determined directly in the supernatant. The cell pellet was washed three times and resuspended in 1.5 mL of fresh WC medium. The resuspended cells were frozen and thawed three times in order to promote cell lysis. Finally, they were stored at -4°C to determine the particulate carbohydrate composition. Afterwards, both carbohydrate fractions were filtered through 0.6-μm pore size glass fiber filters (GF/3 Macherey-Nagel, Düren, Germany) before HPIC-PAD analysis, which is described in the next section.

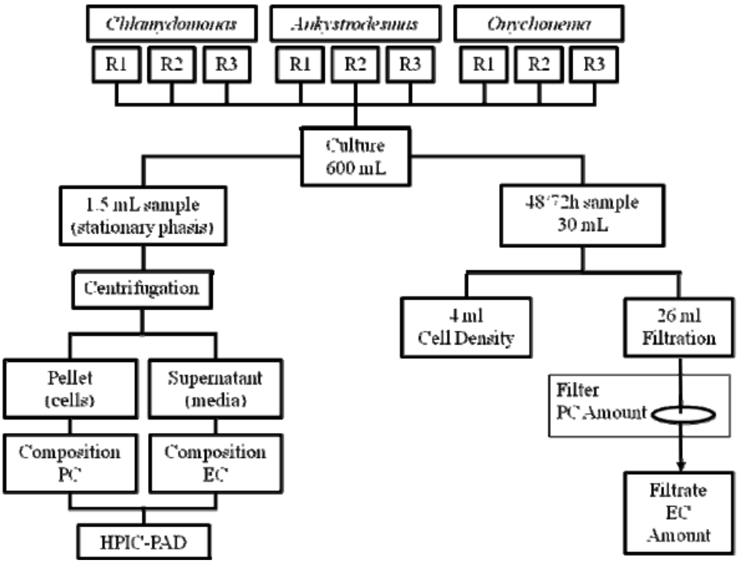

Figure 1. Experimental design showing the triplicate cultures (600 mL) of the phytoplanktonic species (*Chlamydomonas* sp., *Ankistrodesmus* sp. and *Onychonema* sp.) and the sample destination. The sampling procedure was performed for the three phytoplanktonic strains (*Chlamydomonas, Ankistrodesmus* and *Onychonema* sp.) and all the replicates (R1, R2, R3). PC, Particulate Carbohydrates; EC, Extracellular Carbohydrates.

HPIC-PAD Analysis

The composition of polymeric and free carbohydrates produced during the different growth phases was examined by high-performance ion chromatography with pulse amperometric detection (HPIC-PAD) (Gremm and Kaplan, 1997).

Both the particulate and extracellular dissolved carbohydrates were divided into two fractions prior to analysis, the total dissolved carbohydrates (TDCHO) and the free dissolved carbohydrates (FDCHO).

The amount of combined dissolved carbohydrates (CDCHO) was obtained by subtracting FDCHO from TDCHO. The FDCHO samples were injected directly into the PAD-HPIC, whereas the TDCHO samples were hydrolyzed (Gremm and Kaplan, 1997) prior to injection.

The PAD-HPIC analysis was performed on a Dionex DX500 (Sunnyvale, CA, USA) device consisting of a PEEK GP40 gradient pump module, an ED40 electrochemical detector, and an LC5 manual injector with a Rheodyne 9125 valve and a 25-µL PEEK sample loop. The ED40 detector was equipped with an amperometric flow cell, a gold working electrode, and an Ag/AgCl reference electrode.

A PA-10 (Dionex) anion-exchange analytical column (4 x 250 mm), which was fitted with a corresponding guard-column (4 x 50 mm), was used to separate the monosaccharides. The eluent used for separation was 18 mM NaOH. Column recovery was performed with a 200 mM NaOH solution at a flow rate of 1 mL min^{-1} (Gremm and Kaplan, 1997). Uronic acid was measured by applying a sodium-acetate gradient after the elution of neutral sugars (Wicks *et al.*, 1991).

RESULTS

Figure 2 shows the cell density during the experiments with *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C). Exponential growth followed by a stationary phase was observed in all three species; a senescent phase was also observed for *Onychonema* sp. Table 1 shows the growth rate (r), growth rate converted to duplications in a day (k) and the time, in days, for the biomass duplication (g) calculated for the cell densities of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C).

Chlamydomonas sp. had the fastest growth rate (0.8 cell divisions per day) during the exponential phase, which lasted until the seventh day of the experiment. *Ankistrodesmus* sp. grew at a rate of 0.26 cell divisions per day during the exponential phase, which lasted until the sixth day of the experiment. *Onychonema* sp. had the slowest growth rate (0.1 cell divisions per day) during the exponential phase, which lasted until the twelfth day of the experiment. The stationary growth phase lasted until the twenty-sixth day of the experiment and was followed by a senescence phase.

Tabel 1. Growth rate (r), growth rate converted to duplications in a day (k) and time, in days, for the biomass duplication (g) of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) e *Onychonema* sp. (C) in batch cultures.

	A	B	C
r	0.58	0.18	0.07
k	0.8	0.26	0.1
G	1.2	3.8	9.5

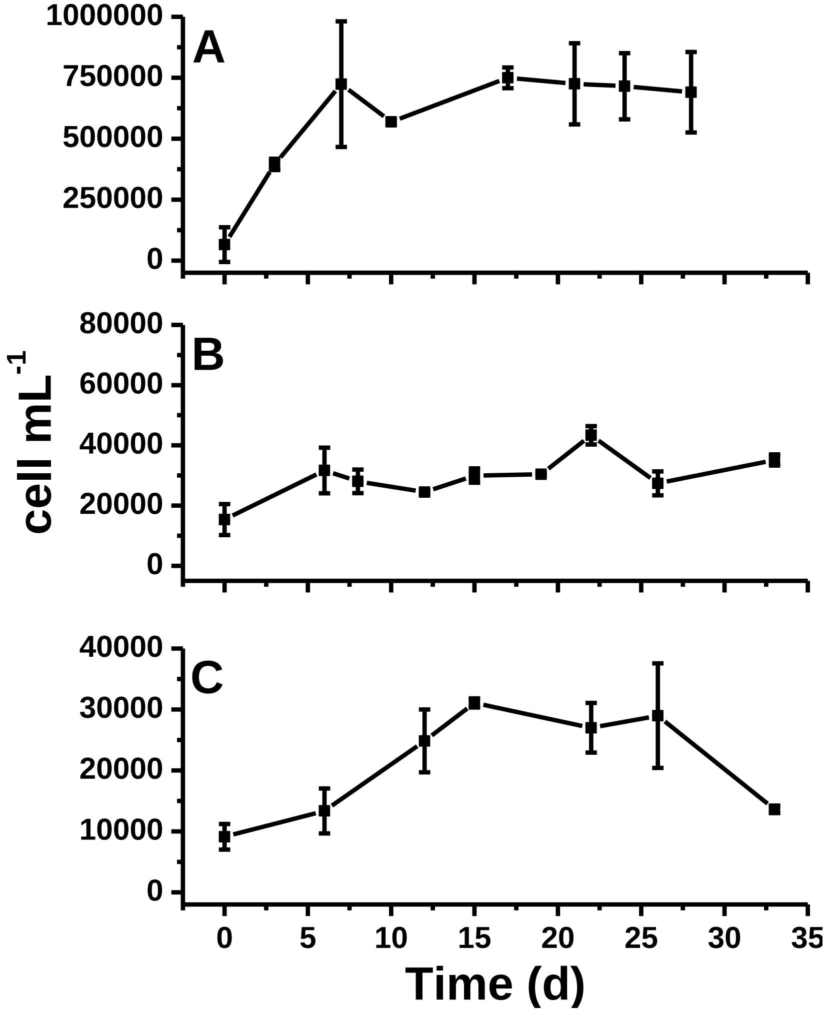

Figure 2. Cell density (cell mL^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C). Error bars represent the standard deviation (n = 3).

Figures 3 and 4 show the absolute particulate and extracellular dissolved carbohydrate content, respectively, during the experiments. Respectively, carbohydrate production reached

44 and 18.6 mg L^{-1} in *Chlamydomonas* sp., 23 and 22.4 mg L^{-1} in *Ankistrodesmus* sp., and 72 and 12.7 mg L^{-1} in *Onychonema* sp.

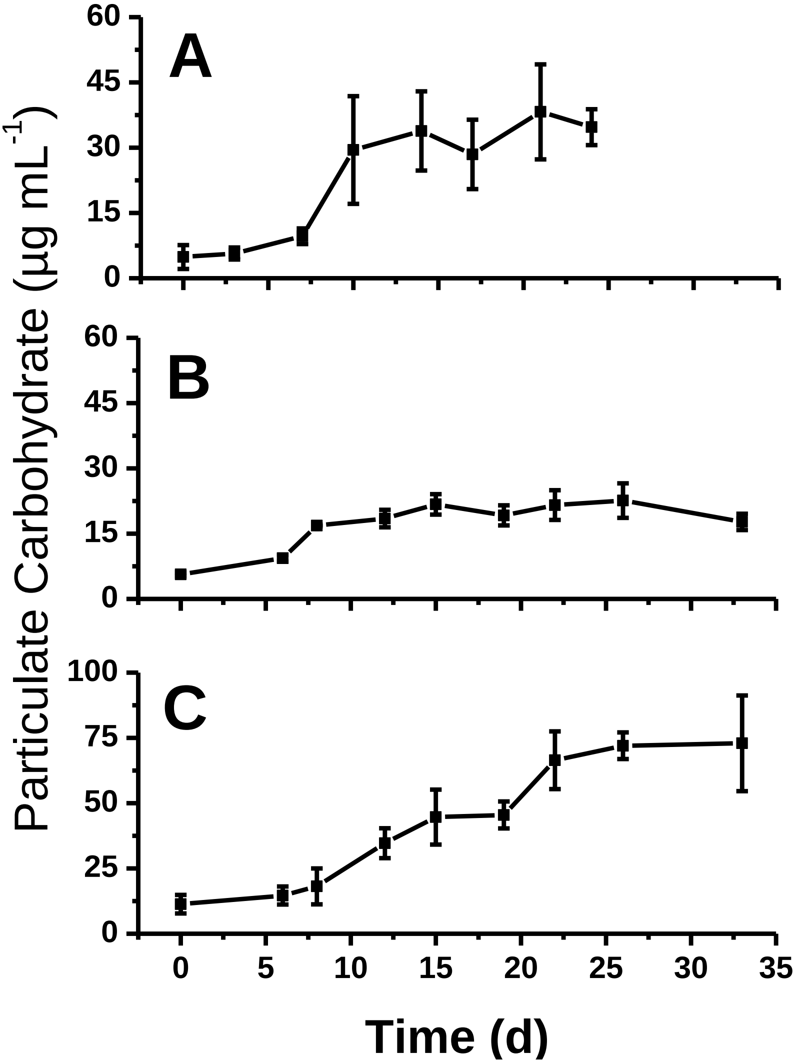

Figure 3. Absolute particulate carbohydrate content (mg L^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C). Error bars represent the standard deviation (n = 3).

In general, absolute particulate carbohydrates accumulated in parallel with growth, and reached a plateau during the stationary growth phase. On the other hand, extracellular dissolved carbohydrates were released continuously until the end of the experiment.

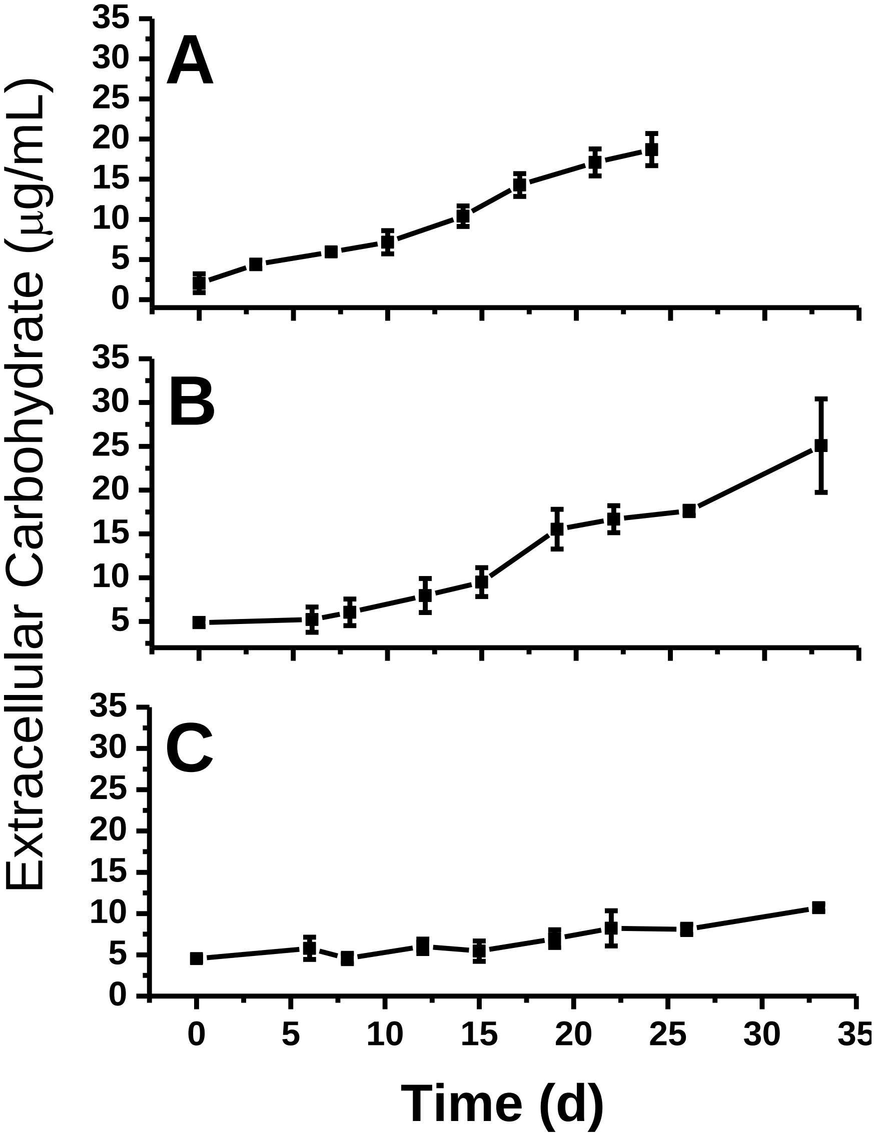

Figure 4. Absolute extracellular carbohydrate content (mg L^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C). Error bars represent the standard deviation (n = 3).

Figures 5 and 6 show the relative per cell content of particulate and extracellular dissolved carbohydrates, respectively, during the experiments.

The former was slightly decreased during the exponential growth phase and plateaued during the late exponential and stationary growth phases of *Chlamydomonas* sp. and *Ankistrodesmus* sp.

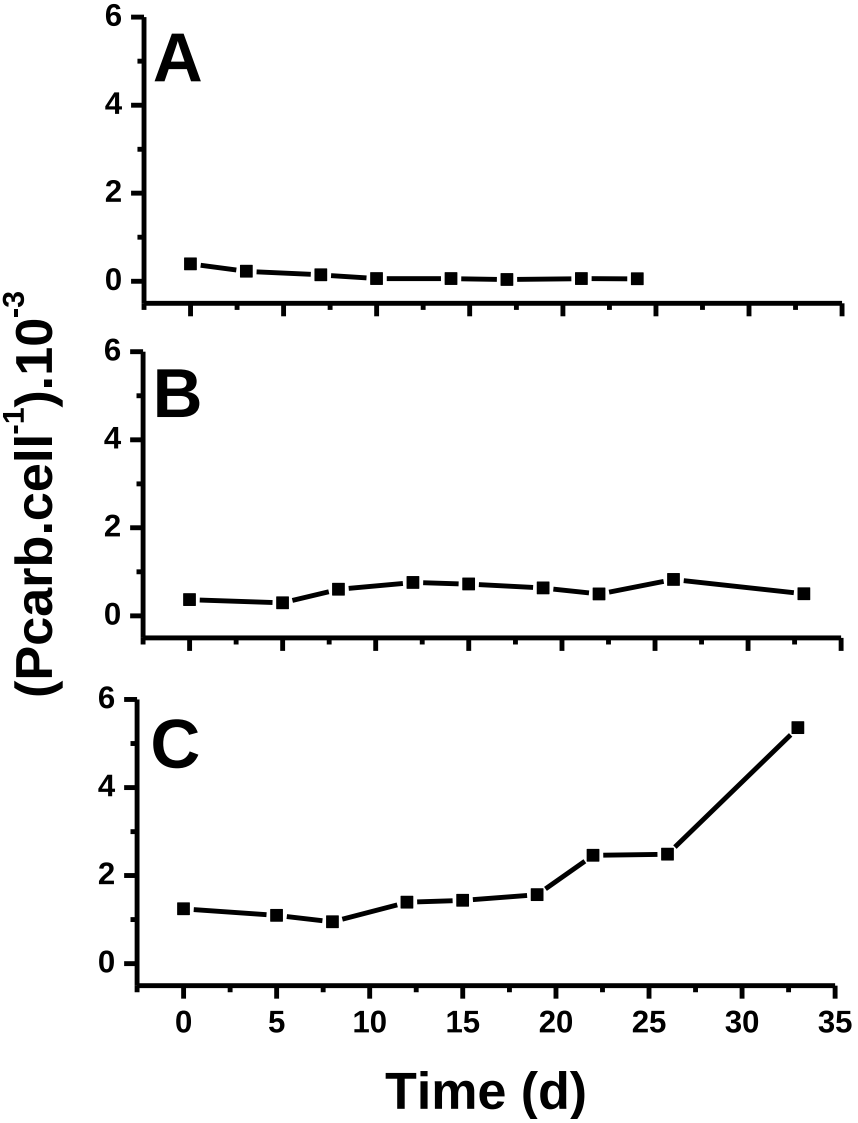

Figure 5. Particulate carbohydrate content per cell (mg L^{-1} cell^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C). Error bars represent the standard deviation (n = 3).

On the other hand, the particulate carbohydrate content in the *Onychonema* sp. culture increased during the entire experimental period. The extracellular dissolved carbohydrate content per cell decreased during the exponential growth phase of all microalgae strains and increased during the late exponential and stationary growth phases in the *Ankistrodesmus* sp. and *Onychonema* sp. experiments.

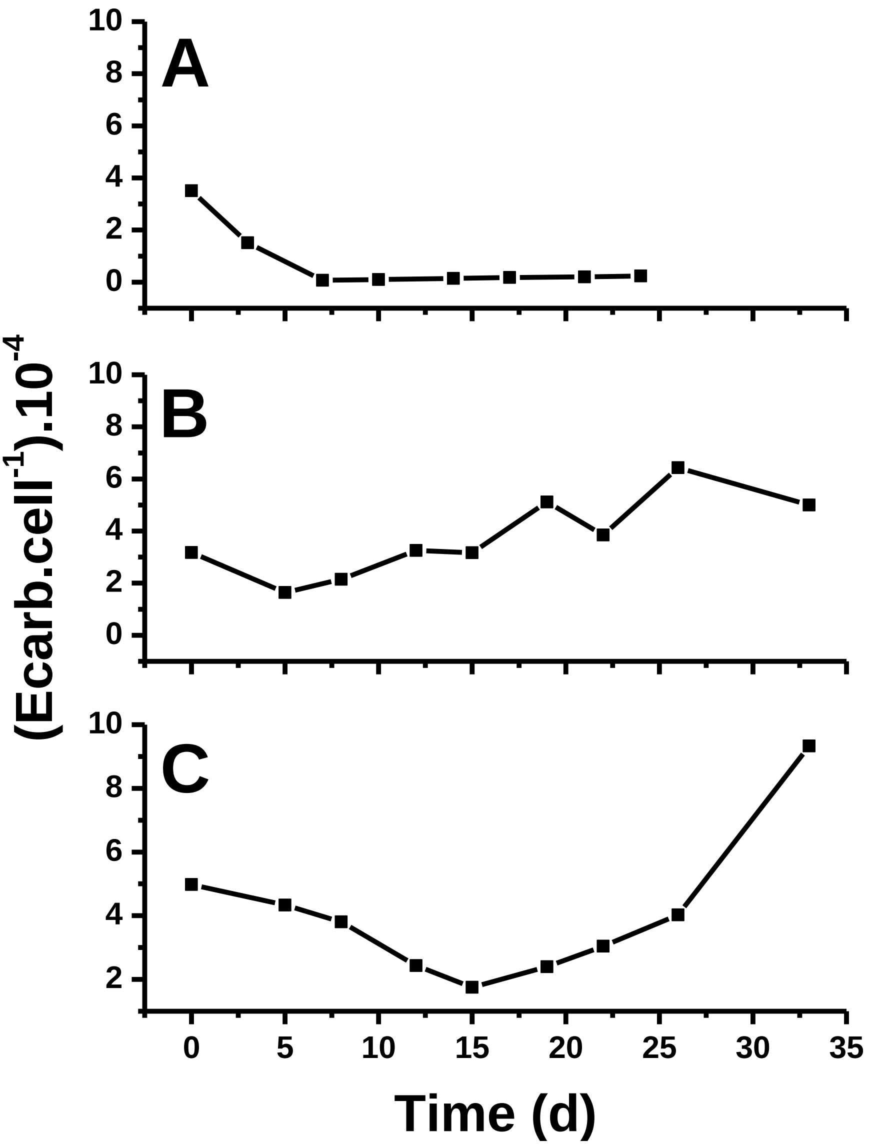

Figure 6. Extracellular carbohydrate content per cell (mg L^{-1} cell^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C). Error bars represent the standard deviation (n = 3).

Figures 7 and 8 show the rate of particulate and extracellular dissolved carbohydrate production, respectively, during the experiments.

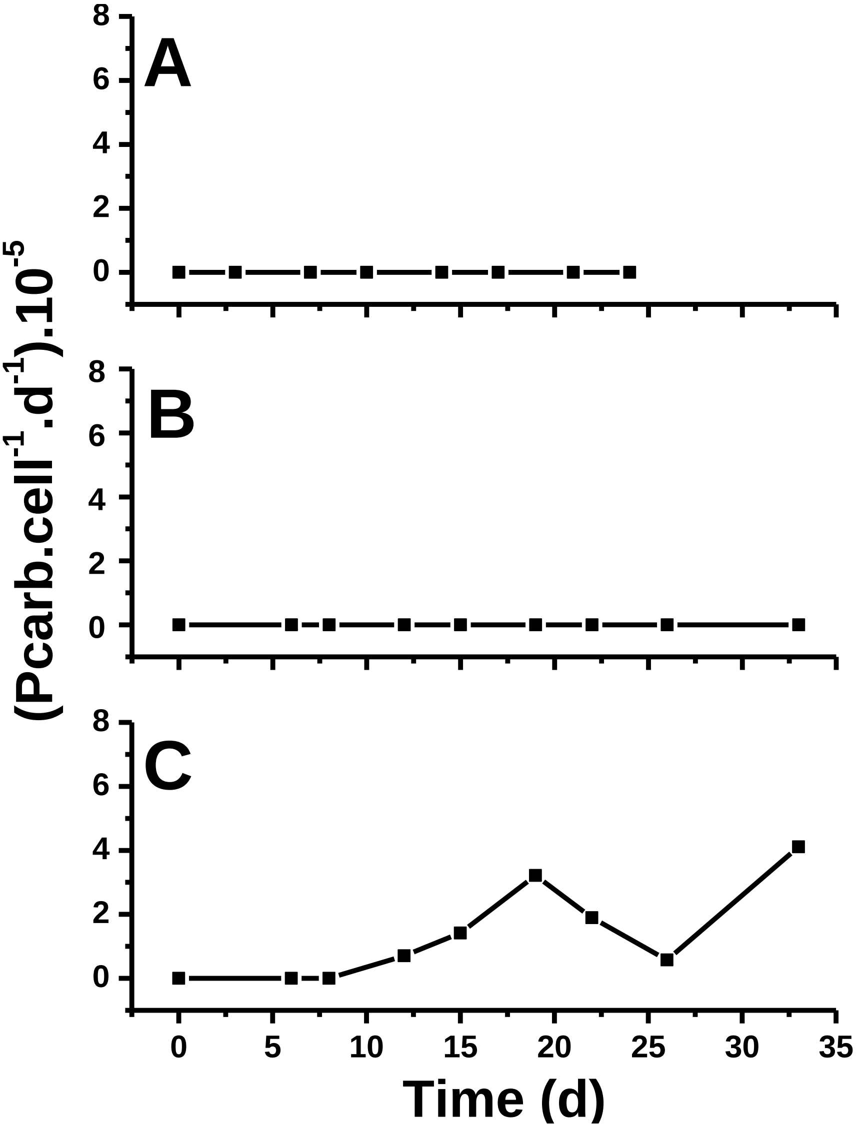

Figure 7. Rate of particulate carbohydrate production per cell (mg cell^{-1} d^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C).

The former remained equal or very close to zero for *Chlamydomonas* and *Ankistrodesmus*. Only *Onychonema* sp. demonstrated an increased rate of particulate carbohydrate production per cell in the stationary growth phase, indicating that there was carbohydrate accumulation even at a low rate of growth.

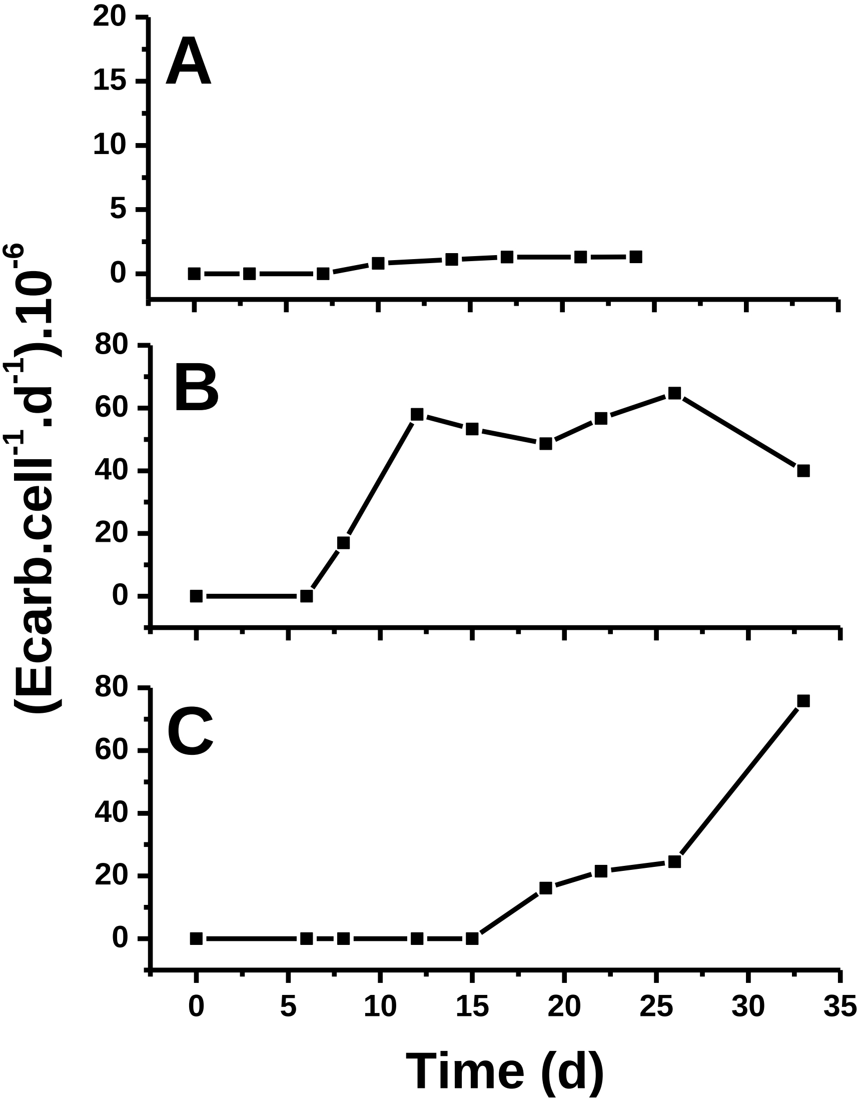

Figure 8. Rate of extracellular carbohydrate production per cell (mg cell^{-1} d^{-1}) during the experimental period (day) for the batch cultures of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C).

On the other hand, the extracellular dissolved carbohydrate production rates were equal to zero during the exponential growth phase and were increased during the stationary and senescence phases in all microalgae strains, especially in the *Ankistrodesmus* sp. and *Onychonema* sp. cultures. Additionally, the rate of extracellular dissolved carbohydrate production was much lower in *Chlamydomonas* sp. than in *Ankistrodesmus* sp. and *Onychonema* sp. experiments.

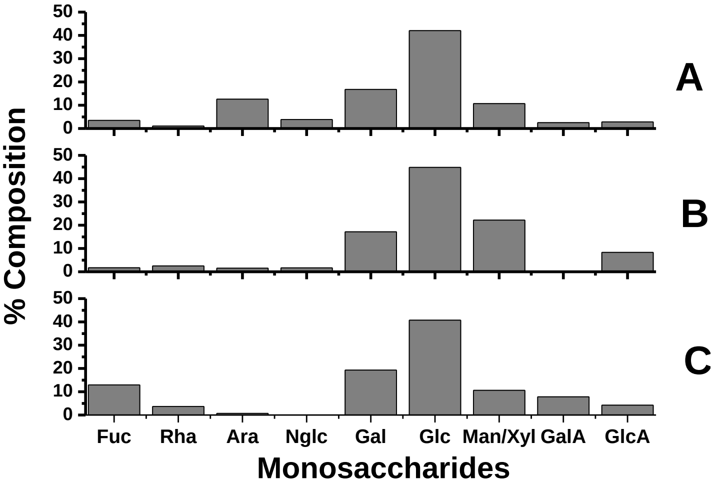

Figure 9. Composition of the particulate polysaccharides (monosaccharide percentage) during the stationary growth phase of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C).

No free carbohydrates were detected in either the particulate or extracellular fractions from all phytoplanktonic species. Figures 9 and 10 show the monosaccharide composition percentage of the particulate and extracellular dissolved polysaccharides, respectively, during the stationary growth phase. In general, the same components were found in all the phytoplanktonic species and the polysaccharide fractions, but significant variation was found with regard to their percentages. *Chlamydomonas* sp. particulate polysaccharides were mainly composed of glucose, galactose, arabinose and mannose and/or xylose (man/xyl) with minor amounts of N-acetyl-glucosamine, fucose, rhamnose, and galacturonic and glucuronic acids. The extracellular dissolved polysaccharides of *Chlamydomonas* sp. were mainly composed of glucose, man/xyl and galactose with significant amounts of fucose, arabinose, glucuronic acid and minor quantities of N-acetyl-glucosamine and rhamnose.

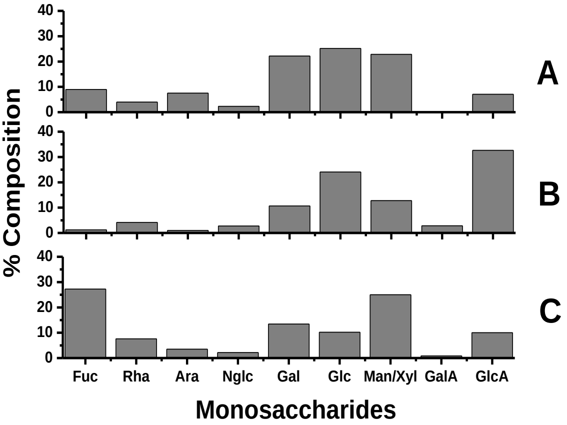

Figure 10. Composition of the extracellular polysaccharides (monosaccharide percentage) during the stationary growth phase of *Chlamydomonas* sp. (A), *Ankistrodesmus* sp. (B) and *Onychonema* sp. (C).

The particulate polysaccharides of *Ankistrodesmus* sp. were mainly composed of glucose, man/xyl and galactose, with a significant amount of glucuronic acid and minor quantities of rhamnose, fucose, arabinose and N-acetyl-glucosamine.

The extracellular dissolved polysaccharides of *Ankistrodesmus* sp. were mainly composed of glucuronic acid, glucose, man/xyl and galactose with minor amounts of rhamnose, galacturonic acid, N-acetyl-glucosamine, fucose and arabinose.

The particulate polysaccharides of *Onychonema* sp. were mainly composed of glucose, galactose, fucose and man/xyl with a significant amount of galacturonic acid and minor quantities of glucuronic acid, rhamnose and arabinose.

The extracellular dissolved polysaccharides of *Onychonema* sp. were mainly composed of fucose and man/xyl with significant amounts of galactose, glucuronic acid, glucose and rhamnose with minor quantities of arabinose, galacturonic acid and N-acetyl-glucosamine.

DISCUSSION

Onychonema sp. is a filamentous desmid that showed a lower growth rate than the cenobial Chlorococcales *Ankistrodesmus* sp. and the unicellular *Chlamydomonas* sp. Desmid growth rates are usually low because their cell shape frequently exhibits more morphological specializations, such as cell projections and polysaccharide capsules, in comparison to simple cell shape of Chlamydomonadales and Chlorococcales that exhibit rapid growth (Giroldo and Vieira 2005, Reynolds, 2006). However, cell shape is not the only factor that determines phytoplanktonic growth rates and many exceptions can be observed due to the influence of other parameters, such as cell size and physiological adaptations (Padisak, 2004). Additionally, the ponds where these species were isolated have environmental conditions that are distinct from our controlled experiments, such as nutrient concentration, pH, irradiance patterns and interspecific relationships. Therefore, it is not expected that the growth rates of these phytoplanktonic species would be identical in both their natural environment and in our experiments. However, batch cultures are an established method to study the physiological effects on phytoplankton growth patterns and cell aging (Giroldo and Vieira, 2005).

Despite the fact that the *Onychonema* sp. culture reached a lower cell density than the *Ankistrodesmus* sp. and *Chlamydomonas* sp. cultures, its absolute and relative particulate carbohydrate contents were higher than the other two strains. The absolute extracellular dissolved carbohydrate content of the *Onychonema* sp. culture was lower than the *Ankistrodesmus* sp. culture, whereas the relative per cell extracellular carbohydrate content was higher in the *Onychonema* sp. culture than in *Ankistrodesmus* sp.. Both the absolute and relative per cell particulate and extracellular dissolved carbohydrate contents of the *Chlamydomonas* sp. culture were the lowest among the strains studied in this chapter. Biovolume could be a key factor in determining the phytoplanktonic particulate and extracellular dissolved carbohydrate contents. Future studies, combined with a precise morphological and molecular identification of such phytoplanktonic strains, will be carried out in order to clarify the relationship between carbohydrates and biovolume.

The rate of particulate and extracellular dissolved carbohydrate production provides significant insights into the physiological strategies of carbohydrate allocation in phytoplanktonic species (Giroldo and Vieira 2005, Yunes *et al.,* 2009, Piedras *et al.,* 2010).

The particulate carbohydrate production rate remained equal or close to zero during all the experiments with the *Chlamydomonas* sp. and *Ankistrodesmus* sp. cultures, which indicates that there was no particulate carbohydrate accumulation even when growth was interrupted in the stationary phase. According to Piedras *et al.* (2010), carbohydrate production rates close to zero indicate that growth is occurring in the same rate as carbohydrate production. In this case, phytoplanktonic cells produce a constant amount of carbohydrate per cell during the entire experiment with no influence of cell aging.

On the other hand, the rate of particulate carbohydrate production in the *Onychonema* sp. culture increased with growth stabilization in the stationary phase, indicating that carbohydrate accumulation was a response to growth interruption. Additionally, the rate of extracellular dissolved carbohydrate production increased during the stationary growth phase in all phytoplanktonic species, especially in *Ankistrodesmus* sp. and *Onychonema* sp. Such a phenomenon was also observed in several studies on microalgae species from several environments (Vieira and Myklestad, 1986; Lombardi *et al*., 1998; Alcoverro *et al*., 2000; Brouwer and Stal, 2002). Phytoplanktonic cells in the stationary growth phase undergo a decrease in cytokinesis while photosynthesis remains active. This change produces an excess of photoassimilated carbon, which is mainly derived for carbohydrate excretion, but is also involved in accumulation as observed in the *Onychonema* sp. culture. Such a process plays an important role in carbon cycling in aquatic environments and is related to the organic carbon accumulation patterns in bodies of water after microalgae blooms (Giroldo and Vieira, 2005; Vieira *et al.*, 2008).

This previous scenario was first proposed by Fogg (1983). The biological functions of extracellular carbohydrates, mainly polysaccharides, are still not completely understood. They are the major component of phytoplanktonic extracellular carbohydrates and are also very complex molecules as corroborated by the data shown in this chapter. Several hypotheses have been proposed to explain the role of such frequent phytoplanktonic behavior. An excess of excreted polysaccharides protects the colonies against predators and also increases flotation by decreasing cell density. (Reynolds, 2006; Piedras *et al.* 2010). In environments with excessive irradiance, polysaccharide excretion might protect the microalgae photosynthetic apparatus from excessive electrons (Smith and Underwood, 2000). Polysaccharide release by phytoplankton also stimulates the bacterial growth associated with such carbon-rich molecules (Giroldo *et al.,* 2007). Bacterial growth using algal polysaccharides as a substrate increases nutrient remineralization and, consequently, may promote phytoplankton growth through the coevolution of complex plankton communities (Wood and Van Valen 1990).

More recently, extracellular polysaccharide production has been related to the formation of transparent exopolymer particles, which are responsible for the formation of large aggregates in marine environments (Alldredge *et al.,* 1993; Passow, 2002). Such particles play an important role in diatom bloom coagulation by providing an adaptive function for the cells of a declining bloom, which drop down to depths with better nutrient conditions than the depleted surface (Passow *et al.,* 1994). Although this process was proposed to explain large aggregates and bloom dynamics in the marine environment, the significance of such a process in freshwater has also been pointed out by some authors (Vieira *et al.,* 2006, 2008). Giroldo *et al.* (2007) demonstrated that degradation of the polysaccharides excreted by *Thalassiosira duostra* influenced the growth of this alga, which enforces the hypothesis that such polysaccharides play an ecological role in bacterioplankton-phytoplankton associations.

The carbohydrate analysis performed by HPIC with pulse amperometry detection demonstrated the differences between the particulate and extracellular dissolved polysaccharide compositions among the phytoplanktonic species. Glucose was the main component of the particulate polysaccharides from all the phytoplanktonic species in this chapter and is probably related to starch cell wall composition. However, the high content of other monosaccharides indicated that the extraction method is efficient for the analysis of other polysaccharides besides those found in reserve and in the cell wall, including the analysis of the remaining capsules, sheaths and biofilms attached to cells. We found a high content of arabinose associated with galactose in both the particulate and extracellular dissolved polysaccharides from *Chlamydomonas* sp. cultures.

This composition indicates the presence of pherophorins, which are cell wall glycoproteins rich in hydroxiproline, arabinose and galactose. These molecules are typically found on Volvocales and Chlamydomonadales (Morita *et al.,* 1999; Hallman, 2006). Because of the cell division pattern of this group, they also are included in the extracellular dissolved polysaccharides because the old cell wall is released and a new one is produced by the daughter cells at each cell division. Pherophorins show a similar composition to some pectins produced by vascular plants, which have a well-known range of bioactivities, such as anti-inflammatory and immunostimulatory effects (Paulsen, 2001). Preliminary studies demonstrated significant analgesic activity from the *Chlamydomonas* sp. particulate extracts (Ana M. Baisch, personal com.).

Particulate and extracellular dissolved carbohydrates in particular from the *Ankistrodesmus* sp. cultures showed a significant percentage of glucuronic acid. Uronic acids are negatively charged and have a well-known potential for metal complexation (Gouvêa *et al.*, 2005), which indicates the biotechnological potential of *Ankistrodesmus* sp. polysaccharides. Both particulate and extracellular dissolved carbohydrates from *Onychonema* sp. showed a significant fucose content, which is similar to the brown algae fucoidans. These compounds are associated with several biological activities, such as antitumoral, anti-inflammatory, anticoagulant and immunostimulatory effects (Cumashi *et al.,* 2007). Future studies will be carried out to confirm the metal complexation of *Ankistrodesmus* sp. and the bioactivity of *Chlamydomonas* sp. and *Onychonema* sp. polysaccharides.

In conclusion, this chapter demonstrated that culture aging influenced both growth and carbohydrate production patterns. Also, our results demonstrated significant differences between the particulate and extracellular polysaccharides of all strains, besides a remarkable variation in the polysaccharide composition among the phytoplanktonic species. The occurrence of polysaccharides rich in arabinose and galactose in *Chlamydomonas* sp., glucuronic acid in *Ankistrodesmus* sp. and fucose in *Onychonema* sp. indicates the potential biotechnological applications of these species.

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Chapter 6

LAKES BEYOND THE EARTH: DRY LAKEBEDS ON MARS, AND ACTIVE METHANE-ETHANE LAKES ON TITAN

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ABSTRACT

Ancient water-filled lakebeds were identified on Mars based on shorelines, terraces, sedimentary deltas, in- and outflow valleys, mineral alterations, sedimentary plains and cracks possibly formed during the drying phase. Most of them were probably fed by precipitation or ice melting, and formed at low latitudes before 3.5 billion years under warmer climate. Later in colder periods, ephemeral lakes with ponded water from outbreak of subsurface aquifers were still present, as well as impact of volcanic activity melted lakes. Many lakes were covered with ice layer, and salts decreased the melting point of their water. Their sediments may hold important information of the ancient climate, chemical alterations and the possibility of life.

Lakes on Titan, on the moon of Saturn are present today, where liquid methane-ethane mixture fills about 400 observed lakes in the polar region. The temperature only in the polar region is low enough (about -179 °C) for the liquids to remain stable, while at lower latitudes only dry lakebeds are present. Lakes smaller than 20 km fill roughly circular depressions, while larger lakes have dissected shorelines. Inflow rivers are observed, and subsurface contribution may also be present. Lakes play an important role in the methane cycle of Titan: evaporation, cloud formation and rain events happen above them. Organic sediments may have accumulated at the bottom of lakes, and their characteristics help to reconstruct pathways of abiotic organic material synthesis, which is important to understand prebiotic chemical processes on the Earth too.

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INTRODUCTION

Lakes may be present on other planets beyond Earth, where liquids accumulate in surface depressions, and the climatic conditions are favourable for the thermodynamic stability of that liquid under the atmosphere (Fig. 1.). In planetary geology, those surface depressions are classified as lakes or ponds, which are currently filled or were previously filled with liquid materials, regardless whether it was water or not. In reality it is very difficult to prove the ancient presence of liquid material [Gyenizse 2008] – but as below we will see there are possible methods to have insight into the history of lake-like surface structures. Molten-lava-filled depressions could also be called lakes, but they are very much different from the features analyzed in this book and we exclude them from this chapter. Although it is worth knowing that beyond the Earth only one planetary body is known where molten volcanic lava lakes are present. It is Io, the satellite of Jupiter, where at least one active lava lake is present, called Loki.

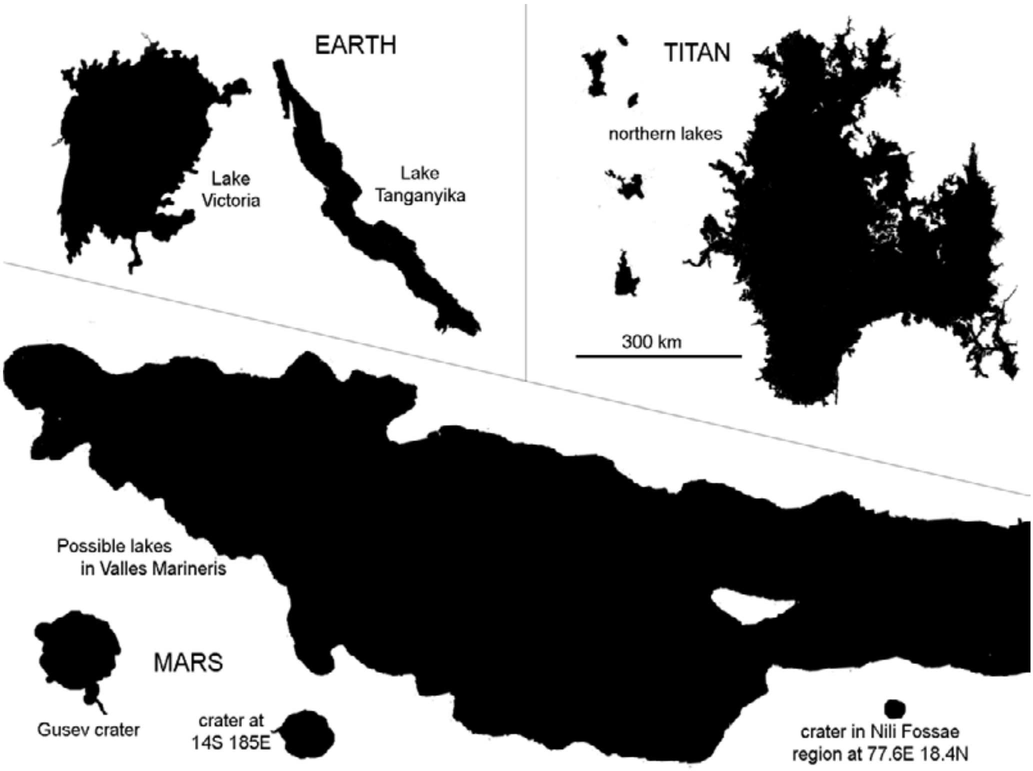

Figure 1. Comparison of lake sizes on Earth (top left), Titan (top right) and Mars (bottom) (partly after Harrison & Chapman 2009)

In this chapter first the signatures of ancient lakes on Mars are summarized, then the currently existing lakes on Titan are characterized. Both cases provide us with a wider outlook and improve our understanding of lake-related processes and their physical background under extreme conditions.

LAKES ON MARS

There is various observational evidence, as well as theoretical arguments on the ancient presence of lakes on Mars, mostly in the depressions of impact craters. The surface of the red planet is cold and dry today, although very salty brines may be ephemerally liquid during the clement periods of the year [Möhlmann 2010, Renno et al. 2009]. Based on the general view of Martian surface evolution, and various morphological features like valleys and channels [Irwin et al. 2008], liquid water was present on the surface above all during the early period of planetary evolution, and partially in recent times too because of the orbital change forced climate changes [Touma J, Wisdom J. 1993]. In the following we summarize first the observational evidence suggesting past lakes on Mars, then the possible characteristics of these lakes. A short list is also presented of the examples of lakebeds analyzed in the literature. The most detailed review of ancient valley network-fed, open-basin lakes on Mars can be found in Fasset and Head 2008 publication where 210 such lakebeds are listed. Beyond theoretical assumptions, the following arguments point to the presence of lakes on Mars in the past:

Shorelines or terrace-like features: along the perimeter of the proposed ancient lakes terrace-like features are visible, which are interpreted as the erosional product of wave activity [Ori 1989] or expansion/contraction of ice cover in the lacustrine basin. These are probably not formed by the original and possibly layered outcrop of bedrock, as rock layers around the perimeter of a crater are influenced by the impact event and such horizontal layers are not expected there [Ori and Baliva 1998]. On Mars, the lack of a large moon and its more distant position from the Sun than the Earth has suggested a lower importance of tides and tidal shoreline features. At the same time, because of low temperatures, in the ancient lakes, the freezing and the shoreline processes by surface ice cover may have a stronger effect and play a greater role in the shoreline forming. Although, there are aspects resembling shoreline-like features in some ancient lava filled craters on the moon [Leverington 2005], which are definitely not the result of lake shoreline processes.

Deltas: Deltaic sedimentary features resembling the Gilbert deltas on Earth are visible at several locations on Mars (Fig. 2.), suggesting the former presence of lakes there [Cabrol and Grin 2000, Hauber et al. 2005]. The sharp topographic change between the topset and the foreset layers indicate the possible level of the ancient lake. Although many deltas are probably formed by fluvial sedimentation during extended periods [Fassett and Head 2005], there is a model, which suggests a short period of dense (sediment-laden) flows may also result resembling features [Kleinhans et al. 2009].

Inflow (and outlet) fluvial valleys to closed depressions also suggest that lakes could be present there, resembling what is well known and analyzed in the cases of some impact craters on the Earth too [Mihályi]. The best morphological indicators are at those lakebeds, where several inlet valleys and one outlet valley were also present (Fig. 3.), suggesting overflow and drain of the ancient lake's water [Fasset and Head 2008].

Mineralogical signatures: Although no comprehensive result is available in this field from systematic research, chloride salt deposits were found by Mars Odyssey spacecraft [Osterloo et al. 2008] in patches sized between 1 and 25 km in the southern hemisphere at low-lying areas with light-toned and polygonally fractured surface there. These features are aged middle to late Noachian (3.9–3.6), a few of them early Hesperian (3.6–1.8). Their presence suggests that near-surface water was available and widespread, and the position in topographic lows suggests they may have formed by precipitation of standing water – although other formation mechanisms like efflorescence from evaporative pumping, volcanic out gassing, or atmospheric-surface interactions are also possible.

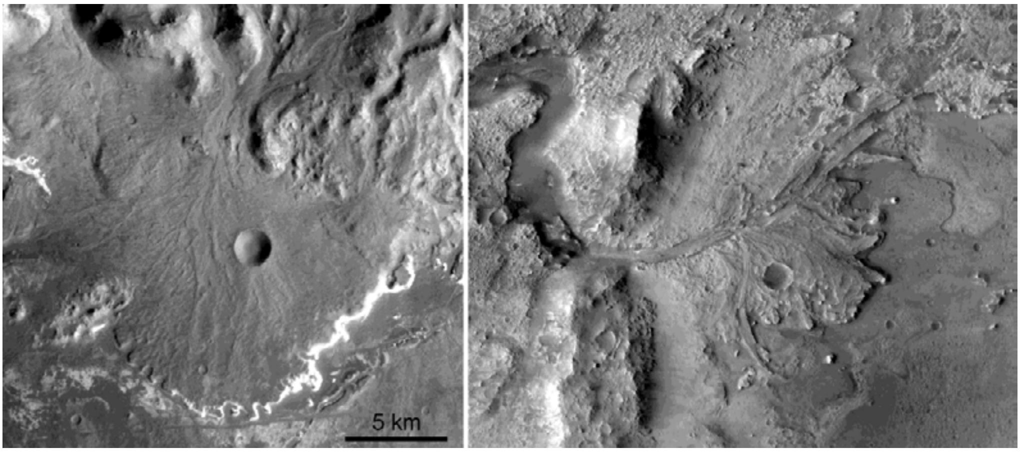

Figure 2. A sedimentary delta formed at the entry of a small valley into Holden crater (left, THEMIS image V35120003) and another delta from Jezero crater (right, CTX image P04_002664_1988) (NASA, JPL, JHUAPL, ASU, MSSS, Brown University)

Sedimentary plains are present on Mars in closed depressions, but only in a few cases were formed by sedimentation from standing water bodies. These morphological signatures are useful in those cases where other features (deltas, inflow valleys, mineral signatures) are also present, which straighten the lacustrine origin.

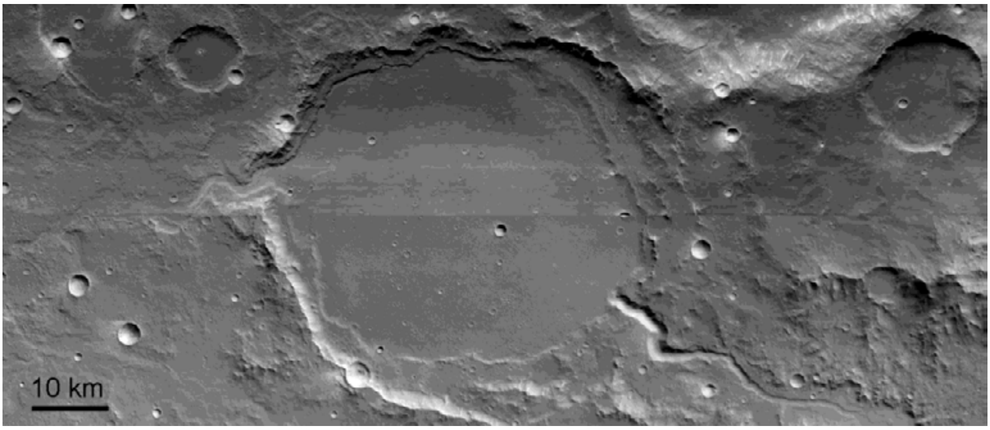

Figure 3. Mosaic image of an ancient dried up crater lake at 14.5S 185.2E, with an inflow channel (left), shoreline and sedimentary plain in the crater (middle) and an outflow channel (right) (CTX images P11_005482_1653, P15_006906_1655, north is to the right) at 14S 185E (NASA, MSSS)

Polygonal cracks form a less certain group of signatures of ancient lakes, where a polygonal shaped crack system could be observed at the bottom of craters. These could be thermal contraction polygons too, but based on a computer simulation their size is usually too large for this process, suggesting another origin, possibly by desiccation of ancient ground. These fracture systems resemble those formed on the Earth at mud dries [El Maarry et al. 2009].

CHARACTERISTICS OF ANCIENT LAKES

To characterize the areal distribution of ancient lakes requires their identification in substantial number. Beside the several smaller (1-100 km sized) features called ancient lakebeds with relatively large number [Fasset and Head (2008)] identified 210 of them, there are signatures of larger ancient lakes, but few in number. This second group consists of possible lakes in Valles Marineris, inside Argyre and Hellas basins, and the great northern ocean. As these are small in number, their areal distribution points to unique sources and processes – so here we analyze only the lake basins smaller in size but larger in number. The possible existence of a large, and later several smaller, episodic liquid bodies in the northern plains called "oceans" in the literature are out of the scope of this chapter.

The oldest Noachian (4.5-3.6 billion years) lakes are located between 60 degrees of latitude [Fasset and Head 2008] and were probably fed by valley networks. Most of them are Late Noachian (3.8-3.6 billion years) (Fig. 4.) and Noachian/Hesperian boundary age [Fasset and Head 2008]. Hesperian (3.6-1.8 billion years) aged lake basins are present between roughly the same latitude range as the above mentioned older group. Hesperian lakes have significant impact on the climate reconstruction and suggest that this period was not as dry and maybe as cold as previously suggested, based on the analysis of dry lakebeds. Although some of these lakes may be fed by the rare breakup of outflow events from subsurface aquifer, (Nicholas Warner) found several lakes in a region and above the main level of the large outflow system called Ares Valles, which are often connected by sinousing valleys and formed about 3 billion years ago – suggesting long term fluvial and lacustrine activity.

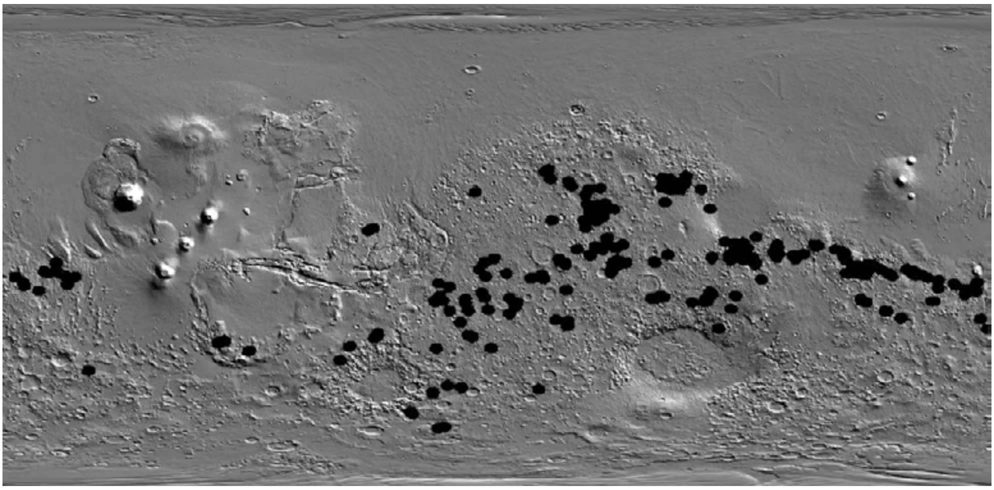

Figure 4. Distribution of 210 Noachian (4.5-3.6 billion years) lakes on Mars after Fasset and Head 2008 on a mercator projected shaded MOLA based topographic map

In the Early Amazonian period (1.8-0.7 billion years) lakes formed also at low latitude and they often show groups in their areal distribution. Their locations usually overlap the areas where liquid water could be stable for them for the longest period. In general it can be said there are many possible valley terminal basins with breached inlet, and without outlet channels are present on Mars too [De Hon 1992]. Many of these lake basins are located along the outflow channels with sedimentary infilled bottoms and breached crater walls at the outlet, where ephemeral ponding happened after the main outflow event. The best example is analyzed by di Achile et al. 2009 and situated in Shalbata Valles. Ancient shorelines and a sedimentary delta suggest a 200 km^2 and 400-500 m depth lake existed there about 3.4 billion years ago.

Regarding the *numerical parameters*, the volume of the largest valley network-fed lakes' were around 10^4-10^5 km^3, values comparable to small seas on Earth, while the smallest Martian lakes could have had 0.02 km^3 volume. The area spanned between 5 and 200 000 km^2.

The *composition* of the ancient liquids in the lakes could be estimated from theoretical assumptions on planetary surface evolution, and remote composition analysis of lakebed sediments. Based on the morphological analysis, the contribution of groundwater was larger in some lakes than in others, and this might effect the composition of the liquid, which could have solved more minerals in the case of long residence time in the subsurface [Fasset and Head 2008]. Lakes formed during the Noachian period (4.5-3.6 billion years) phyllosilicates formed by weathering of basaltic rocks formed in relative warm water. While later in the Hesperian (3.6-1.8 billion years) and Amazonian periods (1.8- billion years) cold and acidic water, dense salty brines could be present ephemerally in the lakes on the planet, forming various sulphate deposits. It can be said in general that the lakes were probably often filled not by pure water but water including various salts in solved forms, which may decreased their freezing point with several tens of degrees in an ideal case.

Lakes below ice cover could be important and frequent among the lakes on Mars. Based on theoretical assumptions, frozen surface ice layer formed on the lake under cold conditions, lowering the heat loss and making longer lifetime. In the case of a thick ice cover, thermal contraction and expansion, e.g. volume change induced by temperature changes may result mechanical stress and produce shoreline-like features [Barnhart 2005]. For example the level, bench-like platforms in Gorgonum Chaos basin could formed this way, where ice covered lake period could be present after the subsurface water breakup from the chaotic terrain nearby [Howard and Moore 2004], which released the water that formed the lake.

POSSIBLE FORMATION MECHANISMS

Based on the observed characteristics and theoretical assumptions, the possible formation mechanisms could be arranged into three groups: impact melted ice, surface and subsurface drainage.

Impact helps lake formation by producing a depression where liquid could accumulate, and also release heat from the melt sheet and by the central uplift, to melt ice on and below the surface even under the cold conditions today. The thermal energy from an impact is able to keep the lake from complete freezing under a thickening ice sheet [Newsom et al. 1996].

Computations on the possible lifetime of impact related hydrothermal activity in fresh impact craters suggest 20-200 km diameter lakes could survive 10^3-10^6 years on Mars [Daubar and Kring 2001, Turtle et al. 2003].

Inflow by surface runoff: Many ancient lakes show inlet fluvial valleys, probably fed them by surface runoff from precipitation and/or ice melting (Fig. 5.). In the case of several valley network-fed lake basins (with outlet valleys) the calculated volume of the ancient lake is proportional to the area of watershed (Fasset and Head 2008]. Some of these lakes were possibly long lived or repetitively fed by rains or surface ice melting, but lakes along the so called outflow channels may formed only once, as these great channels carved by individual water breakout from subsurface aquifers. The precipitation fed open-basin lakes often form lake chains, and located generally at lower elevation than the valley networks, which fed them [Fasset and Head 2008]. They also show weak inverse correlation between the volume of the lakes and their elevation. The small watershed area relative to the lakes in the region between 40W and 80E suggests it could have been more ‘wet” than other analyzed regions.

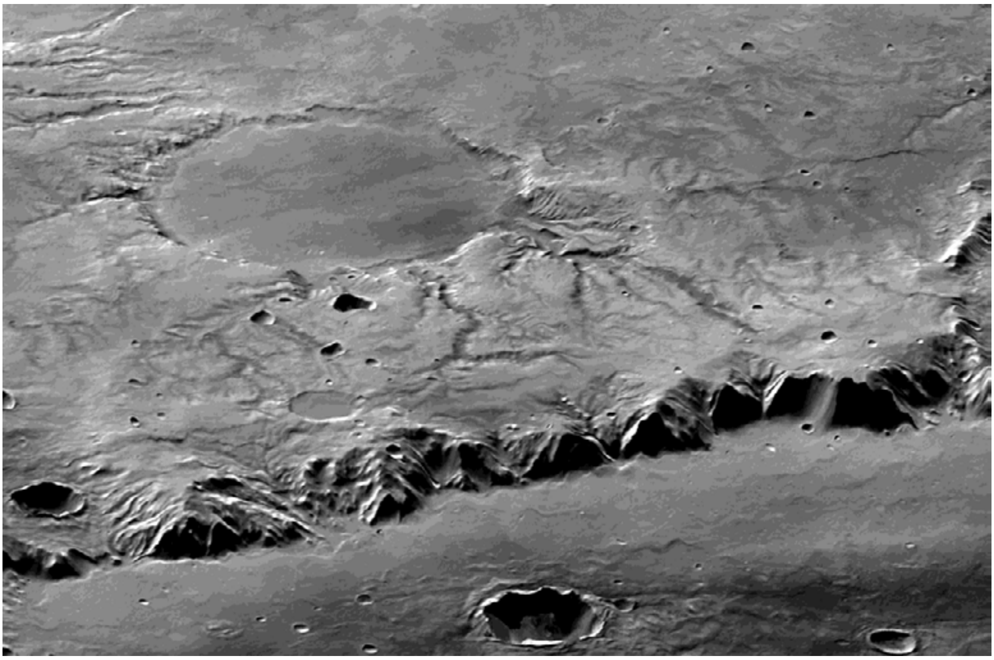

Figure 5. Perspective view of the rim of crater Huygens (running across the scene as a chain of steep cliffs at the bottom from left to right. Another crater in the middle left was filled with water by several inflow channels (Mars Express image acquired at 14S 61E, ESA/DLR/FU Berlin, G. Neukum)

Subsurface seepage: Liquid water was present below the surface as regional or global aquifer based on the presence of outflow channels, which formed by the breakup of subsurface water. There are lake basins which show few inlet valleys and have small watershed area, suggesting subsurface contribution was present in their liquid balance [Fasset and Head 2008], mostly at the region of Arabia Terra and near to the northern-southern topographic boundary.

IMPORTANCE OF LAKES ON MARS

As a conclusion it can be said that Mars was able to hold lakes in the past as large as the largest lakes of the Earth today. They may help in the reconstruction of past climates, and the source of their water holds information on the volatile circulation, precipitation and ice distribution. These lakes may maintain wet environments for certain periods and help various chemical reactions take place, including possible prebiotic processes. As a result lakes may hold important information for the research in astrobiology: in the analysis of the possibility of life beyond the Earth.

LAKES ON TITAN

Titan is the largest satellite of Saturn, covered by a thick nitrogen atmosphere with a mass of about 10 times the atmosphere that surrounds the Earth. The satellite's surface is composed mostly of solid water ice, which is as hard as rock under the frigid temperature. A small part, up to 5%, of the atmosphere is methane, which is continuously destroyed by solar UV radiation, suggesting continuous methane release from the surface by evaporation of lakes and/or by volcanic release.

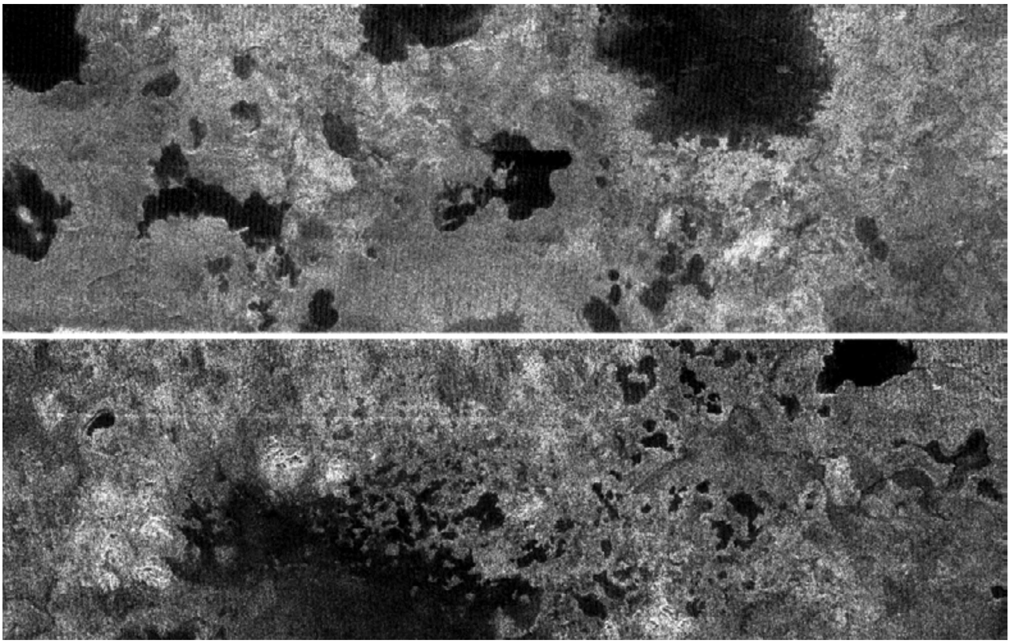

Figure 6. Dark lakes on Titan on a 400 km wide terrain (top, 80°N 92°W), and on a 450 km wide area (bottom, 78°N 18°W) based on radar measurements. (NASA, JPL, SSI)

Under the surface condition on Titan (temperature 94 K -179 °C, 1.5 bar pressure) the methane-ethane mixture is liquid. If lakes are present there, they have to fill depressions and show smooth surface, as well as spectral signatures of the liquids. Based on early radar measurements from the Earth, very smooth patches were observed on some occasions

[Campbell 2007], while other observations failed to detect these features. The Cassini spacecraft, orbiting around Saturn has flown by Titan several times and observed smooth, radar dark patches in the polar regions.

There are several observational evidences, which suggest these polar features are lakes (Fig. 6.). In the case of feature called Ontario Lake on Titan, the topographic undulations are smaller than 3 mm at 100 m distance. Such a smooth surface is probably formed by liquid material following the equipotential surface. The Visual Mapping Spectrometer onboard the Cassini probe by the analysis of spectral signatures identified ethane in the lake [Brown et al. 2008]. Ethane mixed with methane and nitrogen under the condition present on the surface of Titan forms liquid phase, and thermodynamic computations show that the surface temperature and pressure conditions at high latitude, liquid methane-ethane mixture is stable.

OBSERVED CHARACTERISTICS

Several hundreds of radar dark patches, which are lakes, can be seen in the polar regions.. Their general morphology and distribution are summarized below. The diameter of most of the lakes is between 3 and 20 km. About 400 lakes were observed until 2010, and more than half of the observed lakes' cumulative area is from few large lakes with diameter above 26 000 square kilometres. The lakes with the largest area are around 100 000 square kilometres, and two lakes are larger there than the North American Great Lakes.

At the northern polar region above 60 degrees latitude, 14% of the surface were covered by hydrocarbon lakes during the winter season in 2007. At latitudes lower than the polar regions, dried up lake basin-like features are present, probably because the temperature is too high here and methane-ethane liquids evaporate fast. That may be the reason why liquid filled lakes were found only at high latitudes. At the southern hemisphere substantially fewer lakes were observed. This difference may be partially because during the observations at the southern hemisphere, it was summer with higher temperatures. But the strong hemispheric asymmetry in the distribution of lakes orbital forcing may also play a role [Aharonson et al. 2009], as the same seasons are different in the two hemispheres because of Saturn orbital eccentricity

The perimeter of the lakes are rounded and circular is most cases, while there are few lakes with strongly fragmented, irregular and rough outlines (Fig. 7.), resembling those lakes on Earth, which fill fluvial or glacial erosion sculpted depressions. At the southern polar region the lakes show diffuse shorelines relative to the northern ones [Stofan et al. 2008]. Band-like features were observed around Lake Ontario on Titan, which may be of fine grained material.

The circularly shaped lakes may have formed by a specific process like volcanic activity [Wood et al. 2007] or karst-like process. There is no gradation between the round ones and the larger irregular outlined ones, resembling thermokarstic features observed in Alaska [Kargel et al. 2007].

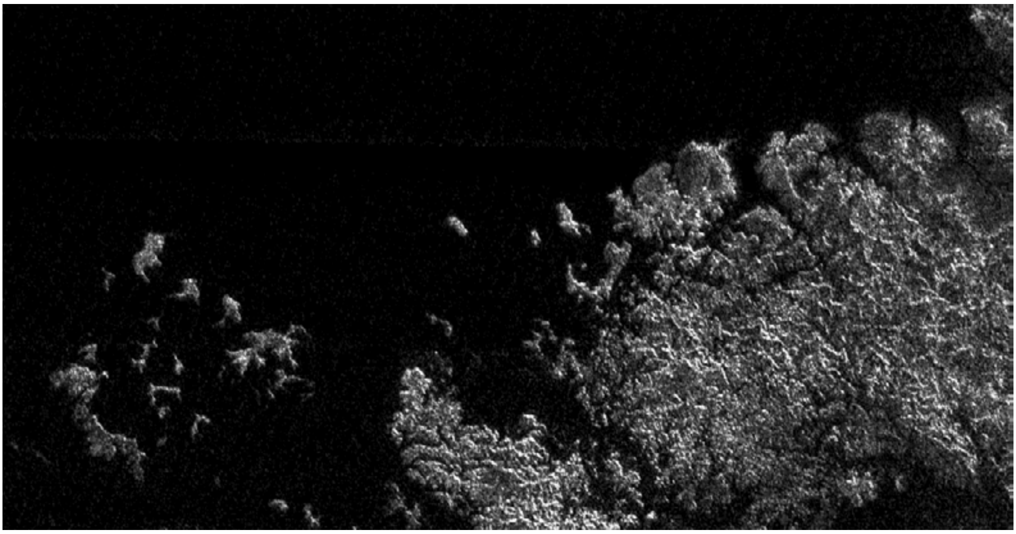

Figure 7. Lake shorelines (69°N 329°W) on Titan, on a 400 km wide terrain based on Cassini's radar mapping. The dark material is the liquid and bright is the terrain composed of solid ice (NASA, JPL, SSI)

COMPOSITION AND SOURCE OF THE LIQUID

Based on thermodynamic computations, pure methane ponds may evaporate or freeze up fast, while lakes composed of methane, ethane and nitrogen would be more stable [Tokano 2009]. These mixtures are stable in the long term only at the colder polar regions, where the atmosphere is close to saturation.

The Cassini-probe observed Ontario Lakes (diameter 235 km, area 20 000 km^2) on Titan and the data from the infrared spectrometer suggest the presence of ethane in the lake. The observations together with photochemical models, assuming thermodynamic equilibrium between the lakes and the atmosphere, suggest that the liquid is probably composed of ethane (C_2H_6) (~76%-79%), propane (C_3H_8) (~7%-8%), methane (CH_4) (~5%-10%), hydrogen cyanide (HCN) (~2%-3%), butene (C_4H_8) (~1%), butane (C_4H_{10}) (~1%), and acetylene (C_2H_2) (~1%) [Cordier et. al. 2009, Mousis et al. 2009].

Evaporite formation is possible in theory, when the main solvent (methane) evaporates [Kargel 2007] and left behind other ingredients. Organic materials are also raining from the atmosphere, and they may accumulate in the polar lakes and serve components for complex chemical processes. It is possible, that various nitrogen-bearing organic polymers and/or azides forming there, which may take part in prebiotic-like processes.

At least part of the liquid in the lakes comes from the atmosphere by precipitation (Fig. 8.), as it is suggested by the observation of Cassini-spacecraft's images, where a lake appeared between 2004. and 2005. at the region of southern convective polar clouds [Turtle et al. 2009]. At the northern polar region in late winter, cloud activity was also observed by Cassini-probe and telescopes from the Earth at the same region where the largest known lakes exist. These clouds seem to be formed by methane evaporation, convection and condensation [Brown et al. 2009].

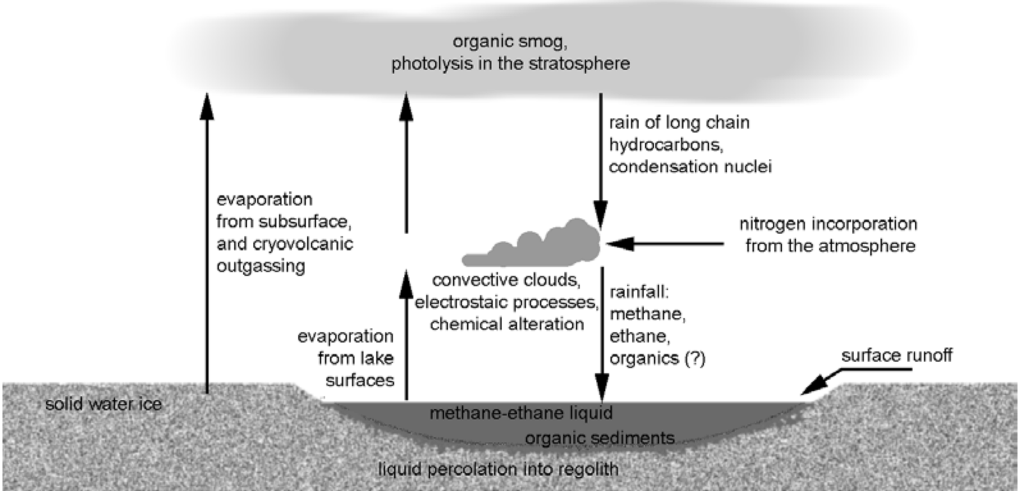

Figure 8. Role of methane cycle and organic material synthesis in the formation and composition of lakes on Titan

Beside the atmosphere, and surface runoff (Fig. 9.), another possible input of liquid may come from subsurface drainage. The topographic level of the liquid in the neighbouring lakes is relatively close to each other, which suggest a common subsurface liquid level in the region. (In long term such subsurface liquid level may also depend on the climate.) The presence of a subsurface methane reservoir is also supported by the calculations, which suggest that evaporation only from surface lakes are probably not enough to maintain the atmospheric methane level observed today.

CONNECTION WITH CLIMATE

Methane (and ethane) takes part in a global circulation, resembling the way water circulates on Earth. The methane evaporates from the surface and may be also released by some volcanic activity or evaporation from subsurface aquifer. The methane released into the atmosphere maintains roughly 5% concentration in the lower kilometres of the atmosphere, while the concentration decreases upwards.

Atmospheric methane may condense and form clouds, finally precipitate as rain toward the surface (Fig. 10.). On the surface channel networks are present, suggesting surface flow and accumulation of the liquid in ponds. During the above-mentioned steps, various other processes, like electrostatic processes, erosion, transport and accumulation of various materials may take place, changing the surface structure. Cloud formation is observed above polar lakes too (Fig. 9.), where they may be formed by regional methane evaporation, convection and condensation cycles [Brown et al. 2009].

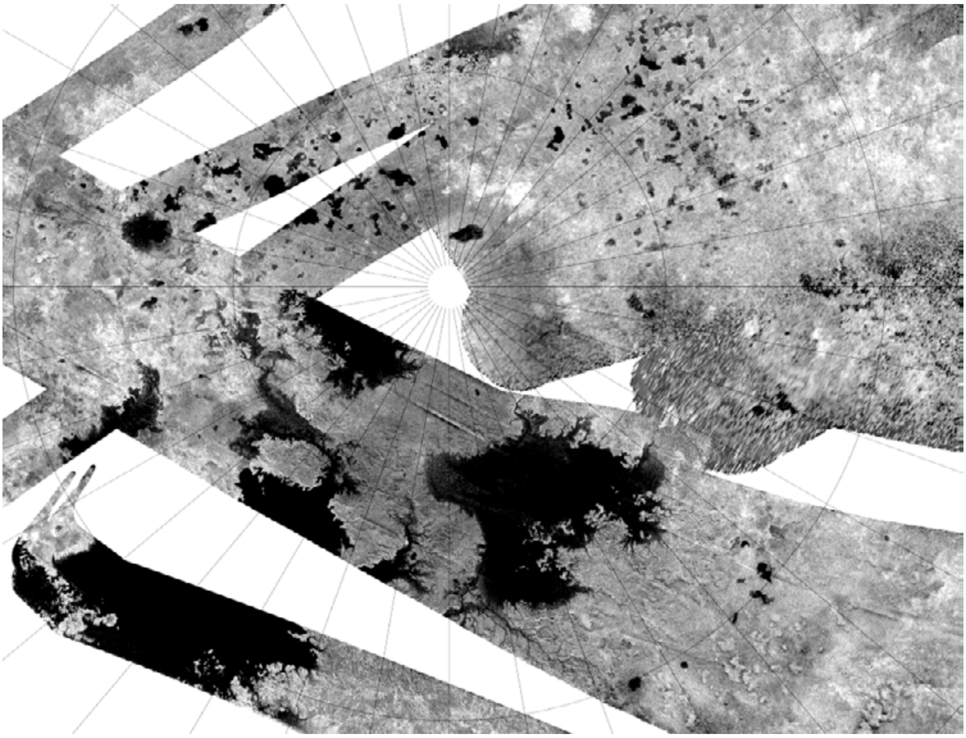

Figure 9. Mosaic of radar images of the northern polar region with dark lakes. About 60 percent of the area above 60 degree of latitude is mapped its 14 percent is covered by hydrocarbon lakes, associated with bays, islands and tributary fluvial networks. The largest lake is 100 000 km^2, greater than the 82 000 km^2 Lake Superior on Earth, and it covers 0,12% of the surface of Titan (NASA, JPL, USGS)

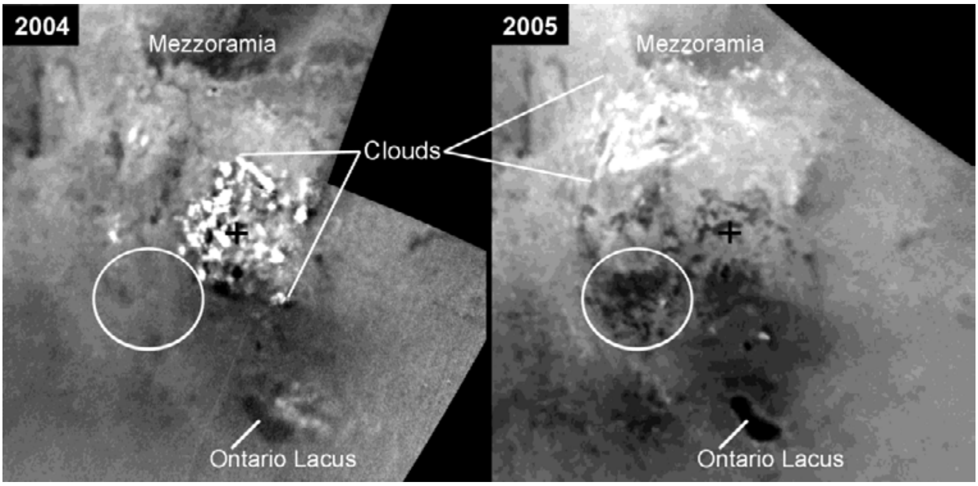

Figure 10. Two infrared images acquired on July 3, 2004 (left), and June 6, 2005 (right) of the southern polar region. The dark regions are liquid filled lakes and the bright patches are clouds, with changing their appearance and location on hourly bases by precipitation. New lakes are formed in the circled area probably by rains. The same dark lakes (like the bean shapes Lake Ontario at the bottom right) show different darkness on the two images because of different illumination, the south pole is marked by the black cross (NASA, JPL-Caltech, SSI))

In the higher region of the atmosphere, above all by solar UV radiation, methane breaks up and the radicals combine into new molecules, forming high-level smog. Long chain carbohydrates may precipitate from there and accumulate on the surface. Because of this step in the methane circulation, a different material may arrive back to the surface than what evaporated from there.

Today there are more liquid filled lakes on the northern hemisphere of Titan than at the southern, probably because of climatic differences between the two hemispheres. The precession of Titan's spin axis together with the eccentric orbit of Saturn around the Sun realizes asymmetric seasons and precipitation at both poles, and the differences change in a long term quasi periodic manner.

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Chapter 7

ZOOPLANKTON ASSEMBLAGES IN SOUTHERN CHILEAN PONDS: POTENTIAL ROLE OF TROPHIC STATUS AND NATURAL ULTRAVIOLET RADIATION EXPOSURE

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ABSTRACT

The zooplankton assemblages in Chilean water bodies is characterized by their low species number and high calanoid dominance, that is due mainly to the oligotrophy of studied sites. Nevertheless, it was reported an increase of penetration of natural ultraviolet radiation, that is due to the ozone depletion. In this scenario, the natural ultraviolet radiation can penetrate into water column that generates damage into biotic components. The present study included two groups of shallow ponds, a first group included oligotrophic mountain shallow ponds in Araucania region (38º S), whereas a second group included shallow ponds located plains of Magallanes region (51º S). The studied revealed that both groups of sites have high exposure to natural ultraviolet radiation. The first group, the trophic status would be the main regulator factor of zooplankton assemblages, whereas in the second group, the conductivity would have a secondary role, because at low conductivity and mesotrophic status would have high species number and low calanoid dominance. Similar results were reported for their counterparts located in Argentinean Patagonia.

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Keywords: zooplankton, species richness, Patagonia, ultraviolet radiation, oligotrophy.

INTRODUCTION

The Patagonian Chilean lacustrine water bodies includes shallow ponds that are widespread along mountain and coastal zones (Soto et al., 1994; De los Ríos et al., 2008a), one of the main characteristics of these water bodies is the role of trophic status and conductivity as main regulators of their zooplankton assemblages (Soto and De los Ríos, 2006), and in zooplanktivorous fish absence, the main predator would be water birds such as flamingoes as was reported for southern Chilean Patagonia (Soto et al., 1994), and swans (Araya and Millie, 2005). Also, other important factor that would regulate the zooplankton assemblages would be the penetration of natural ultraviolet due ozone depletion, because in this scenario, in exposure to natural ultraviolet radiation only tolerant species are present (Marinone et al., 2006).

The zooplankton assemblages, are similar to the descriptions for large and deep lakes, this is the presence of high dominance of calanoids copepods specifically of *Boeckella* and *Tumeodiaptomus* genus, and low species number under oligotrophic status (Soto and Zúñiga, 1991; Soto and De los Ríos, 2006; De los Ríos and Soto, 2009; De los Ríos and Roa, 2010). Nevertheless, there are conditions of mesotrophic status where it is possible found high species number with daphnids dominance (Soto and De los Ríos, 2006; De los Ríos and Roa, 2010). This scenario is similar to descriptions for Argentinean Patagonia (Modenutti et al., 1998; Quirós and Drago, 1999) and New Zealand counterparts (Jeppensen et al., 1997, 2000).

In this scenario, we will review the community zooplankton ecology in two kinds of shallow water bodies of Chilean Patagonia, the first group corresponded to pristine shallow ponds located in northern Patagonia, mainly within native forest between 39-42° S. The second group corresponded to shallow ponds located in Patagonian plains between 44-53° S, that are located within plains with subpolar and semi-arid weather.

SHALLOW MOUNTAIN WATER BODIES OF NORTHERN PATAGONIA

The northern Patagonia (38-42° S), is characterized by the presence of mountain zones with unpolluted ecosystems that are characterized by the presence of perennial forest of *Araucaria araucana* forest between 38-39° S, and *Nothofagus* genus between 39-42° S, and at south from 41° S the southern coniferous *Fitzroya cupressoides* is dominant and coexist with *Nothofagus* forest (Luebert and Plitscoff, 2006). In this scenario, this zone has numerous unpolluted and pristine ponds and shallow lakes that are characterized mainly by their marked oligotrophy (Steinhart et al., 1999, 2002; De los Ríos et al., 2007; De los Ríos and Roa, 2010). A representative example of these water bodies is the Cañi Park (De los Ríos and Roa, 2010), that has numerous fishless shallow ponds (< 1 km^2 surface, < 2 m maximum depth). The zooplankton assemblages of these ecosystems is characterized by the presence of high dominance of calanoids copepods and low species number that is observed under oligotrophic status (Figure 1; Table 1), nevertheless, there are exceptions of mesotrophic status where it was observed the presence of high daphnids dominance and high species number (Figure 1;

De los Ríos and Roa, 2010). These ecosystems due the marked oligotrophy and transparence of the water column due low humic acids concentration are characterized by the presence of high ultraviolet radiation exposure (De los Ríos et al., 2007, 2008a). This scenario is similar to descriptions for northern Argentinean Patagonia (Villafañe et al., 2001; Díaz et al., 2006; Marinone et al., 2006), and northern Chilean Patagonia (De los Ríos et al., 2008a, Figure 2) where it is possible found oligotrophic shallow lakes and ponds in Andes mountains close to Chilean boundary (Modenutti et al., 1998).

These ecosystems, are located mainly in protected areas (Steinhart et al., 2002), such as private areas in example Cañi Park (De los Ríos and Roa, 2010), or public areas protected by National Forestal Council (CONAF-Chile; De los Ríos et al., 2007; De los Ríos and Roa, 2009).

Table 1. Chlorophyll "a" concentration, total dissolved solids, conductivity and crustacean species reported for the studied sites in Cañi Park, a kind of shallow northern Patagonian ponds (Cf: De los Ríos and Roa, 2010, page 82)

Site	Geographical location	Chlorophyll a µg/l	TDS mg/l	Conductivity mS/cm	Species
Del Risco	39°15' 71°42'	0.7	0.01	8.000	*Boeckella gracilis* *Ceriodaphnia. dubia* *Mesocyclops longisetus*
Negrita	39°15' 71°42'	2.7	0.01	0.300	*B. gracilis* *M. longisetus* *Daphnia pulex* *C. dubia* *Chydorus sphaericus*
De los Patos	39°15' 71°42'	10.6	0.01	0.213	*B. gracilis* *M. longisetus* *D. pulex* *Diaphanosoma chilense*
Escondida	39°15'71°42'	12.4	6.00	0.7	*B. gracilis* *M. longisetus* *D. pulex* *C. dubia* *D. chilense* *Ch. Sphaericus*
Seca	39°15' 71°43'	12.3	0.01	0.537	*B. gracilis* *M. longisetus* *D. pulex* *C. dubia* *Ch. sphaericus*
Negra	39°15' 71°42'	0.7	0.01	0.466	*B. gracilis* *M. longisetus* *Hyalella araucana*
Bella	39°15' 71°42'	0.7	0.01	0.212	*B. gracilis* *D. chilense*
Los Pastos	39°15' 71°43'	0.5	0.01	0.533	*B. gracilis* *M. longisetus* *C. dubia* *D. chilense*
Vaca Hundida	39°15' 71°42'	1.2	67.00	136.000	*B. gracilis* *D. pulex* *C. dubia* *D. chilense*

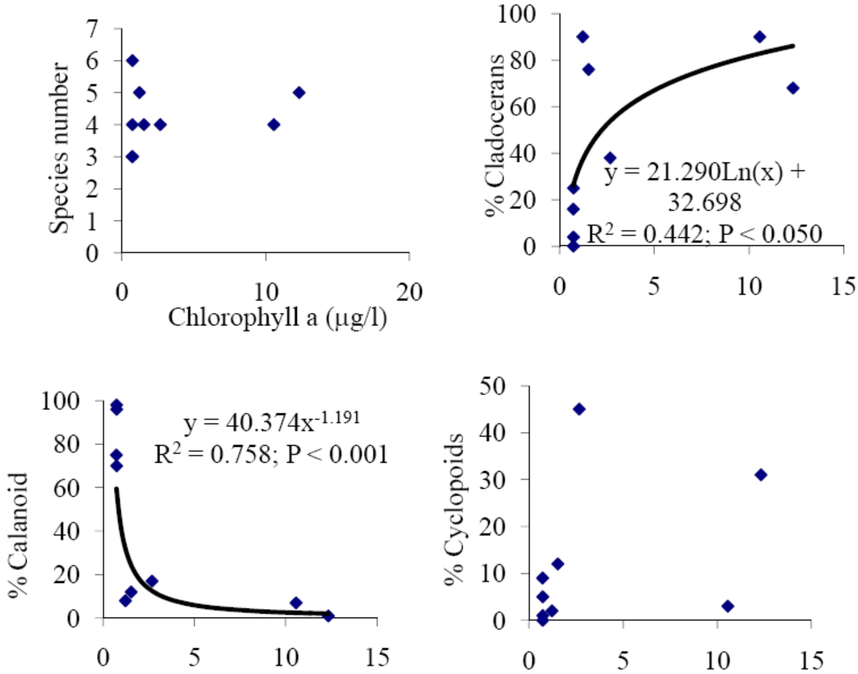

Figure 1. Graphs with associations of chlorophyll concentration with species number, calanoid, cladoceran and cyclopoid percentages for the sites of Cañi Park. Cf: De los Ríos and Roa (2010), page 84.

In this scenario of protected management, the presence of native forest do not allow the nutrients inputs from the basin to the lake, but when the native forest is replaced, it occurs an increase of nutrient inputs to the lake, with the consequence transition from oligotrophy to mesotrophy (Pedrozo et al., 1993; Soto, 2002). This condition of presence of protected areas with access difficult allows the study of unpolluted areas for determine the ecosystem regulations of these ecosystems before the human intervention such as the phytoplankton physiology studies of Steinhart et al., (1999, 2002), and the basic zooplankton descriptions of De los Ríos and Roa (2010).

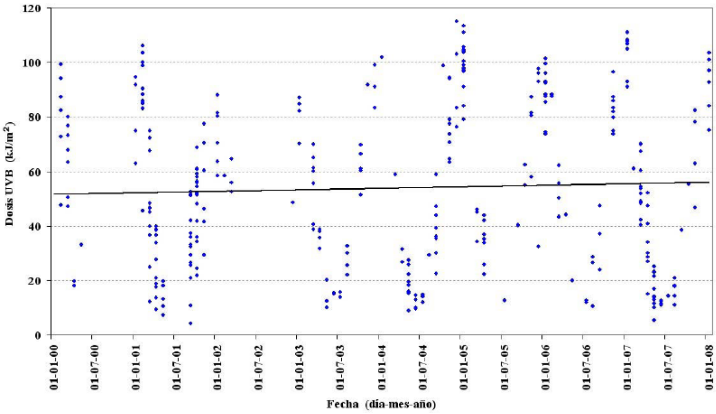

Figure 2 (Continued)

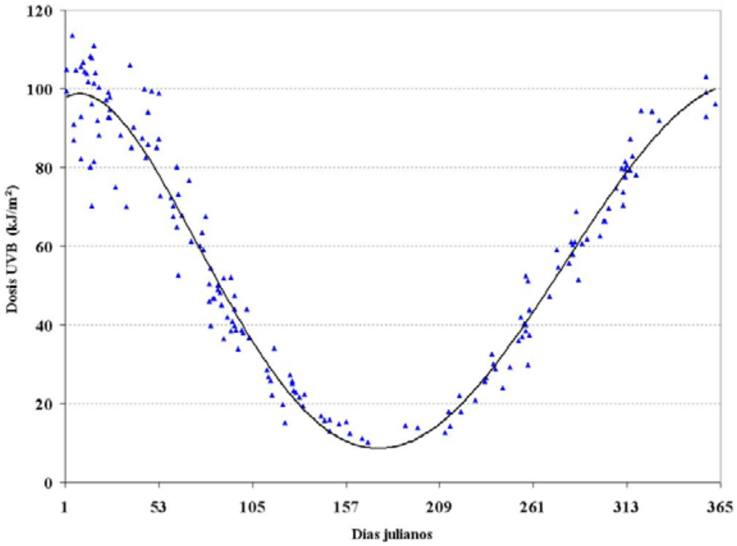

Figure 2. Results of doses of ultraviolet B radiation for Temuco 1) variations between 2000-2008 (up), and seasonal variation for sunny days between 2000-2008 (low). Source: De los Ríos et al., (2008a), page: 214.

Nevertheless, it is necessary more ecological studies about plankton and trophic interactions, because some of these water bodies have introduced salmonids populations, that would generate alterations in native zooplanktivorous fishes, zooplankton and phytoplankton assemblages generating a cascade effect (Soto and Zúñiga, 1991) that had not studied exhaustively.

SHALLOW WATER BODIES OF PATAGONIAN PLAINS

The Patagonian plains are located between 44-54º S, in a zone characterized by the presence of plains with subpolar weather, with shrubs and herbs as vegetation communities of its surrounding basin (Luebert and Plitscoff, 2006). In this scenario, the water bodies has a wide conductivity gradient, because it occurs a high evaporation due the exposure to strong winds and the low precipitations mainly in spring and summer (Soto et al., 1994; Campos et al., 1996). In this context, on the basis of studied for shallow ponds of Torres del Paine National Park (51º S), the zooplankton assemblages are regulated mainly by trophic status and conductivity gradient, because under oligotrophic status and wide conductivity gradient the calanoids copepods are dominant, and there is low species number, whereas daphnids are dominant with high species number under mesotrophic status and low conductivity (Table 2; Soto and De los Ríos, 2006). A special situation occurs when the salinity increases, because in this scenario, the copepods and cladocerans disappeared and these are replaced by brine shrimps (Campos et al., 1996), specifically *Artemia persimilis* (De los Ríos, 2005). Also, other important component, is the presence of intrazooplanktonic depredation that is done by the calanoid *Parabroteas sarsi* that is an active depredator of cladocerans and juvenile copepods (Vega, 1996, 1997, 1998). These complex trophic webs and community structure are similar with descriptions for close sub-Antarctic island (Dartnall, 2005; Hansson et al., 1996; Hansson and Tranvik, 1997, 2003; Pugh et al., 2002).

The trophic webs of these ecosystems are characterized by the fish absence, and the main depredators would be water birds such as swans, ducks and Chilean flamingoes that use the shallow water bodies as nesting and feeding areas (Soto, 1990; Campos et al., 1996; Araya and Millie, 2001), Some of these bird species is the Chilean flamingo, that is an active crustacean zooplankton predator (López, 1990), and it is probable that this role are repeated in shallow Patagonian water bodies (Soto, 1990), and also it is probable that the migratory routes have an important role for species dispersion considering the zooplankton high species richness observed in southern Patagonia (Menu-Marque et al., 2000). If it is considered that some species are widespread in Patagonian water bodies (Araya and Millie, 2005), it is probable that aquatic birds would be important as predators and as dispersion agent.

Some of these environments are ephemeral due high evaporation (De los Ríos et al., 2008b), in this scenario, we have the scenario of habitat availability and colonization and extinction process at populations and communities, it is an interesting process if we considered the presence of diapause eggs in species present.

Also, some of these species located in the studied sites are endemic or poorly studied, in example fairy shrimps (*Branchinecta* genus) that appears only under oligotrophy and low conductivity (De los Ríos et al., 2008c). If we considered that some of these water bodies are exposed to global changes that are expressed in drying and flooding with the consequent creation and extinction of available sites, we would have consequences at ecosystems levels, because these will affect the presence of migratory aquatic birds (Soto, 1990; De los Ríos et al., 2008b).

Also, this zone is exposed to natural ultraviolet radiation, and in this scenario, the exposure of natural ultraviolet radiation can be attenuated in these water bodies, because these have high concentration of dissolved organic carbon (De los Ríos, 2003), that is a natural screen against natural ultraviolet radiation penetration (Morris et al., 1995; Marinone et al., 2006). The results observed for shallow ponds of Torres del Paine National Park, indicate that the daphnids are dominant and the high species number occurs under mesotrophic status, low conductivity and high dissolved organic carbon (De los Ríos, 2003).

These results would indicate that the daphnids are not dominant in oligotrophic status and high exposure to natural ultraviolet radiation, that would agree with experimental observations (De los Ríos and Soto, 2005), and field observations (Marinone et al., 2006).

Other important consequence of exposure to natural ultraviolet radiation under extreme environment would be morphological variations that would have genetic alterations of species present, with the consequences at long term such as speciation process or extinction risk (Pandourski and Evtimova, 2009).

Table 2. Chlorophyll "a" and dissolved organic carbon concentration (DOC), conductivity and crustacean species reported for the studied sites in ponds of Torres del Paine National Park (source: De los Ríos et al., unpublished data)

Site	Geographical location	Surface (km^2)	Maximum depth	Conductivity (mS/cm)	Chlorophyll *a* (µg/L)	DOC (mg/L)	Species reported
Redonda	51º 01' S; 72º 52' W	0.1	5.0	1365.00	6.30	9.10	*D. pulex* *B. gracilipes* *Parabroteas sarsi*
Juncos	51º 01' S; 72º 52' W	0.1	5.0	403.20	6.70	14.12	*B. poppei* *P. sarsi*
Larga	51º 01' S; 72º 52' W	0.1	5.0	4330.00	15.40	15.61	*D. pulex* *B. gracilipes* *B. poppei* *P. sarsi*
Paso	51º 02' S; 72º 55'W	0.1	10.0	498.00	7.40	10.83	*D. pulex* *B. gracilipes*
Cisnes	51º 01' S; 72º 52' W	0.1	0.1	13200.20	17.90	168.50	*B. meteoris* *P. sarsi*

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Chapter 8

LABORATORY STUDIES ON BEHAVIOR OF BOUNDARIES BETWEEN GRADIENT ZONE AND CONVECTIVE ZONES IN A SALINITY GRADIENT SOLAR POND

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ABSTRACT

One of the most important problems in the operation of a salinity gradient solar pond is the stability of boundaries between gradient zone and convective zones. Although mach progress has been made recently, there are still many clarifications such as the mechanism of the heat and mass transfer through the gradient-convective boundary and the kind of dynamic processes that influence the gradient stability. In order to obtain an improved understanding of these dynamic processes, experimental studies have been conducted in a laboratory thermohaline system which is similar to solar ponds.

Based on Particle Image Velocimetry (PIV) visualization-experiments and quantitative measurements, physical mechanisms of these processes are discussed.

Keywords: Solar pond – Dynamic processes – Double-diffusion – Gradient stability – PIV visualization.

1. INTRODUCTION

The solar pond is a captor of solar energy, able to store and keep heat accumulated for extended periods. It is a body of water with a certain quantity of salt, whose concentration

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increases with depth, going from a rather low value on the surface to a value close to saturation in depth. A solar pond consists of three layers of water with a different saline gradient: an Upper Convective Layer (UCL) of fresh water, where convective flow takes place, and which hence releases heat to the atmosphere through irradiation and evaporation; a Non Convective Layer (NCL), where saline concentration increases with depth, prevents convective flows of water, and slows down enormously the transfer of heat to the upper surface; A Lower Convective Layer (LCL) with high saline concentration, where the solar energy accumulates (Figure 1). Dynamic processes in salinity gradient solar pond have been studied extensively by many researchers. Wienberger (1964), Tabor (1966), Rabi and Nielsen (1974) studied experimentally the double diffusion mechanism. Hull and al. (1989) suggested an empirical relation between the salinity and the temperature gradients in the NCL.

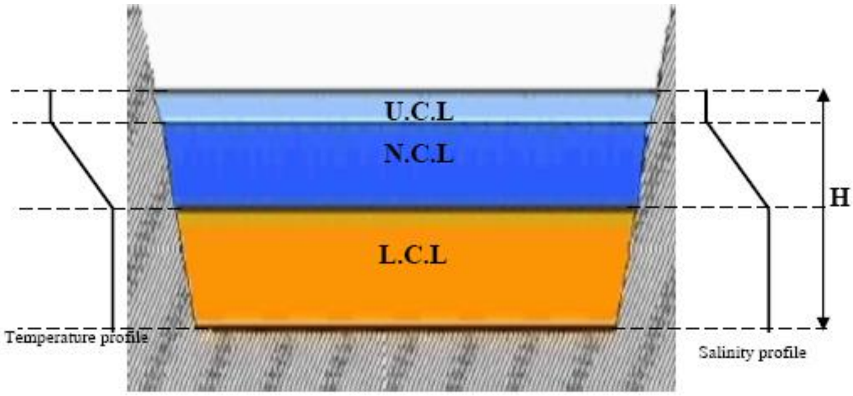

Figure 1. Schematic of a salt gradient solar pond.

Kamal and Nielsen (1982) showed in their experiments, that the generation and releasing of thermal plumes at boundary layer may play an important role in the boundary behavior. Although the variety of dynamic processes observed in a number of laboratory studies (Meyer et al., 1982), (Lewis et al., 1982), (Newell, 1984), (Mehta et al., 1982), (Poplawsky et al., 1981), (Karim et al., 2010), it is still not well known the double diffusion mechanism through the gradient-convective boundary and the effect of dynamic processes on the gradient stability.

In this paper, experimental studies under carefully controlled conditions have been conducted to further investigate the different physical mechanisms involved in boundary behavior.

2. LABORATORY-EXPERIMENTAL SET-UP

All the experiments to be described in this paper were performed in a laboratory tank. The laboratory tank apparatus consisted of a rectangular Plexiglas tank and a copper exchanger insulated around its edges, through which circulate a stream of hot water adjusted by a thermostat at desired temperature, thereby providing uniform heating over the base. A photograph of the entire apparatus is shown in Figure. 2.

The inner dimensions of the experimental tank were 100 mm x 20 mm and the depth of the tank was 55 mm. To achieve the best insulation, the sides of the tank were insulated, except the front face that enabled visualization of the flow.

The system is composed of two superimposed layers of miscible fluids: salt-water (10% in weight) and fresh-water, initially isothermal and with free surface. The system is suddenly heated from below at constant temperature.

The temperature profiles of the stratified solution was measured by copper constantan thermocouples that had been installed at 5 mm intervals, except for the lowest one which had been set at 2 mm above the bottom of the cell. All the thermocouples were connected to Agilent acquisition-channels. The measurements of density were made using a single-point conductivity probe.

The stratification was seeded with particle tracer. Illumination of the particles was provided in a plane-light-sheet, parallel to the sides' walls and generated by expanding the beam from a 20mW He-Ne laser with a cylindrical lens. Acquisitions data and experiment - information's are recorded by a CCD camera on a format of 578 x 512 pixels and stored on hard disk of computer with the given video frequency of 25 frames per second. So, Velocity fields were obtained by using a P.I.V system.

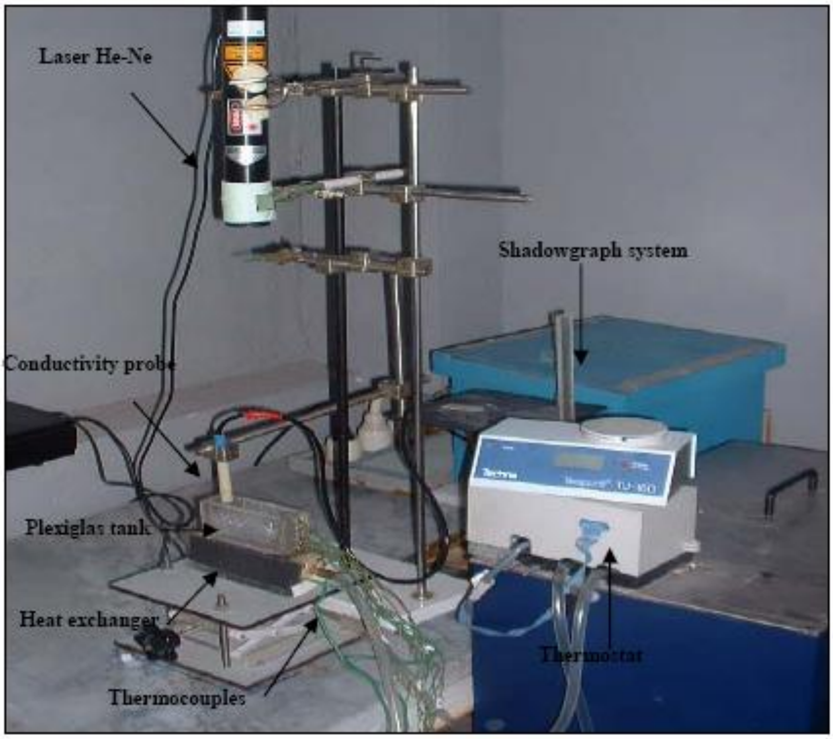

Figure 2. Experimental setup.

3. RESULTS AND DISCUSSIONS

3.1. Qualitative Study of the Flow

Once the heat is turned on, a temperature gradient develops in the bottom and a local convective motion appears, inducing a mixed layer whose sizes depends on the stabilizing salinity distribution. As heat is continuously supplied to the system; the mixed layer expands at the expense of overlaying stable regions.

P.I.V visualization (Figure 3 (a) and 3 (b)) shows organized convective structure in the bottom layer. These convective-structures cause the deformation of the interfacial layer (NCL) and cut off thin portions of fluid from it; such portions are eroded and homogenized with the rest of the fluid. The thickening of the heat interfacial layer and its breakdown initiate convection in the upper layer (Figure 4); the motions in the bottom layer seemed to be more intensive than that of the upper layer.

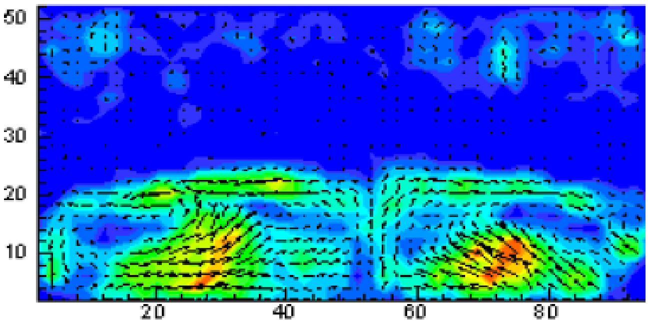

Figure 3. (a) P.I.V. visualization of the vortices in the bottom layer.

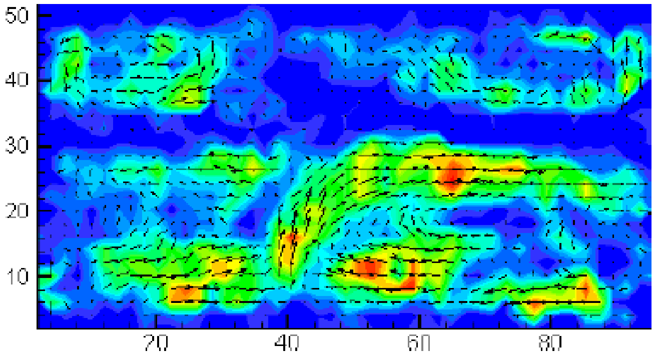

Figure 3. (b) P.I.V. visualization of the vortices in the bottom layer; convection initiate in the upper layer.

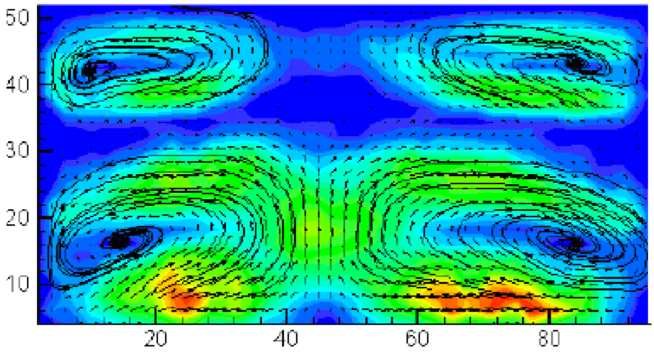

Figure 4. P.I.V. visualization of the vortices in the bottom and in the upper layer.

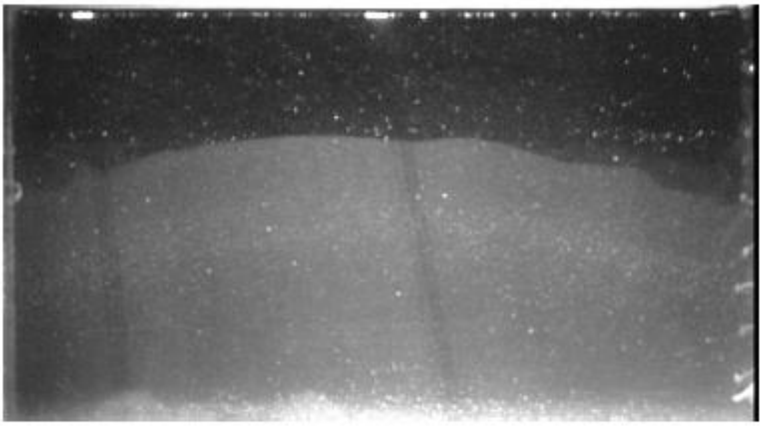

Figure 5. P.I.V. visualization of the increase of the area available for heat and mass transfer.

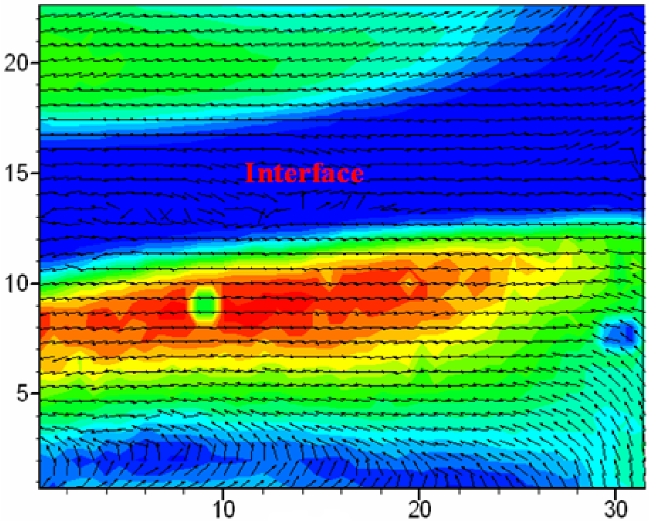

Figure 6. P.I.V. visualization; close-up view of the gradient zone.

The continuous eroding action seems to be the main cause of making the upper edge of the interfacial layer more diffused than lower one.

The eddies of the lower convecting layer start penetrating the non convecting layer, thus distorting it and increasing the area available for heat and salt transfer (Figure 5). Since, the motion in the bottom layer is more intensive the velocity of the erosion is bigger in the lower edge of the gradient layer.

While convection is started in the lower and upper layer, no convection is observed throughout the interface, so double-diffusion may be the essential cause of the instability of the interface. Indeed, the close-up view of the gradient zone (Figure 6): field dimension #30*20 mm^2) showed that both upper and lower eddies erode edges of the gradient layer. At the boundaries of this gradient layer the fluid is in a different condition than at the interior. It is ideally stratified on one side and convective on the other. In the interior of the gradient layer, disturbances can result in movements which lead to local mixing.

3.2. Quantitative Study of the Flow

Once the heat is turned on, an unstable temperature gradient develops above the heated surface. This gradient induces local thermal instability and convection motion in the bottom layer, as said previously.

Temperature fluctuations (Figure 7) at different vertical positions across the experimental tank are measured to examine the different structures in the edges of the gradient zone.

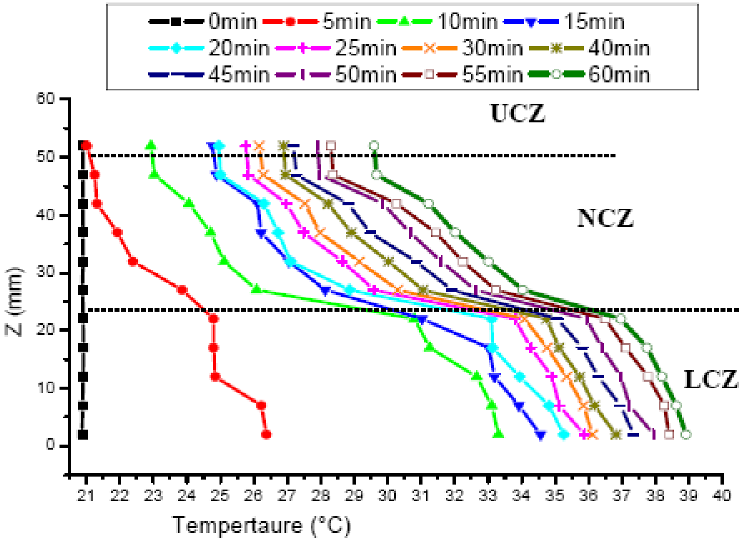

Figure 7. Temperature profiles.

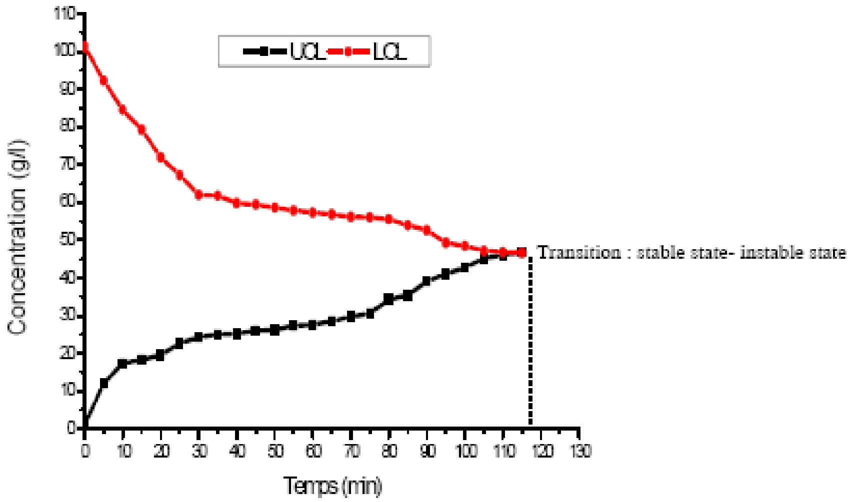

Figure 8. Average concentration.

Figure. 7, showed a low temperature close to ambient in the UCL followed by a gradient layer where the temperature increases with the depth to its maximum value, and finally, a nearly constant high temperature at the LCL. Temperature profiles shows that the maximum temperature occurs at the bottom of the LCL . This can be attributed to a higher salt concentration at the bottom than in other points in the LCL (Figure 8).

In spite of a convection zones, there are a few temperature differences in the vertical temperature distribution of the LCL and the UCL. This temperature difference becomes the cause of convection and erosion. Indeed, as the temperature increases in the bottom of the LCL, the density of the salt water solution of the LCL decreases. The lighter water going up until reaches the boundary surface of the LCL and NCL. When the heating is increased, the expanding fluid pushes up the NCL, causing erosion.

CONCLUSION

The dynamic processes which involve boundaries behavior between gradient zone and convective zones were studied experimentally in a laboratory tank. Both temperature and salinity in the tank were similar to those in a real solar pond. The major observations from these laboratory studies are as follows:

i. The double-diffusive phenomenon produces significant effects on various large-scale features of the salt gradient solar pond.
ii. Double diffusion convection plays important roles on the gradient zone erosion.
iii. The initial temperature profile is nearly a straight line. As the temperature at the LCZ increased, the heat propagated into the gradient zone. The temperature as well as the temperature gradient in the gradient zone increased with time.

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Chapter 9

VARIOUS PONDS ALIVE

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ABSTRACT

Various ponds alive can be elucidated in five points as follows. [1] “Ponds” can best be characterized as so many “circles” whose centers are everywhere, and whose circumferences nowhere. Such circles are never at rest but ever continuing to grow out and out, rounding and rounding things that emerge in life. These circles are ponds to nurture us to grow; without them we cannot even survive the day.

These ponds and circles actually exist fivefold way, among so many ways. They are my daily ongoing, my living, my cultures, interculture, and storytelling, and the list goes on; each describes a circle, a pond, and a world. Obviously, these circle-ponds are my self interacting with my world to inter-dance our lifeworld.

Here at the ponds, I am a tiny dragonfly dotting my tail without dotting it fivefold onto the ponds, making ripples of expanding circles inter-mingling and inter-vanishing, only again to dot as rain drops to form many new fascinating ripples of small circles, centers-everywhere, edges-nowhere.

[2] Let us put this situation another way. This lifeworld has so staggeringly many grains of sand, in each of which I see a world, so zillions of sand-grains show zillions of different worlds, each expanding as a pond-circle with center-everywhere, edge-nowhere. All this makes a fabulous world of life, all thanks to me and to my inter-dancing with and within the circular ponds!

[3] Thus the circular ponds are the countless kaleidoscopes of changing patterns and colors of values, fashions, each correlated with all others, interchanging, inter-changing. Now these countless kaleidoscopes are of two sorts, the non-being sort of the Hwa Yen Buddhist vacuity-mirrors inter-reflecting, and the being-sort of Chuang Tzu the Taoist, nothing infused with things, to delightfully slither back and forth between life and death, making Heaven and Earth, season after season.

[4] Worldly people would never have imagined such complex kaleidoscopes of ponds that encircle them, much less realize that they *are* these ponds, and so they laugh at

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all this, calling it a bad name such as "relativism." As Lao Tzu said, on hearing the Tao of Heaven Net, low people would greatly laugh Ha Ha; not laughing the Net Heavenly, the countless ponds in circles would not be Heavenly everywhere.

[5] A pond is where a frog of life jumps in to make a sound (as a Japanese haiku intones), and so many ponds would sound so many sounds of so many frogs jumping in. The sounds make us realize: The pond is the frog that is the sound made by jumping in, echoing silence, spreading the pond as circles everywhere-centers, nowhere-edges. To go through all these sounds of the jumping frogs into the ponds of this world is relativism active, inter-dancing the lifeworld. In short, the world is various ponds alive.

Primeval pond, in constant sounds of primal silence so profound so disorderly! Thick vines are entwined with gnarled trees tall and short, each spreads to entwine the other, and another, until they inter-involve everywhere to weave out an eternal twilight of thick shades shimmering, flickering, dawn and dusks, imbibing rancid redolence of putrefied wet soil teeming with life in death, death in life.

Nowhere is richer than the pond that is everywhere in the middle of nowhere. I am so obsessed with this pond alive, one yet so varied, so many, that I continue to collect books after books of their descriptions and photographs. Each volume is similar to any other, yet how distinct each is, charming me without ceasing, without rhyme or reason! [1]

Wallace Stevens says [2],

"The poet has his own meaning for reality, and the painter has, and the musician has; and besides what it means to the intelligence and to the senses, it means something to everyone, so to speak. Notwithstanding this, the word in its general sense, which is the sense in which I have used it, adapts itself instantly. The subject-matter of poetry is not that "collection of solid, static objects extended in space" but the life that is lived in the scene that it composes; and so reality is not that external scene but the life that is lived in it. Reality is things as they are. The general sense of the word proliferates its special senses. It is a jungle in itself."

The jungle of the ponds is where the sense is one jumping out many, the general in particulars, crisscrossing, joining in droves to disperse, over and over again, making jungles of ponds, called "alive" as kids, hawk-soaring, fish-jumping, ever moving never tamed. Listen to this.

"Now the old man looked up and saw that the bird was circling again. 'He's found fish,' he said aloud. No flying fish broke the surface . . . But as the old man watched, a small tuna rose in the air, turned and dropped head first into the water. The tuna shone silver in the sun and after he had dropped back into the water another and another rose and they were jumping in all directions, churning the water and leaping in long jumps . . ." [3] Things are topsy-turvy in the blue ocean, ever flying-diving to live on.

Now, my friend, do not bewail over such primeval ponds vanishing, for they are all over nowhere in particular, called "urban sprawls," thick with noises and smells, dirt and risks, lives and deaths, highways and high-rises. Such urban sprawls jostle with stodgy rural expansions, among the prairie homes.

These homes sprawl around “Lake Wobegon, where all the women are strong, all the men are good-looking, and all the children are above average,” as Garrison Keillor tirelessly tells us. Of course, the Lake and the prairie homes are nowhere everywhere; they are so common we never notice them until someone like Keillor picks them up for radio shows. The weekly shows have lasted forty years, and they are still going strong and above average, so popular.

So, the ponds so varied are all around for you to live and choose. You want it? You will have it, poverty and profundity, histories and trinkets, economic booms and unemployment woes, fetishes and decays, music and museums, global warming and bitter winters. You name it, and it is there somewhere. Can we see any difference here from primeval ponds alive? They are all “sound and fury, signifying nothing”! Shakespeare said so, and his “so” is now enshrined in literature signifying something we cherish, whatever “so” or “something” is.

Bergson [4] wondered aloud why humanity with constant intelligence could have been attended with stubborn superstitions so foul and constant. We can express the same wonder about why humanity with constant intelligence could have constant dullards jostling with Einstein, holy sages with hobos and hoodlums, Thomas Edison and Mother Teresa with Al Capone and Adolf Hitler. Our lifeworld is the varied ponds alive indeed, to take our breaths away.

Now, we do not realize. *We* are the ponds, and so the ponds never cease to exist. We are everywhere nowhere in particular, so the ponds are everywhere nowhere all around, teeming with life and death, profound and absurd, saintly insane. Here is the humus of humanity where all hustle and bustle jostles into our lifeworld. Various ponds alive are the origin of themselves, the harvest of themselves, inter-entwined as causes and effects, one to the other, to and fro, back and forth.

Such ponds, we must remember, are *many and varied*. Plurality displays varieties of riches. One culture and one language can keep scholars busy for life. Think of being bicultural, bilingual, what riches that entails! How about thrilling multilingual multiculturalism! They are so many countless ponds so variously alive, primeval and urban and rural! The thrill of travel to many different lands and regions lies here. So many places have so many worlds.

The world we live is bewilderingly pluralistic. Just watch any group of insects that never come alone; they all come in groups, and in various groups. Any plant bespeaks its species, cedar or oak or red maple. They are all beyond our tabulations, keeping us busy doing their taxonomy. Seasons vary also; each season of each year is all distinct from all others. No wonder, poems flourish beyond classification.

By the same token, each walk of life has its own swing and charm, with its own headaches and thrills, as an infinite variety of journals and autobiographies constantly testify. Buddha proposed a leitmotif of the music of life we all compose and perform, birth, senescence, sickness, and death, and we all perform the life-music with infinite variations so distinct.

Moreover, the world is made of countless varieties of such walks and music of lives, with countless fascinations and frustrations. The world is a plural-single so rich, a collective noun, a collection of zillion miscellanies. Our lifeworld is usually taken as singular, “the world,” but our universe is so rich as to better be taken as “pluri-verse” as William James correctly intuited.

The Christian monotheism takes God as Three in One. Is its God one or three? Whatever else it means, though, the description must mean that the Christian One is rich beyond our human understanding and imagination. Still, “pluri-verse” or “Trinity” is too awesomely far away to handle, and so we take the world as “various ponds alive,” which is the theme of this essay.

The rich plurality of various ponds is alive, intimated by three incredible images in increasing complexity, the strange circles, the zillions of grains of sand, and inter-reflecting kaleidoscopes. The world as various ponds is alive in these three ways, circular, sandy, and kaleidoscopic, bewilderingly relativistic. Now, these features are entered one by one, quite fascinatingly, as follows.

§ ONE: Circles Centers Everywhere, Circumferences Nowhere

The lifeworld ponds are circles whose centers are everywhere, whose circumferences nowhere. A circle with a center and an edge stays put as a circle. A circle of everywhere-center and nowhere-edge *goes* round and round, out and out. It cannot stay but swirls stunning us, for “everywhere” of here is “here and elsewhere,” “nowhere” is “ever expanding elsewhere from ‘here’,” and “elsewhere” moves somewhere “else” not “here”-anywhere.

This circle is then a moving coherence, a circle of many circles blending one into the other in waves, out and out. The world is made of such circles so many, bewilderingly inter-involving. Each goes out to include others that include it, interchanging to inter-change. Thus Emerson writes [5],

> The eye is the first circle; the horizon which it forms is the second; and throughout nature this primary figure is repeated without end. It is the highest emblem in the cipher world. St. Augustine described the nature of God as a circle whose centre was everywhere, and its circumference nowhere .... Our life is an apprenticeship to the truth, that around every circle another can be drawn; that there is no end in nature, but every end is a beginning; that there is always another dawn risen on mid-noon . . . .

“Without end” ciphers the beyond as “every end a beginning” does my self gazing at the horizon, opening out. The circle’s center everywhere is “I” freely moving, as its circumference nowhere is I beyond me moving out. I am the Beyond in me, living on to accompany all things. No wonder, I am happy *with* flying birds above that hoard nothing, in songs of inter-thriving life that pulsate this world, singing the lifeworld.

“Those who hear not the music think the dancer mad”; I am madly dancing my own music I hear to disappear into a community of beings beyond me, and the community keeps expanding as it dances with me, out and out. I am happy beyond joy and sorrow! “Ultimate joy, no joy,” chimes in Chuang Tzu.

All this describes the world as lively ponds ever dynamic, inter-involved, inter-expanding. We cite only five circles, all ordinary and stunning: my daily ongoing, my living, my culture, interculture, and storytelling, and the list goes on; each describes a circle, a pond, and a world in plural. Obviously, these circle-ponds are my self interacting with my worlds to inter-dance our lifeworld. We are here dragonflies tail-dotting without dotting to produce circles expanding their centers all over, edges vanishing out and out.

First, the ponds are “my” daily *ongoing* combined into so many “my” ongoings. Daily ongoing is both coherent as one day, and at the same time continues to open out into another day, for “there is always a tomorrow,” as someone smiles and says when he has missed this last train to go for an engagement.

My day is mine, *centered* as my day and myself, and yet my day is mine because it is not just mine but connects inexorably to the next, and to another “me” with another “my day.” My day centered goes on and on into an open tomorrow, forever, every-when, and goes into another person’s day, influenced by that day expanding my day’s *circumference* nowhere, going far invisible. And then this my day inevitably connects to other “my days” into many “my day”s. Many ponds are right here as my daily ongoing.

Secondly, the ponds are *my living*, combined with many “my” livings. My living is a pond dotted with raindrops of many inspirations, joys, and sorrows, as portrayed in my diary, journal, and business portfolios. These raindrops of joys of inspiration and sorrows of disappointment are meaningful—coherent, centered—everyday, everywhere-centered, and keep expanding out and out.

These ripples are each centered and coherent, moving on to blend with my other drips of today, then tomorrow, and blend with ripples of other people and ponds, and vanish, and even my memories of them fade, joyous and sorrowful, as days go on; their edges fade as they expand, into nowhere.

Thirdly, the ponds are my *cultures*, for all my life’s ongoing and my living are en-cultured and culture-enfleshed, for without my culture—language, ways of thinking and taking the world—no one, not even me, can understand my day, much less my joys and sorrows. My ongoing and my living make sense only in terms of my culture. My culture shapes me meaningful in my world.

Mind you. My culture I do not make; it shapes me into myself. My culture is my center that goes with me everywhere showing me as “me.” At the same time, as my culture carries me everywhere, I inadvertently change and reshape it, even while I speak my standard cultural language in my own accent, conduct my daily engagement my way and not your way, and my lifestyle I form and show as it is fashioned by the fashion of the day.

Besides, my very reshaping of my culture is also subtly influenced and shaped unawares by my neighbors’ ways of shaping our common culture. In “keeping up with the Jones” the Jones shape me as I shape the Jones—ad infinitum, that is, the edge of my culture turns into ours, and “our culture” has the edge that goes vastly out and out, far out there nowhere. My culture is the ponds with everywhere-centers and nowhere-edges.

Fourth, the ponds are *interculture*, for in today’s small global village, no dog barking here, no cock crowing at dawn anywhere, is not heard elsewhere. No fashion created in one culture is not carried over, blown up, modified, and reshaped, however unawares, by instant communication media. The medium is the message, and both the medium and the message here are cultural and interculture. In fact, the matter cuts much deeper and un-cannier.

To be *aware* of my culture at all is already to go outside the immediacies of my ongoing of my living to look at, in terms of cultures other than my own. Self-awareness is already intercultural. “Myself” can appear to me as myself, which is other than my spontaneous self, by being mirrored in my other alone, as I can look *at* my face only via another. Existence is inter-existence to the core; I *am* interculture. Interculture is inherently plural, many ponds. My pond appears as itself, only as intercultural ponds, many and various. I am many others.

Finally, the ponds are a various telling of many *stories*. All above is told in stories we must realize. Stories are various as their telling is variously manner-ed. Each story has its coherent center sensible, to enable understanding, and as such interblend with all others, vanishing into them as they mutually expand to blend into one another.

All such storytelling begins at the basic simple level of words. Words are themselves alive, to tell their own stories of etymologies and histories and connotations, and these word-stories interblend to compose sentence-stories of my ongoing, my life, my culture, and my interculture, with all other selves' life-ongoing, cultures, and interculture. Storytelling facilitates and embodies various ponds alive; storytelling is the structure of such many varies ponds alive with daily ongoing of living in cultures intercultural, exploding round and round, out and out.

All these inter-involvements cipher various interactions between my self and my ponds. To begin, the world is a pond; we are a dragonfly hovering over it, the tail touching the water-surface without touching it, constantly making one circle after another, each expanding and vanishing into the others. Such freedom, so light and delightful, takes our breath away.

The dragonfly hovers, flies as it touches the pond-water, touching the pond as it flies over, uniting the flying and the touching. "Hills far/ mirrored/ in dragonfly's eyes," Issa "reported." [6] Flying around moves around the hills and perspectives, moving even the canons of thinking, the thinking-style, and hovering and touching all over applies its shifting perspectives and thinking-styles, expanding to vanish nowhere, as they vanish into other circle-ripples of perspectives and thinking-styles. Do shifting styles and perspective make so many ponds unlimited?

Let us watch again. Dragonfly flying is lived living thinking expanding as it makes circle-ripples edgeless and pan-centered, constantly life-dotting over the pond of the lifeworld so many ponds. Flying expands moving to express thinking, never standing still on the solid bank of staid logical canons to *deal with* all moving things, including the dragonfly flying life hovering over the pond-waves constantly rippling, with breeze blowing wherever it wants.

Now, this dragonfly is not alone but joined by countless others flying over countless ponds, hovering over countless lifeworlds. The touches move and fly to touch and the ponds then turn alive and various, thanks to the touches flying-moving. We would not be surprised, then, if the ponds melt into the dragonflies, and both turn into one pond-dragonfly in its throbbing *plurality* showing things quite alive, beyond naming. The situation is breathtakingly beyond our imagination, stunning beyond our dreams! Ponds and dragonflies gather to hover and dance, singing the world, so many, symphonic.

§ TWO: Zillion Sand-Grains, Zillion Worlds

Zillions of grains of sand at the bottoms of various world-ponds also intimate them alive; suspending bits of sand in ponds turn the ponds so dirty and alive. The sands disperse and sway as waves stir the pond water blown up and down by the wind. In each grain of sand we see a world whole, as William Blake intones [7], as these zillions of sand-grains are alive, swaying, gathering, and dispersing as waves sway and winds blow, season after season, in rain and in snow, as breeze and as gale.

Thus, zillions of grains of sand alive in seasonal hues and shapes mirror the lifeworld, as these sand-grains envision countless worlds of various ponds alive, as these sand-grains show an incredible variety of appearances to show an incredible variety of world-ponds alive, in four ways below, among many others. A grain of sand implies, one, to be one-ed is integrity; two, to be pure is to focus; three, simplicity is specialty; thus four, the small is the vast. The four points together describe how sand-grains mirror various ponds of the world alive, for "alive" appears as variously varied in time and space.

One, a sand-grain implies that to be one-ed is integrity. The law of identity, P is P, is concretized as the law of integrity, A is A. Truly one is one-ing one-ed, A A-ed, to promote the integrity of a thing, and the smaller a thing is, the easier it is to solidify its integrity, for the smaller a thing is, the harder it is to penetrate it, much less pulverize it.

Thus the smallness of a thing consolidates the natural law of integrity. Not accidentally, Jesus points us to the smallest of seeds, the mustard seed, what grows up the greatest of trees for birds to come nest [8]. Integrity is alive, and the small facilitates its life-integrity. It follows that the tiniest grain of sand is the stalwart of living integrity.

Two, a sand-grain implies that to be pure is to focus, free of distraction, of dissipation to bury in the crowd. Integrity induces the purity of focusing, and is synonymous with it. Once having remembered a thing, a dunce never forgets who is pure enough to focus as no one else can. This is why the dunce would get ahead in scholarship where the shrewd is too smart to stick to the silly rut of research [9].

"Purity of heart is to will one thing [10]." Here what is crucial is "one thing" that conduces to the purity that is in turn the source of clarity of vision, and a grain of sand betokens "one thing" most clearly. Understanding this confirms that a grain of sand conduces most to seeing the whole world.

Three, a sand-grain implies that simplicity is specialty. A dullard mentioned above is simple and so quite apt to specialize. No astuteness of a shrewd merchant can patiently stay for long through a single track of research. In this light, we see that the simple digs the deepest, and nothing is simpler than a grain of sand, so we can best see a whole world in a tiniest grain of sand.

Kids are as nothing as grains of sand, their simple purity is the root of specialty and scholarship, and they are the greatest in the kingdom of perfection that *belongs* to them. The great ones are those who lose none of their baby-heart. Thus, in the smallest common such as sand-grains, nothing joins everything and imperfection joins perfection; here things are let no-do, and not a thing is not done.

What is no-do? Tommy shouts, "I don' wanna' sleep!" He is ready for a nap he hates. Mom knows, so she says, "Ok, don't sleep; just sit here beside your pillow. I'll read your favorite story, ok?" Tommy nods. "Once upon a time . . ." and Tommy hits the pillow. Mom achieves her love-goal, and lets Tommy satisfy his need; not a thing is not done. She did not "do" (push him into bed), not "not do" (let him go), but did no-do. Tommy slept himself; people do their own ruling and the Mom-ruler wisely retires, as Lao Tzu "reports" (2, 9, 17).

People are a Tommy; they know only pushing others and smashing others. They are not aware, and don't want to be aware, of the soft power [11] of motherly pull to draw our opponents out to induce common humanity. Such soft power to gently draw other's human potentials is an application of no-do. No-do is simply to listen and let myriad all be, all listening to all, accepting all. Such a no-do does nothing but embracing things to encourage proliferation of things, to produce the plurality of ponds.

Mom on her part, while caring for Tommy this no-do way, turns into Tommy's kid way that is also a no-do. Tommy goes out after nap, full of pep, to play with kids. They spin tops, one after another. Look how they yell and shout, as they twist their bodies and jump up and down, hand-clapping, foot-stamping, whirling with their tops; they *are* tops until the tops stop, and they spin them with all their might all over again, and again!

For what purpose to they do such a stupid thing? For nothing! *That* is the fun; it is for nothing! Spinning tops is *just* fun! In their fun spinning tops they turn into tops spinning, for nothing! In their nothing-doing—no-do—stamping and twirling, they fulfill their common human selves that spin as tops with tops, spinning with the Heaven and Earth that spin as tops. I cannot keep my eyes off them! Neither can Mother Nature! Much less can Mom! Tommy is *her* boy, marvelously yelling, stamping, and twirling! He is spinning himself because he is so young he cannot spin a top yet! He *is* the top spinning!

Such a "child heart" unstoppable unconquerable is the fountain of true scholarship that is true wisdom (Li Chih); the child is the greatest *to whom* the Kingdom of God, Perfection, belongs (Jesus), where the Great Ones lose none of their baby-heart (Mencius) [12]. Nature always top-natures, begins spinning at the beginning of creation as kids doing no-do, spinning tops for nothing, never forcing myriad all, and thereby achieves the goal of their being themselves. That is creation; that is creativity as kids, ever beginning to spin tops of the world, spinning as tops!

Four, a sand-grain implies that the small is the vast. "To see a world in a grain of sand," chanted Blake instinctively. We cannot believe it on first hearing it, for how could a tiniest grain of sand allow us to see the world the vastest? Yet we soon somehow instinctively nod to it. We are now to see how it sounds incredible but that it is actually an inevitable truth. But how could it be?

On first hearing "to see a world in a grain of sand," we simply cannot believe it because "small" indicates a small range of vision of a frog in a well, and of a person confined to a small room without TV, magazine, telephone, computer, or visitor, and nothing is smaller than a grain of sand, much smaller than a well or a room, and so nothing is smaller in range of vision than that from a grain of sand. The tiniest sand betokens the tiniest vision, we would claim as a matter of course.

But No! Blake asserts precisely the contrary to our prevailing common sense. It is quite incredible to say, "In a grain of sand to see a world"; it naturally piques our inquiry into what the matter is here. I remember the eye doctor often gave me a sheet of paper to look through its hole to improve on my vision at the vision test. A peep through a tiny hole improves my vision perhaps because the hole cuts distraction to help me focus.

Isn't the tiny sand the tiny hole through which to see the world clearly? "Small" betokens focus and clarity of vision. Besides, concentration facilitated by smallness is power. Atom-fission and atom-fusion produce atom-power, thanks to atom being the tiniest in the world of things we can handle easily. No wonder, powerful atomic microscopes and atomic telescopes have been designed and manufactured. Sand-grain is "a-tom" that can not-cut any further, the smallest ever, and the smallest sand is the vastest in clarity, in power, and in vision.

Now, if a sole grain of sand implies such riches of implications, we can imagine what stunning riches zillions of grains of sand would yield. Such are the incredible riches of various ponds alive that constitute our lifeworld. The ponds are alive because the riches of implications of its zillion sand-grains cannot be definitively determined but sway and shift as the sand-grains gather to disperse, gather again to disperse again, in shapes and sizes beyond imagination. Sand-grains mirror various ponds alive in swaying waves, in blowing gales.

§ THREE: Inter-Kaleidoscopes, Vacuous, Being-Nothing Involved

The word “mirror” has emerged spontaneously in the above description. The lifeworld is an inter-mirror, inter-mirroring in zillion manners beyond description. We cannot help but look into how such bewildering inter-mirroring of the various world-ponds alive transpires. Fortunately, we would have lost in words on how to describe it, were we to be devoid of the two age-old traditions, the Chinese Hwa-Yen Buddhism, and the Taoist Chuang Tzu’s superb storytelling.

Vacuous Kaleidoscopes

Here are the *vacuous* kaleidoscopes of lifeworld. Suppose I enter a huge room that has two huge mirrors facing each other, and a small candle-light between them. Upon entering the room, I am at once dizzied. The two mirrors are now zillion mirrors; the candle-light is now zillion lights. Here is a huge kaleidoscope of infinite reflections making countless kaleidoscopes, what we call the extraordinary “various ponds.” These mirror-reflections are usually described as “causations” that are “interdependent [13].”

I am of course totally lost in all this huge brilliance. And then I realize. This brilliance *is* my knowledge, for without me there would have been no brilliance reflected in no mirror, as a falling tree in (faraway) no-man’s-land is no tree, no falling. So I am lost here, while knowing I am lost. I am that strange tiny candlelight that *knows* I am lost in the infinity of mirroring, and so I am not lost while I am lost.

Besides, all is brilliant here because here is not a single speck of dust. In fact, nothing is here; “here” is nowhere. “Vanity of vanity, all is vanity” I mumble, knowing that my mumbling is also all-vacuous. The Judeo-Christian Bible said so in long face, utter and sober. I am not following the Bible, though. I am sober, too, but my sobriety is a strange lucid joy, a calm joy of no joy, “joy” because I am lucidly in the know, “no joy” because all is vacuous, my joy included.

All this is of course a fool’s paradise, giggling no giggle, where this fool knows he *is* a fool, so this fool’s paradise is also no-fool’s paradise. This realization makes this paradise a real paradise—of no-paradise, for all is vanity so vacuous, in all joy of vacuous joy. It is a no-joy joy of a blow-off of all, Nirvana, where the blow-off is brilliance, the knowledge-brilliance, of no-brilliance.

So, this is the glorious world of brilliant multi-mirrors of nothing, for the multi-reflections are spotlessly brilliant because of spotlessness of all, complete vacuity, where even “complete” and “vacuity” are vacuous of meaning. I am so happy here nowhere, clean, rid even of happiness. This is the glorious Hwa Yen, the Flowery Splendor of Chinese Buddhism, the Buddhism peculiar to China alone, as seen in the *Gandavyuha* (Detailed Description of Flowery Splendor) [14].

Kaleidoscopes of the Common and of Life-Death

Now, here are the kaleidoscopes telling us of depths in the common, and of *life-death* and *being-nothing*. To begin, here are five brief stories about the depths in the daily common [1] silence as deep, not silent, not wording, [2] Tao said as unsayable, [3] bull-butchery of suffering that feeds us, [4] fit snug in the things to self-forget that is “right,” and [5] ancient words said to be scum by an ancient wheelwright.

[1] Silence as deep, not silent, not wording: Take my talk that speaks in words. Why do I talk? I talk to capture what I intend, the meaning of the words I utter. So once my meaning is conveyed, I must forget my words, in the same way as when I get a rabbit, I must forget and discard the rabbit trap. So, should I forget words and just keep me silent? No, for my silence will fail to convey what I intend.

Thus my words exist for my silent meaning, as my meaning needs my words to exist at all. Words are meaningful, not mere empty chatter, thanks to their meaning, and meaning must depend on words to convey, for without words meaning just vanish as vapor in midair. Words and silence (meaning silently meant) are mutually opposed (words are not silence, silent meaning is not sounded words) and mutually dependent (each must depend on the other to exist). I must thus live on, with words in silence. It is a tough world.

Worse, the complexity of my just talking does not end here. I utter words to open out beyond me, i.e., I say words in order to convey my message, my meaning silently intended, to my friends. At the same time, my friends must understand the above complex involvement between words and silence, before they can really understand me. In other words, they must "forget words in order to word with me." Thus I yearn after such a one who forgets words to word with me. Are these matters complex beyond us? Hey, this is only my talking, nothing is commoner than that!

Now, actually, the matter cuts deeper. I do not know what I mean until I say things out, articulate myself in words, while my words are shaped by what I mean. I mean through words as words express my meaning to *shape* it. Meaning and saying, silence and sounds, interdepend, interpenetrate, to inter-shape. Such awesome interdependence of inter-creation of sound-existence and no-existence of silence, between silence meant and words sounding forth meaning, is awesome indeed!

Thus we must mind our saying—no chatterbox—to utter our mind, again without chatterbox. We must say (sound) what we mean to mean (silence) what we say. Silence then speaks aloud as speech deepens silence, and the world shakes to shape up, by silent *words* wording silence, and *silence* worded in silence. Here there is neither words nor silence, but both interblending to inter-deepen, to inter-shape—to word with the one who forget words.

[2] Tao said as unsayable: Chuang Tzu declares (2/59), "Great Tao declares not." We see five points here in this strange declaration. *One*, Tao does not declare but just goes on going, for "Tao walks it and forms" (2/33). Tao is the way things go, thereby also things' going itself. How Tao goes is what Tao is; Tao-as-noun is Tao-as-verb.

Two, Tao is commonly taken and defined as the Principle of things, which has two meanings. As the *principle* of things, Tao governs—"principle" governs—things beyond things, for Tao is over things. And yet, as principle *of things*, Tao belongs to things, and depends on things to form its self as what goes through things.

Three, Tao declares as itself not-declaring. Declaration is worded; not-declaring is wordless, so declaring not-declaring is worded as wordless. Does Tao declare, then? Yes and No. *Four*, Tao is this "and," all over things, all through sound and silence. Tao is an A-whatever and a not-A whatever denied, both combined. Tao is the negative Yin and the positive Yang, the Yin in the Yang, the Yin as the Yang, and at the same time the Yang in the Yin, the Yang as the Yin, inter-involved.

Five, Tao is thus a dynamic noun-verb, principle over things through things, somewhat similar to "people-ruled as ruler." Thus, ideally, people-rulership would not corrupt into harming people, due to the paradox of ruled-as-ruler. Tao as principle over things and through things would also not leave things for Platonic heaven, nor would it vanish in ups and downs of thing-contingencies. All this is due to the paradox of Tao in and out of things, ruling things and going through things.

[3] Bull-butchery of suffering that feeds us: Such going-through is far from placid and eventless; it is full of the drama of paradox of mortal pain in creation, violence violating things in eruption of existence. Look at a kitchen-fellow butchering a bull, Chuang Tzu says in his Chapter Three with a significant title, “The Lord-principle Cultivating Life 養生主. [15]” We see seven points here.

One, the lowly kitchen fellow does not cut into the bull. His cleaver-knife just dances with the bull into the bull. The bull-dance is far from casual; the kitchen-fellow dances with the bull to the sacred music in the royal ritual. *Two*, the bull co-dancing is far from being butchered; it just dancing into loosening itself and falls quivering to the ground, entrusting itself to the ground of being, full of blood of life.

Three, such dancing bloody butchery *feeds* life. That is what the kitchen fellow is for, after all; with his deathly knife he feeds the lives of royal family—that is all of us. Lowly kitchen fellow thus teaches us that death feeds life. *Four*, the bull in China is big and precious, and comes to signify a thing 物, as bull 牛 knifed out 刀 into a conspicuous bull-thing 物. Thus the kitchen fellow knifes through the bull to show us the creation of myriad things among us.

Five, still, knifing butchery remains bloody pain. Bull-butchery, danced out in the sacred music of creation of things, is mortal pain that feeds us to fulfill us. Feeding fulfillment is creation of existence attended with mortal pain. *Six*, bull-butchery thus unites an A opposing a not-A, death feeding life, pain felling existence in fulfilling existence of a thing. Thus violence dances to the sacred music of creation of existence. Such is the drama of existence standing out of ambiguity. *Seven*, this story has powerful cash value. Life is fed and fulfilled with life-killing; suffering is good, not evil.

[4] Being fit snug in things, to self-forget, that is “right”: We in mortal suffering of life can go on happily by way of fitting ourselves in it, in fact, so fitting that we forget ourselves in the fit-in-the-world. “Fit 適” in China also means nonchalantly happy. For their incredible connection, hear these beautiful chants of life-fitting Chuang Tzu (19/62-64) has produced for us in Chapter Nineteen significantly titled, “Attaining Living 達生.”

> “Forgetting feet is the fit of the shoes. Forgetting waist is the fit of the belt. Forgetting things’ Yes and No, right and wrong, is the fit of the mind and heart. Not changing inside, not following outside, is the fit with the events-meeting. Beginning at fitting, and now ever not without the fit, is the fit of forgetting the fit.” So incredibly deep! So pungently penetrating!

Being fit and snug in things, beginning at my shoes and my belt, makes me feel so good as to forget even myself. Now whether Yes or No, right or wrong, I fit into things to forget my own mind, now composed, and my heart, now worry-free. I cease to change or follow, inside or out, in the midst of events meeting and dispersing; it is my fit care-free into ups and downs of all sorts of events in joy and in pain. Step by step, I come to so fit with myriad all, inside and out, that I forget even the fit of the fit! That is the perfect fit; isn’t it? Here forgetting prevails, all things are let go, fit and happy.

Daring to fit and be snug in things of butchery nature as above mentioned, we are now lost to ourselves being lost in things. Things are part of us, we are part of things. “Entering animals without disturbing their groups; entering birds without disturbing their walks” (20/36), we freely come and go among things that are now our home.

Now, “fit and snug” describes becoming oneself in things, becoming whole, fulfilled with things. Such is the fullness of things and climax of us ourselves in them. In contrast, “forgetting and lost” describes our disappearance, losing the self. Self-fulfillment and self-loss mutually oppose to mutually exclude, yet here, thanks to “fit and snug,” these inter-opponents join into one so natural, and this oneness is “right” unspeakable beyond morality, the way we *should be* in things. What is right is the union and unity of the un-unite-able things, mutually exclusive.

All this, told as stories, tells us among others to relax and refrain from do-good-ism, never to bully ourselves into what goes on by itself. Do-good-ism is one of the roads to hell paved by goodwill. Never be “holier than thou.” Never give advise that is worse than “a dime a dozen.” These “cash values”—and there are more—originate in the paradox of the fit as self-loss, self-fulfillment as self-disappearance. Self-fit self-forgets in joy of no-joy.

[5] The ancient words said to be scum by an ancient wheelwright: Ancient Chuang Tzu told us the above stories to enhance us. Should we follow him? Incredibly, he at once alarms us with another story, saying No! Hear this amazing story (13/68-74) to conclude Chapter Thirteen significantly titled “Heaven’s Tao 天道.”

> “Lord Huan was reading a book in the hall above; a wheelwright was cutting a wheel down under. Setting aside his chisel, he went up to ask the lord, ‘Allow me, whose words are in the book my lord is reading?’ Lord Huan said, ‘They are words of the sages.’ ‘Are the sages here now?’ ‘Already dead.’ ‘If so, then, my lord is reading scum of ancient people.’ ‘I’m reading a book; how could a wheelwright say this and say that? You are ok if you have something to say; if you have none, you die.’
>
> Wheelwright said, ‘Your subject looks at the matter with the subject’s own concerns. In cutting the wheel, if slow, then it catches and cannot go in, if fast, then it slips to skip over. Not slow, not fast, got it in hand, responded in heart, mouth cannot say, yet it has *its* knack, the subject cannot instruct his own son, who cannot receive it from the subject. Thus I am 70 and still cutting wheels. People of ancient have died with what they could not convey. If so, then, what my lord is reading is scum of ancient people.’”

This is an incredible story, and is incoherent on six counts at least. *First*, a lowly wheelwright, perhaps illiterate, here teaches his lord deep in scholarship, not the other way around as is usually the case. *Secondly*, the lord ought to be wiser than the wheelwright, for the lord reads ancient words of the sages, and yet the wheelwright downgrades those words as scum, dead and useless.

Thirdly, of course the lord is extremely incensed, demanding from his wheelwright servant the rationale, on pain of execution. Here the lord is quite unworthy of his scholarly wisdom. *Fourth*, the wheelwright draws on his lived professional *experience* to respond, for the dead ancients cannot transmit their experience, nor can they experience now. They are scum useless to experience that is all-important.

The point is clear. Words must have the cash-value of experience that ancient words lack. So far we are impressed with the wheelwright's astuteness. We even see him paralleling Socrates (in *Phaedrus* 274-275) who downgrades writing for lively dialogue because written words cannot respond. But there are more surprises in this story.

Fifth, the wheelwright uses words to explain how dead and useless words as written are to the living at this moment here now. Words (lived) are used to downgrade words (written). Worse, he said, with words, he cannot even use his words-now to convey his professional experience, wordlessly "hand-got, heart-responded," to his own son. So, he uses words to cut down on words.

If so, is he sure he can word-convey word-uselessness to his lord? "Words are useless" means "words are useless to experience." So, word-uselessness belongs to experience-realm; he cannot word-convey word-uselessness as he cannot convey experience. Thus he cannot cut down on the effectiveness of even his own words, much less to the lord. Isn't all this word-negation, with words of his, an exercise in self-defeating futility?

Sixth, this whole conversation is 2,400 years old, quite ancient. This story is part of those "ancient words" that the wheelwright said are scum. Is *this* story "scum" and useless, then? The answer is a paradoxical Yes and No. This ancient story negates itself as "All Cretans are liars" said by a Cretan. So Yes, it is a paradox seemingly useless, and yet No, for *this* paradox is strangely not useless but quite useful to our living now, different from Cretan's paradox. This sort of scum is scum and no scum. What's going on here?

An A-whatever combined with a not-A its denial makes an unstable paradox, of course. We must note, however: there is paradox and there is paradox; all paradoxes are not created equal. Cretan's paradox is due to its self-reference, it goes nowhere, and we do not know what to do with it. But this wheelwright's paradox, also self-recursive, has its bite into living experience, for all responses of wheelwright's come from experience, based on experience, nothing but experience, to sober us to glue us to experience, not play with empty dead words.

The Wheelwright is a Whitehead saying, "There are no whole truths; all truths are half-truths. It is trying to treat them as whole truths that plays the devil [16]." The saying is of course a logical splash over our sober common sense, to wit, "Nothing is perfect." And of course both these statements are a glorious self-contradiction; we are tempted to ask Whitehead whether *his* saying is whole truth or half-truth, and either way he would be stuck in a logical cul-de-sac.

Whitehead is a master logician; he must have known the logical trouble, and still went ahead and said it anyway. It is this "anyway" that saves his day and our days, for his saying so anyway forewarns us. To be forewarned is to be forearmed in our logical steps. Thus, self-referentially self-defeating as it is, Whitehead's saying quite benefits us. It is a useful paradox.

And so we have two sorts of paradoxes. All paradoxes self-refer to defeat themselves, but P-1 self-defeat uselessly, P-2 self-defeat usefully. P-1 is like "All Cretans are liars" said by a Cretan, or "What the other side says is true" written on one side of paper, and "What the other side is false" written on another side of the same paper. They are all useless mind-teasers.

In contrast, P-2 is like Whitehead's quip on half-truths, a wonderful P-2 to guide us on. Whitehead's other quip is also quite useful, "The [logical] precision is a fake," for 1+1=2 does not universally apply to actuality as logic demands—gunpowder and a spark do not make 2.

"The precision is a fake" is another quip that concludes his last published essay, "Immortality"; Whitehead is a master logician cherishing precision, yet here by precise argument, he trashes precision. It is his paradox, yet it is a useful exhortation to logic to advance to accepting incoherences in actuality, as Wittgenstein advising us to climb up on the ladder of his sayings to kick it away, in order to understand the actual world [17].

The Wheelwright's is P-2 that guides our reading and saying. All Chuang Tzu's stories belong to P-2. P-2 amounts to an advance in logic precisely because of illogical self-incoherence. We see further that "paradox" expresses an unstable, and so dynamic, gathering of incompatibilities to portray the variety of many-ness of the ponds, expressed by the bewildering kaleidoscopic circles centers-all-over, edge-nowhere, a paradoxical self-defeating feature of a "circle" to express its dynamics.

Let us repeat. Paradox is thus another name for the kaleidoscopic circles all-centers and no-edge, both one and many, one in many, and many as one, composing various ponds alive. China is one of such strange yet common lakes, whose bottoms we can see clearly yet the bottoms withdraw from us, bottomless-ly. The various ponds are myriad things jostling, mutually excluding and jointly exploding ahead forward.

Thus China is a Lake Wobegon whose bottom can clearly be seen, and yet as we go in to plumb the bottom, the bottom recedes, revealing itself to be unreachable. The lake is the heaven underneath where Thoreau sees calm wintry twilight of soft summer embracing the fishes swimming in quiet composure. We marvel at his incomparable poetry of nature here [18]:

> "I cut my way first through a foot of snow, and then a foot of ice, and open a window under my feet, where, kneeling to drink, I look down into the quiet parlor of the fishes, pervaded by a softened light as through a window of ground glass, with its bright sanded floor the same as in summer; there a perennial waveless serenity reigns as in the amber twilight sky, corresponding to the cool and even temperament of the inhabitants. Heaven is under our feet as well as over our heads."

This lake is actually our "heaven *inside*" beyond human, said Chuang Tzu (17/50), as it is actually beyond us in us. Such situation is quite ordinary, one kaleidoscope that is so many, one in many, many in one, an A adding to a not-A into a composition of no composition, intoning many kaleidoscopic ponds inter-shimmering, as our stories above describe, timelessly in time, everywhere nowhere, as if nothing were the matter.

Let us just take one common example, an image of a person we entertain, say, "Confucius." "Confucius" is identifiable as such yet is quite diverse, for my Confucius is not yours, nor is it hers. Still, we can easily identify our different Confucius's as "Confucius," a composite identifiable as such, as if nothing were the matter. "Confucius" is then one kaleidoscope so many, for your Confucius is not mine or hers, and yet "Confucius" is Confucius we see. All above five stories are of kaleidoscopes describing such depths in the common concrete.

Now, these kaleidoscopes *also* describe fabulous four ordinary stories below of *life-death* and *being-nothing,* told extraordinarily by the Taoist Chuang Tzu [19] [a] drumming lullaby to his wife's death, [b] a happy ending to the kidnapped Lady Beautiful, [c] Chuang Tzu's butterfly dream enjoyed, and [d] Chuang Tzu's pillow-talk with a roadside skull happily making seasons with Heaven and Earth.

[a] Chang Tzu drummed lullaby to his wife's death: The book of *Chuang Tzu* has it that his wife died, and his friend the name-logician Hui Tzu went for condolence, who found him sitting cross-legged, tapping on a big empty bowl upside down as drum, singing beside the coffin. Shocked, Hui Tzu accused Chuang Tzu of such an extraordinary indecency on an occasion of such ultimate seriousness.

Chuang Tzu softly said that at first he was of course quite saddened at his beloved wife's death—and then realized. When the time came, the natural elements naturally collected themselves into his wife, and they lived happily. When the time came, the natural elements naturally dispersed themselves, and his wife disappeared back into nature. It would be unnatural, indecent, and wife-disturbing of him to wail; he should quietly sing lullaby to accompany his wife's sleep.

[b] A happy ending to the kidnapped Lady Beautiful: In those rough days of fourth century before the Common Era, kidnapping was common and routine. A Lady Beautiful of high-ranking family was kidnapped by a barbarian chief. Her first several long months were wrapped in her tear-drenched robe.

But then, she slowly came to realize. Daily entertained by three sumptuous meals, nightly comforted in the square royal bed with soft-spoken chief, she now wondered why she had to wail over her "misfortune." She came to repent of her tears. Now, Chuang Tzu tells us, we are all Lady Beautiful, one day to be kidnapped by a barbarian chief, Mr. Death. We may resent it at first, but who knows, we may repent of our tears, happily dying ever after.

[c] Chuang Tzu's butterfly dream enjoyed: Chuang Tzu confessed that "last night" he dreamed to be a butterfly happily fluttering from one flower to another, quite sure that he was a butterfly. Then he awoke, and found, quite surely, himself a man. On second thought, though, he was not sure. Was he a man having dreamed to be a butterfly? Or is he a butterfly dreaming now to be a man?

Either situation makes sense, but any one would exclude the other, for both situations cannot be true at once. Such is the world in distinction among things interchanging. Now, "butterfly" is a universal symbol of fluttering between life and death. We must be awakened *to* such "dreams" happily fluttering between life and death.

[d] Chuang Tzu's pillow-talk with a roadside skull happily making seasons with Heaven and Earth: Death without burial is a shame; dead, leaving just a skull, tossed on the roadside, is an unspeakable misery, the worst of shame no death can wipe out. Sadly, such worst misfortune was not uncommon in rough days of fourth century ancient China.

Traveling, Chuang Tzu happened to see a dry skull on the roadside. He touched it with his staff, asking what wretched misfortune had befallen it to reduce it to such unspeakable predicament, and then slept on it as his pillow. That night, the skull appeared in his dream, laughing at his imbecility, for it has been enjoying joy unspeakable, making rounds of seasons with Heaven and Earth.

Incredulous, Chuang Tzu asked if it wanted him to request the Things Maker to restore it to former life with its family. Knotting its brows, the skull replied how it could at all discard such pure ultimate joy for the worldly cares of obsequiousness to boss and parents and worrisome cares for subordinates. Dead on the roadside, no one bothers, is *the* ultimate of happiness no one can rob of the dry skull.

Chuang Tzu would therefore smile in his stories as these [20].

"Messrs Oblation, Carriage, Plow and Come talked to one another, 'Whoever takes nothing as his head, life as his spine, and death as his buttocks, whoever knows dying, living, existing, and perishing as one body? I will be friend with him.' The four mutually looked and smiled. Nothing was against their hearts-of-being, so they became friends. All too soon, Mr. Carriage fell ill. . . . Mr. Oblation asked, 'Do you hate it?' He said, 'No! Why should I? Soon [it] changes my left arm into a rooster, and I will seek [during] night-hours [to crow]. Soon [it] changes my right arm into a pellet, and I will seek an owl to roast. Soon [it] changes my buttocks into wheels, and with my spirit I will ride it; why [then] need I change a carriage? Besides, to gain is timely, to lose is to follow; dwell in time, stay following, and no grief or joy can enter. This is what the ancient called 'bonds loosened.' . . . Why should I hate it?'

All too soon, Mr. Come fell ill, gasping, dying. His wife and children circled him and wept. Mr. Plow who went to visit him said, 'Shoo! Out! Don't startle change!' Leaning on the door, he talked to him, 'Great! Change molds! What will you make next? Where are you going? Will you make a rat liver? A bug's leg?' Mr. Come said, 'A child under parents goes anywhere, only at their bidding. The Yin and Yang to us are not less than our parents. If they bring me near death and I do not listen, then I defy. What blame is there in *them*? Huge Clod loads me with a figure, labors me with life, eases me with age, and rests me with death. So what 'goods' life is why it 'goods' death. Now if as a great smith casts metal, it jumps and says, 'I must become an Excalibur!' then the smith must think the metal inauspicious. If one who chanced to be shaped a man insists 'Just a man, just a man!', then Change the Molder must think him inauspicious. If the heaven and earth are a great forge, the Molder-Change a great Smith, where could I go and not be all right?'"

How ebullient is such looking forward to self-journey after death under Heaven! Truly this is ultimate happiness without happiness [21], "wu wei," doing nothing adverse to life under Heaven. Storing all under heaven under all-under-heaven, and nothing gets lost (6/26), even after my death.

Such is Chuang Tzu's revolution, putting upside down our common view of death and life. These four stories are in joy-crescendo *to* death from softly lullaby-ing the dead wife, through death-kidnap as perhaps a good fortune, fluttering pleasantly between life and death, to the ultimate joy of casual undisturbed death on the roadside. We are hopefully to be persuaded to *love* our death while casually living here now! Chuang Tzu's deep joy goes far beyond Albert Camus' sober final judgment over the absurdity of life, "One must imagine Sisyphus happy [22]."

Now, we must note two crucial features in all these stories. *One*, these stories are all quite daily, common, and ordinary, *and yet*, staying ordinary as they are, they are quite surprising. These stories show us how stunningly unusual the usual routines of life are. All we need is just to open our eyes wide and watch and discern; there is no need to go out of this world, whatever that means, to see *this* world as out of this world. This last point deserves elaboration.

Two, these stories tell us that this world natural and mundane, as ordinary as they are, always transcends this world. This-worldly *is* otherworldly. Is our lifeworld being or nothing? Is it life or death? Or are they both? But does it matter? What matters is to see that this world is uncanny in otherworldly way, and we constantly slither in and out of this world, unawares or not. All this tells us how *alive* our "various ponds" are.

Thus the circular ponds are the countless kaleidoscopes of changing patterns and colors of values, fashions, each correlated with all others, interchanging, inter-changing. These countless kaleidoscopes are of two sorts, the non-being sort of the Hwa Yen Buddhist vacuity-mirrors inter-reflecting, and the being-sort of Chuang Tzu the Taoist, nothing infused with things, to delightfully slither back and forth between life and death, making Heaven and Earth, season after season.

§ FOUR: Relativism Life-Worldly, Intercultural

So, nothing is usual in our usual lifeworld. What is usual is always unexpected. We must expect all things as unexpected, so much so that even things we expect to be unexpected could happen anytime as expected. This situation makes us realize that there is no single ultimate truth anywhere, while so many things keep happening at once.

Someone naturally says, “Aha, this is relativism bred in uncertain plurality of things. Truth is certain, final, and single. Your view does not even show the path to truth; all this is sheer relativism.” “Relativism” here is an abusive term; anything we dislike as wishy-washy we relegate to the wastebasket of “relativism.” All right, then, let us probe what “relativism” can really mean.

People often think that just to discuss relativism sides with a “heresy.” Nothing is farther from the truth. Relativism is really a vital élan in relentless pursuit of insights in their relentlessly open linkage. We must realize. “Relativism” has *two* meanings, as a noun, an assertion of a thesis, and as a verb, describing life-process. This realization generates seven crucial points, as follows.

[1] We often take relativism as an *assertion* of categorical terminal judgment to absolutely deny all absolutes. Put this way, relativism defeats itself; doesn’t it assert its own denial? It is irresponsible; doesn’t it take all views as equally valid depending on one’s perspectives, cultural, ethical, or otherwise? Philosophers since Socrates (contra sophists) such as Kant (contra Hume) are supposed to have fought/demolished relativism as we do heresies.

Many questions are thus asked to relativists, “Is there an absolute truth at all?” “Are all views equally valid?” “Is there a universal form of reasoning?” and “Can we judge between two views?” [23] They are insoluble conundrums requiring acrobatic ingenuity [24] to respond; relativism is cornered if we take it as an *asserted* view.

But, then, this “dead issue” of relativism mysteriously persists. We say relativism is dead wrong but it is far from “dead.” It keeps popping up everywhere in life, in thinking, and in history. No separate article, “Relativism,” exists [25], yet indexes have “relation,” “situationism,” “skepticism,” “subjectivism,” “anarchism,” all siblings to relativism if not its synonyms. Ubiquitous yet non-existent, relativism is a mystery if taken as a *set view* against absolutism, an *asserted ism* on an absolute par with absolutism.

[2] Such impossible maze alive that refuses to leave us signals that relativism attends life *and* that it is wrong to take relativism as a noun, a static definitive view equal to absolutism. Relativism must instead be a verb challenging the absolutist approach to life-issues. Challenging an assertive approach, relativism cannot itself be as assertive and definitive as absolutism [26] but stubbornly “reactive” to it [27].

How relativism does indicates what it is. Relativism must sinuously *describe* an actual situation, not judge, declare, and categorically assert a view but realistically points and proposes, sifting, searching, ever on the go. Is this why Lao Tzu and Chuang Tzu constantly tell stories of common living, alerting us to its unsuspected implications, and egging us on to reflect on them, yet proposing no definitive views?

Is this how the Taoists came to be accused of committing *relativistic* life-withdrawal, vague, indecisive, and irresponsible? Relativism simply, unceasingly, tells stories of life, one after another, so that we can live *through* various views and attitudes to learn one after another to cultivate life.

[3] Its interesting offshoot is on words "better" and "best" usually taken as mathematically *exclusive* ordinals; A better than B, B is not good as A, A the best, nothing is good as A. We yet understand parents proclaiming their children as "the best in the world," spouses proud of their beloved as "the greatest in the world," and children priding in their mothers as "the most beautiful in the world." Are we "more blessed than others" with foods, free worship, and cash for rainy days? Yes, but those are "blessed" also "who weep." (Jesus)

So we use "better" and "best" as stories of a happy situation, where "better" and "best" are *non-exclusive* blessedness. In life, things can be each the "best" without excluding others, ever changing as weather. Fuzzy and inductive logic try to capture such "flukes" in actuality. Logical non-exclusion is the warmth of human relativism.

[4] "But relativism cannot blindly describe; it must describe how we *should* behave." Yes, it does. Ever alert, empathic, and critical to events and views, relativism points to an appropriate life-posture. Relativism tells us that we are "on the way," and so must be ever "on the way," seeking, sifting, judiciously trailing the Tao of Nature forever naturing without ceasing.

No view is perfect yet none is totally wrong, and we must carefully and patiently go *through* every view that comes, comparing, weighing, and integrating them, never pompously pronounce the final judgment. Relativism is the story of life-normative quest, ever turning anti-life postures to pro-life ones [28].

[5] "But relativism cannot go aimless, it must have a *goal*." Yes, but its goal is not fixed eternally in the Platonic heaven. Aristotle told us [29] that "happiness" is our common goal but differs as every life differs from every other, and differs as life grows. "Is happiness one or many?" The answer is of course it is both one and many, and the question of "or" is a wrong question of staid logic. Life differs as it grows; growth changes beyond *definitive* assertions to fix; so changes its goal, growing stage by stage.

My son Johnny used to excitedly vow that he *was* going to be a garbage collector driving a big loud truck! I said, "All right! Good for you, John!" Later, he vowed that he *was* growing up to be a milkman with a pencil on the ear! I said again, "All right! Good for you, John!" He is now a violinist, music historian, and medical technologist. Nothing is wrong with changing interest as one grows/changes; "all ends are endless" (Dewey) that is life-pragmatism. As life's goal varies endlessly, so relativism's shifting goal is unpredictable *and* non-arbitrary *for* life—private or public [30].

[6] "But we cannot just wander around. What is relativism's method?" Its method is careful discernment, going *through* each view from inside it, existentially [31]. This is the truth hid in its "laughing stocks," "all views are equally true," "relativism indiscriminately tolerates all things."

What relativism cannot tolerate is the intolerant finality of judgment that closes off life-openness to things that come. All views are not equally valid, nor is relativism all-tolerant, but its method of sifting them applies equally to all views, and cannot be canonized [32]; it has to sinuously *trail* each specific view as it emerges daily.

[7] Here is a bombshell on argumentation. Relativism does not argue but simply story-describes actuality, and thereby *argues*—as Socrates did powerfully when he *described how* he came to be indicted as an atheist corrupter of youth. He then described how, on the contrary, he improved their souls (no parents came to indict him) as he (not an atheist) followed the Delphic Oracle in total disregard of his own living, and his own life [33]. His life-description demolished the indictment of "impiety" and "seducer and corrupter of youth."

Kierkegaard and Voltaire, Hugo and Tolstoy, kept telling stories, Western thinkers have been conducting "thought experiments," arguing with "examples" and "counterexamples" from life, and *all* Chinese thinkers have been tirelessly telling stories from history, actual or imagined. They all "argue" by telling stories.

"Story-argument" is persuasive because it ruthlessly follows life itself that persuades living. They say facts are not opinions on value, nor are examples points, so relativism confuses description with demonstration. Such assertion commits false dichotomies on the high judgment seat of "abstract thinking (Marcel)."

Thinking should be concrete as life, being part of living as human; far from being a contradiction, "concrete thinking" is the way of human life. Life forms history; it is an ongoing "story argument" to which Chinese thinkers constantly appeal. So should the West with the rest of the world.

In all, relativism *opposes* absolutely asserting "the truth," [34] in thinking, to become history among friends. Opposing logical/analytical necessity [35], relativism thinks in pragmatic coherence (Rorty) and story-description (China). Opposing "mirroring [36]," relativism facilitates friendly conversations. Opposing fixation, relativism goes *through* ideas in contradiction. Opposing reason that tries to shape history, relativism in story-description *becomes* history.

Thus relativism revolutionizes thinking as it ruthlessly trails actual situations. Relativism spatially goes through various views, story-describing them, discerning what they respectively are, thereby appropriately criticize their appropriateness. Going through these views critically, relativism makes history as it judiciously dialogues with the past views that in turn shape, straighten, and enrich the present situation. Spatially and historically, relativism goes through positions into so many kinds of world-ponds.

In such dynamic ways, relativism as an élan of going-through countless positions, as they arise in space and in time, jibes with the dynamic circles all-centers and no-edge that go out and out, constantly expanding. Relativism is this everywhere-nowhere circle that moves into many circles, round and round, one into many going through many, making various ponds of lifeworld.

Everything is alive as such relativism-circles inter-depending, inter-reflecting, one kaleidoscope as many kaleidoscopes with countless shades and perspectives, swirling and waving, gathering and dispersing. All this describes the varied sorts of ponds alive in every grain of sand gathering as river into countless diverse rivers of the lifeworld.

A pond is where a frog of life jumps in to make a sound, as a most famous Japanese haiku intones, "Ancient pond; frog jumps in; sound of water." Nothing noteworthy is here at the pond, and everything is here—pond-world, frog-life, activity-jumping, and sound that excites a bird. And then we see so many ponds that sound so many sounds of so many frogs jumping in.

These worldly sounds make us realize: The pond *is* the frog, for here the pond appears as pond, thanks to the frog disturbing it. The pond-frog in turn *is* the sound made by the jumping in of the frog, for the sound lets appear the pond-frog that otherwise would have remained silent, nowhere, in the same way as a tree falling in no-man's-land is no tree, not falling.

All in all, the pond-frog appears by the frog jumping-in, and the frog-pond sound echoes the cosmic silence all around, to spread the pond as many ponds of many circles everywhere-centered and nowhere-edged. We go through everyday all these sounds of the do-nothing frogs, jumping into the countless silent ponds of this lifeworld.

The world is so many different ponds, each alive with fascinating details different everyday everywhere. It is relativism dynamic, inter-dancing with the zillion grains of sand at the bottoms of the ponds, each a fascinating kaleidoscope mirroring this whole world. In short, the world is various ponds thus fascinatingly alive.

§ History, Mistakes, Alive always

These ponds and lakes, varied and alive, exist everywhere nowhere in particular—always. Why always? It is because history has no end, nor does Nature, always. Life simply continues as history has no end. The goal of life is the goal of history. As life is always unfinished [37], so its goal is never finished, and history continues, not without goal, not without goal-less, always unfinished.

How does history continue? History does not repeat; it rhymes itself, and rhymes never cease. History rhymes because people reenact the yesterday today, never repeat it, to enable understanding to reenact life, again today and again tomorrow, as the days keep coming anew afresh, again and again.

Days dawn continually, renewing today once more, unceasing. All this makes history, as our days keep dawning and going by, as days come always to be made continually—as we say, "You made my day"—no end in sight. Or rather, in history ends are endless, and goals go beyond themselves, one replacing the other. History reenacts itself as we reenact yesterdays today for tomorrow to arrive well and vigorous—all the time, for time has no end, ever alive throbbing ahead, having no end in sight.

The common saying, "All is well that ends well," so enamored Shakespeare that he made it into a comedy. It is fit to become a comedy because the endless history that we are has the unending hope to end well any today that we are in. History is thus always well ending, well without ending.

This is because, to put it another way, history always judges looking back, and this *process* makes no mistakes, and so history makes no mistake. History keeps judging this way to abolish mistakes always, for afterthought is always better than all others; don't ask me why, it *is* just better.

History thus always betters itself, continuing to correct mistakes judged mistaken. This process of finding and correcting mistakes is history, and this process makes no mistake, and so history makes no mistake, so that it makes "all well that ends well" without ending.

History keeps going this way to abolish mistakes always. Going always is going *alive*, "going continually this way" makes no mistake, and so countless ponds all alive make no mistake, by going ahead always as history. This is world-milieu in time in history to enable mistakes to make themselves, and then to correct mistakes to go ahead. All this describes countless ponds so various and alive, continuing to exist to go on variously as circles all-centers and no-edge, going ahead bettering all, well ending, well without end.

Now, pain comes when things are judged in want of fulfilling the goal, and so mistakes betoken pain and poverty. The ponds and lakes are oceans of suffering, Buddhism says. It does not matter, for the oceans themselves suffer no pain, no poverty, for *they* have no mistake, i.e., no suffering, as history itself. So, history has no pain as it goes from yesterday to today with no mistake, no suffering but sliding on. All is well ending well unending (Shakespeare), so day *after* day are good days (Zen Buddhism).

Every today just dawns no matter what; each day is goal-directed (it dawns) without a goal (unending, for nothing), and judging is always goal-directed, and the judging fulfills the goal of judging, and so judging is self-goaled, never in pain of want even as lived time we undergo is filled with pain. History has no pain as it has no mistake but is always judging mistakes.

The countless ponds alive full of pain cleanses itself of pain as their histories go on, and on, in sound and fury in utter silence (no one cares), slithering from life to death, from death to life, in pain in no pain. Alice in this Wonderland sees and undergoes things topsy-turvy and somehow straightening themselves in the end. All this confusion unscrambling itself is portrayed by a mathematics professor in Oxford, Dr. Charles L. Dodgson, Lewis Carrol for Alice. He chimes in with a great mathematician Whitehead quipping, “The precision is a fake,” for 1+1=2 applies not to gunpowder plus a spark [38].

Wonderland always explodes into bits and pieces, and portraying them somehow makes sense, for in each piece Alice sees a whole world, and so myriad pieces see myriad worlds, exploding round and round, out and out. A world is orderly, and myriad worlds are disorderly (myriad) orders (world), pain (full of mistakes) painless (as the whole world), and making mistakes without making a single mistake. Lifeworld is such a strange wild, wild world because it is so alive, always going ahead without ceasing.

“Mistakes without mistakes” can also be portrayed another way, like this. Nozick says, “The word philosophy means the love of wisdom, but what philosophers really love is reasoning. They formulate theories and marshal reasons to support them, they consider objections and try to meet these, they construct arguments against other views. Even philosophers who proclaim the limitations of reason—the Greek skeptics, David Hume, doubters of the objectivity of science—all adduce reasons for their views and present difficulties for opposing ones.”

The philosophers’ love of reasoning and arguments comes from all Western philosophers being obsessed with finding and correcting *mistakes*, for that is why they keep arguing among themselves. Both Plato and Royce came to be interested in the problem of how mistake is possible [39]. They are thus obsessed with mistakes.

And so, being their observers, we can say that what makes possible their arguments, judgments, and corrections, what keep them going, are precisely “mistakes,” for they put the cart before the horse, or rather, they mistake the bad cart for the good horse. Pain and suffering, i.e., mistakes, are what make possible sages and religions to flourish. Thanks to “mistakes” and pain, the countless ponds come alive variously in lively arguments, and what is to be thanked for cannot be mistaken (no one thanks mistake, does he?), thus mistakes are without mistakes.

This is another beautiful wild card that throws a monkey wrench (never mind mixed metaphors here) into the orderly logic about this lifeworld orderly disorderly alive. The world is alive, thanks to death-making pain and mistakes. *Oceans* of suffering themselves do not suffer mistakes in all their waves of mortal mistakes. Countless ponds are alive, thanks to deadly mistakes continually erupting (disorder) for history to continually correct (order).

Remember, the world without mistakes is dull and dead. Admirable loyal subjects and heroes thrive only in disastrous disorders; no shimmering crime, no shining police. This is what originated Han Fei's no-nonsense Legalistic Realpolitik in China [40]; it has worked, at least disastrously. Mistakes it is that keep the lifeworld alive and exciting, in pain and poverty.

Countless various ponds alive are fountains of eternal youth whose elixir can be easily snatched from every grain of sand scraped from any lake-floor. Can you imagine? Chuang Tzu (23/76-77) sees that the crippled people beyond praise and blame can throw away fancy clothing, and convicted criminals beyond life and death can climb to any height, and so they are "men of heaven" so perfect, so heavenly. That is true humanity beyond all fear and shame, authentic virtue beyond all morality.

It is thus that nothing is more precious and admirable than such, nothing more immortal, more alive always, exhibited among the ugly crippled and the heinous criminals. All this makes up the mad, wild world of so many centers all over, its edge nowhere, always alive, no dull moment as naughty Tommy shouting, "I don' wanna' sleep!" The lifeworld is various countless ponds profoundly alive, topsy-turvy, always going ahead of us, as if nothing were the matter, for all this is routine world alive, thanks to mistakes and pain. The world is wild and routine, always.

§ Cash Value of Various Ponds Alive

"All this is quite far out, rambunctious, and boisterously unreal, out of this sober world. Does such incredible 'insight' have any cash value to our real sober life?" Yes, of course, tremendously, tragicomically, cosmically, and historically. This realization that our lifeworld is stunningly varied, countless ponds strangely alive, gives the *ultimate* justification to all kids singing the world and dancing their lives, *growing* quite cosmic. Now these kids cannot be ridiculed as insane thanks to our lifeworld being such stunning zillions of ponds alive.

Andrew aged five wanted to change his birthday to get birthday gifts anytime he wants; his dad said he cannot change it, but he disagreed. O, how refreshing his demand is! None but kids alone can come up with such stunning demand! I his "Gumpa Akong" was drawn in. Intrigued, I told him how to do it. This is how. He can *forget* his birthday; to forget begins all, all over again. Even if his Mom told him of his birthday (he whispered, "It's February 26!"), he can refuse to believe it, and *ask* her to "prove it!" [41]

Forgetting as Taoist and asking Mom to prove her information as Hume demands, change his birthday, you see. Now he can change his birthday, any day every time he demands it, if he wants to, for *his* "birthday" is as good as what Mom tells him. After all, this is *his* birthday he is handling. He nodded in silence, in a strange sort of composure only he understands.

I was going to tell his Mom how he can change his birthday, when he shouted me down, "Don't tell! It's a secret!" I asked, "Do you have secrets?" "No," he said. So this is his secret of no secret—his birthday change! Why is it a secret to Mom? The reason is simple; kids always have reasons simple and straight.

Mom is only a *witness,* albeit uniquely firsthand, to his birthday, and so she would have hard time *proving* it, for a fact is proved when it is repeated, and birthday is a fact only once-in-a-lifetime, incapable of repeating. So, Andrew's birthday-change is kid's *magic*, you see, and Mom must not know its secret, for telling her his magic of how he changes his birthday may ruin *his* changing it, as divulging the magic de-"magicizes" the magic! O, how cute, how deep his secret Magic Land is where he has no secret!

In fact, Andrew may not realize this, much less do I, that "today" begins the rest of his life and my life, and his unique incredible demand to change his birthday activates this truth, to make me and make him realize this every today as every birthday of his and of mine. So, his asking to change his birthday has already changed it; in the very asking, right now, his birthday of everything comes about, for his demand makes his today *sparkle* with the beginning of the rest of his life, for kid's demand sparkles things afresh, as he the kid *is* forever fresh, *making* everything fresh.

He-asking-demanding is the delightful scandal of every particularity of "birthday"-creation of everything, anything of the future. I cannot help but sing [42],

Future comes
One day at a time.

My future is here,
I must walk out to it.

Morning fresh,
Evening calm;

Every day is a new day,
The first day of my life.

The squirrels are here
Hopping with me.

My future is my birthday today, one today at a time hopping with my Andrew hopping, hopping with our squirrels. This is *the* morning where/when I can do anything, as kids can do anything. Andrew is *the* first morning of creation of all! [43] Now, doesn't this story give all of us a smile? Even I laughed as I told you this stupendous story! Such open secret of Andrew's, such breathtaking smile he evokes! This is many ponds alive changing their birthdays!

This insight of kid's, unawares, into so "many world ponds alive," makes all of *us* kids, always growing irresistibly, illicitly, illimitably. We are kids dancing the world when we are called "poets" celebrating, "musicians" singing the romping mysteries of the world. We are called "scientists" as we let go our kid-curiosity, forever exploring how the world of nature works.

We are called "technologists" when we apply our "scientific knowledge," fun-knowledge, to manage the world as kids manage their games as they keep inventing new games. We are kids playing the management of such fun-ponds alive. We are called "merchants" when we trade our products to make our living to fun-prosper continually, up and about, as kids make and trade their fun "products" and fun things.

"Poets," "musicians," "scientists," "technologists," and "merchants"—they are all nicknames for being playing "kids." These nicknames are our excuses for our living and acting as kids, singing the world and dancing the lifeworld as kids as adults. Mind you. All this is enabled and justified by our lifeworld being the countless varieties of ponds alive, so that we ourselves meld into these ponds.

Otherwise we would have been insanely boisterous, "all in sound and fury, signifying nothing." Now various ponds alive firmly respond to Shakespeare's complaint on the senselessness of this world. Various ponds alive *are* the significance of all our life-activities through all histories and all cosmoses beyond imagination beyond all mistakes. This is the end of all that ends well, so all is well, after all, unending. Nothing is more stunning, and nothing is more sober, than this enabling plurality of ponds alive that are our world and we our selves; all is well here.

The whole point here is to go through to grow history-mature, "sea worthy" of the countless ponds, one after another, scorching shine and dark rain, living and dying, come what may, always ready to dragon-fly one time in high honor, snake-slither another time in low unjust pain, useful in making it through and then retire without complaining, with calm composure as one cries quietly over spilled milk, and again retire as a good seasoned sailor through thick and thin, on highways of the ocean or in hidden dark coves.

Such is to live in, and live through, countless ponds alive, losing ways and finding them again, in zillions of sand-kaleidoscopes in them, gone-on, passed-on, alive through death, joy in pain. Am I crazy mumbling all this? Of course I am crazy, sane in insane ponds alive, no-do and nothing not-done, nothing said, no word, no silence, bouncy in many slashes of wounds, surviving them all in silence without silence.

Realizing to be in various ponds alive, I continue to adapt to shifts of waves and winds to adapt them, an adept, composed, taming them. I am a spinning top whirling calm, turning into an agile dragonfly over ponds after ponds alive, in twilight dawn of thickets surrounding primeval ponds rancid and raucous, *ever* beginning life through deaths as if nothing were the matter. I am pain-proofed, joy-immune, being insane in life-sanity. Such is the whole point of pointing at various ponds alive so countless. Such is the cash value of this essay delightfully insane, on stunning ponds *alive* so countless.

Here I am, almost done, with thing of interest to say remaining to say. I have been splashing in the ponds where my thoughts collect, when my thoughts are things' ponds. There is something of the pond to every person whose metaphor spews a new reality from the original that turns unreal, as every life grows. Growing is life; no growing, no life. Growth is metaphor of new reality that is ponds *after* ponds proliferating in rancid air breathing death to breathe life.

Ponds are life in thoughts in metaphor growing more ponds, full of sound and fury, signifying without signifying; such busy calm! Description is an element, air and water, frogs in twilight, vanishing in daylight of ecological twilight. Great Lakes are hooting splashing, lapping waves. Here I let myself go, and I turn into the ponds so countless so alive for no rhyme, no reason.

Such poetry of the ponds responds to our daily necessity of getting the world right. "Poetry is the gaiety (joy) of language" (Stevens [44]) in the ponds of life in death, death in life. Language of ponds that includes death is the music of joy over death. I feel better bathing in the ponds of life my poetry creates.

I splash in the twilight of imagination beyond reality, all too real beyond actuality growing, turning ponds more numerous, moment by moment. This world of ponds is out of this world. Here I "can never be born enough," in "embryonic omnipotence" (cummings [45]) of a naughty baby; *each* today comes, one at a time, as my birthday, in ponds various alive.

Poetry is packed stories, inviting to be unpacked into stories. This invitation is poetics. Story-thinking tells of poetics. This essay tells the stories of poetics chanting aloud the sound of the music of things' senses, chanting and telling it to the hills and the rivers, shouting, "the lifeworld is the ponds various, alive!"

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[2] Wallace Stevens, *The Necessary Angel: Essays on Reality & the Imagination* (Vintage, 1965), quoted in *Modern Poetics*, ed. James Scully, NY: McGraw-Hill, 1965, p. 139.

[3] Ernest Hemingway, *The Old Man and the Sea*, NY: Charles Scribner's Sons, 1952, p. 35.

[4] Henri Bergson, *The Two Sources of Morality and Religion* (1935), Garden City, NY: Doubleday & Co., 1954, pp. 102-103.

[5] *The Essential Writings of Ralph Waldo Emerson*, NY: The Modern Library, 2000, p. 252.

[6] Sam Hamill renders it as "The distant mountains/ are reflected in the eye/ of the dragonfly," in The Little Book of Haiku (1995), NY: Barnes & Noble, 2002, tr. Sam Hamill, p. 83. Sadly, I could not find the original in *蕪村集一茶集*，栗山理一等校注，譯，東京小學院, 1989.

[7] "To see a World in a Grain of Sand" begins the long poem, "Auguries of Innocence," in *The Complete Poetry & Prose of William Blake*, ed. David V. Erdman, NY: Doubleday, 1988. pp. 490-496. What the poem's title means may intimate what is tried here, i.e., what *innocently* appears in the world *augurs* how things destine in irrevocable laws of nature, such as laws of retribution, laws of reaction to action, etc.

[8] Matthew 13:31-32.

[9] One version of *Strange Stories of Liao Studio* begins with such a story of the community's laughing stock, a "stupid" fellow winning the hand of the most charming lady in town, "A Pao," and winning the First Rank in Royal Examination. See the story of「阿寶」 that begins *聊齋誌異*，臺北市三民書局, 2009, pp. 1-13.

[10] Søren Kierkegaard, *Purity of Heart Is to Will One Thing*, tr. Douglas V. Steere, NY: Harper & Row, 1948.

[11] I am extending Joseph S. Nye, Jr., *Soft Power: The Means to Success in World Politics*, NY: PublicAffairs, 2004. It has an awesome cosmic potential to "no-do." See also Robert O. Keohane and Joseph S. Nye, Jr., "Power and Interdependence in the Information Age," *Foreign Affairs*, September/October 1998, pp. 81-94, and Nye, "Get Smart: Combining Hard and Soft Power," *Foreign Affairs*, July/August 2009, pp. 160-163. Nye is myopically obsessed with politics, without cultural basis of "soft power," and so has to "combine" soft power with hard power; "smart power" is a copout.

[12] This is Li Chih (1527-1602 李贄)'s central thesis that is in 「童心說」in 李贄文集，北京社會科學文獻出版社, 2000, I:91-93. The child as the greatest to whom the kingdom of God belongs is said by Jesus in Matthew 18:4 and 19:13. Mencius (4B12) said that the Great Ones keep their baby-heart. Lao Tzu said (37) that the Tao no-does, and nothing is not done.

[13] "A Big Ocean, countless waves" can also be said here. The "ocean-waves" parallels the "room-mirrors." They are identical, for they are both vacuous. Where are the sand, the waves, and the winds?

[14] Hwa Yen Buddhism is aptly and correctly, though dryly and insufficiently, summarized in Wing-tsit Chan, ed. & tr., *A Source Book in Chinese Philosophy*, Princeton University Press, 1963, pp. 406-424. I have tried to put in verve and actuality to it.

[15] See Kuang-ming Wu, *The Butterfly as Companion*, Albany: State University of New York Press, 1990, pp. 279-359.

[16] *Dialogues of Alfred North Whitehead* (1954), recorded by Lucien Price, Boston: David R. Godin, 2001, Prologue, p. 14, where Mrs. Whitehead said, "His thinking is a prism. It must be seen . . . from all sides, then from underneath and overhead. To have seen it from one side only is not to have seen it." This explanation of Whitehead's self-defeating wisdom is also a wonderful description of our various kaleidoscopic ponds as the lifeworld.

[17] "Immortality" is in *The Philosophy of Alfred North Whitehead*, ed. P. A; Schilpp, La Salle, IL: Open Court, 1951, pp. 682-700. Wittgenstein's famous quip concludes his *Tractatus*, 1922, to elucidate itself by kicking itself.

[18] Henry D. Thoreau, *Walden and Resistance to Civil Government*, NY: W. W. Norton, 1992, p. 188.

[19] The first and last stories are taken from Chapter Eighteen, titled significantly "至樂 Ultimate Happiness," and the middle two stories are taken from Chapter Two, also significantly titled "齊物論 Taking All things Equal," of the Book of *Chuang Tzu*. See also Kuang-ming Wu, *The Butterfly as Companion*, Albany: State University of New York Press, 1990.

[20] *Chuang Tzu* 6/45-60; I tried to bring out the vigorous original. Apostle Paul also thought about not objecting to our Creator in Romans 9:19-21. Paul (not Chuang Tzu)

has God as Love, but did not think (as Chuang Tzu did) on how we should behave—joyously—under the almighty Creator.

[21] *Chuang Tzu* 18/11.

[22] Albert Camus, *The Myth of Sisyphus*, NY: Alfred A. Knopf, 1959, p. 91.

[23] These are some of the typical questions treated in Martin Hollis and Steven Lukes, eds., *Rationality and Relativism*, MIT Press, 1986.

[24] A self-proclaimed relativist Joseph Margolis (*Truth About Relativism*, Oxford: Blackwell, 1991) tackles these challenges head-on, rambunctiously stirring up turgid pages. We agree, relativism is as alive as he is spirited, yet we wonder if it is as unapproachably complex as he makes it out to be. We would not be surprised if his noisy turgidity came from his lack of appreciation of the pervasive *élan* of relativism, to miss relativism.

[25] See, e.g., Paul Edwards, ed., *The Encyclopedia of Philosophy*, Eight Volumes, NY: The Macmillan, 1967 and Philip P. Wiener, ed., *Dictionary of the History of Ideas*, Five Volumes, NY: Charles Scribner's Sons, 1973, two massive encyclopedias of thoughts.

[26] Watch how risky A. N. Whitehead the mathematician's quip is, "There are no whole truths; all truths are half truths. It is trying to treat them as whole truths that plays the devil." (*Dialogues of Alfred North Whitehead* [1954], Boston: David R. Godine, 2001, p. 14) Now, isn't *this* statement the "devil" that treats a half truth it asserts as a whole truth? Another of his quip comes to the rescue: "The vitality of thought is in adventure. Ideas won't keep. Something must be done about them." (Ibid., p. 250, Chapter 12, April 28, 1938). "There are no whole truths" does not assert but urges "adventures of ideas"; asserting any idea (even "no whole truths") as a "whole truth" stops the "adventure"; the stoppage is "the devil" that saps the "vitality of thought." The "adventure" is Gotthold E. Lessing's "ever moving pursuit (immer regen Trieb) after Truth" chosen over "all Truth (alle Wahrheit)" (*Wolfenbüttler Fragmente*, in *The Oxford Dictionary of Quotations*, 1966, p. 313). If this is not dynamic relativism we do not know what it is.

[27] Richard Rorty, *Philosophy and the Mirror of Nature*, Princeton University Press, 1979, p. 377 describes his "edifying philosophy" as "reactive"; its pp. 377-379 describes our relativism here.

[28] Here are Rorty's insistence on "progress from" cruelty, and China's of pro-life posture.

[29] Jonathan Barnes, ed., *The Complete Works of Aristotle: The Revised Oxford Translation*, Princeton University Press, 1984, II: 1729 (beginning of *Nicomachean Ethics*). Sadly, prosaic descriptive Aristotle never bothered to reflect on how problematic his report was, "happiness" as a mix of one and many; he had no self-reflection, no self-examination Socrates wanted.

[30] Privacy and the public join here; Rorty's private-public difference is not needed.

[31] See Kuang-ming Wu, "Existential Relativism," Ph.D. thesis 1965, Yale University Philosophy Department; it elaborates on this point.

[32] Rorty says that "pragmatism" has no "new philosophical method or strategy," in *Philosophy and Social Hope*, USA: Penguin 1999, pp. xx-xxi.

[33] See *The Apology*, Edith Hamilton and Huntington Cairns, eds., *Plato: The Collected Dialogues*, Princeton University Press, 1961, pp. 20-24 et passim.

[34] An absolute assertion of the final truth plays god-in-thinking. This is anti-human, anti-life, and cuts thinking from concrete life-actuality, as Plato did. Rorty may or may not have thought about this point.

[35] Rorty may have opposed logical/analytical necessity for its being *autonomous* (*The Linguistic Turn: Recent Essays in Philosophical Methods*, The University of Chicago, 1967), cut from actual necessity that it assumes it *mirrors* (*Philosophy and the Mirror of Nature*, Princeton University Press, 1979).

[36] Rorty, ibid., 1979, and *Objectivity, Relativism, and Truth: Volume 1: Philosophical Papers*, Cambridge University Press, 1991.

[37] Yehudi Menuhin has written down his unfinished life. Yehudi Menuhin, *Unfinished Journey*, NY: Alfred K. Knopf, 1977, and *Unfinished Journey: Twenty Years Later*, NY: Fromm International, 1999. No one did “unfinished journey” twice; Menuhin is a kid indeed, who begins anew every minute, always unfinished. Cf. Ruth St. Denis, *An Unfinished Life: An Autobiography*, NY: Harper & Brothers, 1939.

[38] This quip concludes his last published essay, “Immortality,” in *The Philosophy of Alfred North Whitehead*, ed. Paul Arthur Schilpp, La Salle, IL: Open Court, 1951, pp. 682-700.

[39] With this observation, Robert Nozick begins his ambitious book, *The Nature of Rationality*, Princeton University Press, 1993. The possibility of mistakes has fascinated Western thinkers since Plato (the *Theaetetus*). Josiah Royce built his idealism on it (*The World and the Individual*, 1900-1901). Western philosophy is a series of inter-pickings-apart of mistakes.

[40] See「難一」 in *韓非子*，臺北市三民書局，民86，p. 547.

[41] David Hume is the kid here; he dares to disbelieve in any birthday! His so-called “skepticism” is really *kid*-asking in wonder, refusing to settle anywhere; it is kin to relativism. This is where the world is born. Skepticism, relativism, and birthday are sisters in the creation-family of *kids*, and this is a secret!

[42] Kuang Wu, “Future Comes One Day at a Time,” *Timeless Voices*, ed. Howard Ely, Owings Mills, MD: The International Library of Poetry, 2006, p. 1. Apropos of its theme, this poem is the first one to begin all in this book.

[43] Andrew outshines Henry Bugbee’s *The Inward Morning: A Philosophical Exploration in Journal Form*, State College, Penna.: Bald Eagle Press, 1958.

[44] Wallace Stevens’s “Adagio” in *Opus Posthumous*, quoted in *Modern Poetics*, ed. James Scully, NY: McGraw-Hill, 1965, p. 150.

[45] These are e e cummings’ phrases in *Poems 1923-1954*, quoted in *Modern Poetics*, op. cit., pp. 121, 122.

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Chapter 10

THE INFLUENCE OF FERTILIZATION ON DUCK BREEDING IN EXTENSIVELY MANAGED FISHPONDS OF THE BRENNE, CENTRAL FRANCE

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ABSTRACT

Strong alteration of waterfowl habitat may derive from fish-farming intensification in fishpond systems. The specific effects of fertilization on duck breeding were described in fishponds of the Brenne region (Central France) where fish stock density is usually lower than in fishpond systems of Central Europe. The study was carried out in 1999, 2000 or 2001 in a sample of 75 ponds, either unfertilized (F0) or fertilized with organic *or* inorganic manure (F1), or with organic *and* inorganic manure (F2). Fish-stock mean density doubled from F0 (215.9 kg.ha^{-1}) to F2 (441.9 kg.ha^{-1}). Biomass density in macrophytes of potential invertebrate prey for ducks was higher in F2 than in F0 and macrophyte abundance did not differ across fertilization categories. Duck brood density (number/square root of pond surface area) in F2 was higher than in F0 and in F1. Moreover, 5-week old pochard *Aythya ferina* brood size was higher in F2 than in F1, probably as a result of a higher persistence of broods with ≥ 4 ducklings. We conclude that manure application and correlative increase in fish density is not necessarily antagonistic with duck breeding provided that fish stock is below 500 kg.ha^{-1}, water turbidity does not hinder macrophyte development and large enough helophyte belts are available for nesting .

Key words : duck breeding, fishpond, fertilization, invertebrates.

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INTRODUCTION

Negative relationships between fish and waterfowl in lake ecosystems have been described in many studies (Pehrsson 1979, Hill et al. 1987, Parker 1991, Mallory et al. 1994). Fishponds however are among important breeding habitats for ducks in Europe (Bukacinska et al. 1995, Musil 1999, Lutz 2001) despite usually high fish stock density. Fish-farming intensification may nevertheless lead to dramatic collapse in waterfowl populations. For example, a remarkable decline of duck breeding in the Czech republic by the end of the 1970s was related to intensified fishpond management (Musil et al. 2001).

Fish-farming intensification may impinge on duck breeding : i) by increasing fish stock and hence the competition with ducks for invertebrate resources or by the direct impact of carps on macrophyte beds (Spencer & King 1984, Wright & Phillips 1992, Hanson & Butler 1994, Pokorny & Pechar 2000) in which ducks may find invertebrate prey (Krull 1973, Danell & Sjöberg 1982), ii) by littoral scraping and the correlative decrease in shore vegetation that provides possible nesting habitat. The decrease of littoral helophyte stands may force duck females to nest in narrow strips of vegetation. Correlative nest concentration or short distance to vegetation edge could then increase predation risk and affect nesting outputs (Göransson et al. 1975, Krasowski & Nudds 1986, Owen & Black 1990, Albrecht et al. 2006).

In French fishpond regions, fish-farming management is usually balanced by the economic influence of waterfowl game. In the major regions for waterfowl, hunting activity may even outweigh the economic importance of fish-farming. One of the practical consequences of waterfowl hunting is the managers′ interest in aquatic vegetation. But even when vegetation is preserved and secure nesting habitat for ducks, pond fertilization by fish-farmers may theoretically influence brood density and duckling survival in different ways. The resulting increase of planktonic populations and correlative higher fish stock density could decrease water transparency and hinder macrophyte development (Daldorph & Thomas 1991, Hargeby et al. 1994, Hosper 1998). Manuring is therefore likely to negatively affect feeding habitats of breeding ducks and their broods. But higher plankton density might also increase invertebrate abundance and provide ducklings with higher food resources or decrease the competition with carps for benthic prey.

The objective of this study was to investigate this influence of pond fertilization on duckling rearing in a major duck breeding place in France, the Brenne.

METHODS

Data Collection

The study was carried out in 1999, 2000 and 2001 in the Brenne region, central France (46°49′N, 01°13′E). With more than 1,000 fishponds, this region is one of the most important wetlands for duck breeding in France (Broyer 2002). Waterbodies are mainly surrounded by a mosaic of permanent meadows and arable lands.

We selected randomly 22 fishponds in 1999, 26 in 2000 and 27 in 2001, in which duck broods were monitored weekly with a telescope (x 20-60) from mid-April to the end of July.

Age and number of ducklings from broods of the different species (European Pochard, *Aythya ferina*, Mallard, *Anas platyrhynchos*, Tufted Duck, *Aythya fuligula,* Gadwall, *Anas strepera*) were recorded every week to determine the number of different broods in each fishpond. Broods were monitored until the age of 5 weeks, considering that possible confusion with adults could more easily arise for older ducklings.

By questioning fish-farmers, we were able to split the pond sample into 3 fertilization categories : F0 = no fertilization (n = 28), F1 = organic *or* inorganic fertilization (n = 35), F2 = organic *and* inorganic fertilization (n = 12). It was not possible to obtain reliable information for each studied water body on the exact quantity of manure brought but usually organic fertilization consisted approximately of 500 kg.ha^{-1} of cow manure and inorganic chemical manure corresponded to 20-35 kg.ha^{-1} of nitrogen. Data on fish stock density (in kg.ha^{-1}) were obtained after the winter harvesting that followed the duck monitoring, for 14 fishponds in 1999, 25 in 2000, 20 in 2001. In Central Europe (Bohemia, Silesia, Bavaria and Saxony), a lower occurrence (<30%) of breeding pochards was found by Lutz (2001) in fishponds where shore emergent vegetation area was <10%; this vegetation area was <5% in 42.6% of ponds where fish stock was >900 kg.ha^{-1}. In Brenne, the percentage of total pond surface area covered by shore emergent vegetation (*Phragmites communis*, *Schoenoplectus lacustris*, *Typha latifolia* and *T. angustifolia*, *Carex sp*., *Juncus effusus* and *J. conglomeratus*, *Phalaris arundinacea*) decreased with fertilization but mean values remained above 10% (F0: 17.1% (SE=4.0), F1: 13.1% (SE=2.2), F2: 11.1% (SE=2.8).

Invertebrate biomass density in macrophytes was assessed in 21 fishponds in 2000 and 20 in 2001, at the onset of the duckling rearing period (mid-June). Submerged macrophytes (mainly *Potamogeton* sp*., Chara* sp*., Callitriche* sp*., Ranunculus peltatus, Najas marina*, and *N. minor, Myriophyllum spicatum, Ceratophyllum demersum*) were sampled by two operators with a (25 cm x 25 cm) square landing net, and a pair of scissors to collect the parts of the plants found in the upper 25 first cm of the water column, i.e. the most accessible to young ducks. Floating and submerged vegetation was collected in the landing net, which was kept vertically, at a constant depth and over a maximum distance of 1 meter. A scythe blade was welded on the lower bar of the landing net's frame. The net was plunged vertically, very slowly in the heart of the selected macrophyte stands, swiftly pulled forward and extracted from water in horizontal position with collected vegetation hanging inside. The latter was then cut with scissors along the scythe bade so as to fall inside or outside the net. The operation was done as quickly as possible to prevent invertebrates from escaping. At least 3 samples of the most representative aquatic vegetation were collected in each pond and pooled. Sample number (3-5) varied according to macrophyte bed diversity (according to the variations of dominant species and vegetation density). The collected vegetation volume was measured by water displacement in a test tube; the shifted volume of water after the introduction of plant material was directly used as a reference to compare invertebrate biomass density between different sites (in mg.0.1 litre^{-1} of macrophytes). Invertebrates were separated from plants under a water flow and sorted by successive sieving (2-mm mesh, then a 0.5-mm one). Their biomass (mg dry weight) was measured after desiccation for 24 hours at 60°-C.

At the same period, the proportion of the total pond surface area that was covered by macrophyte beds was assessed and classified into 3 levels : 1 = < 10%, 2 = 10-30%, 3= > 30%.

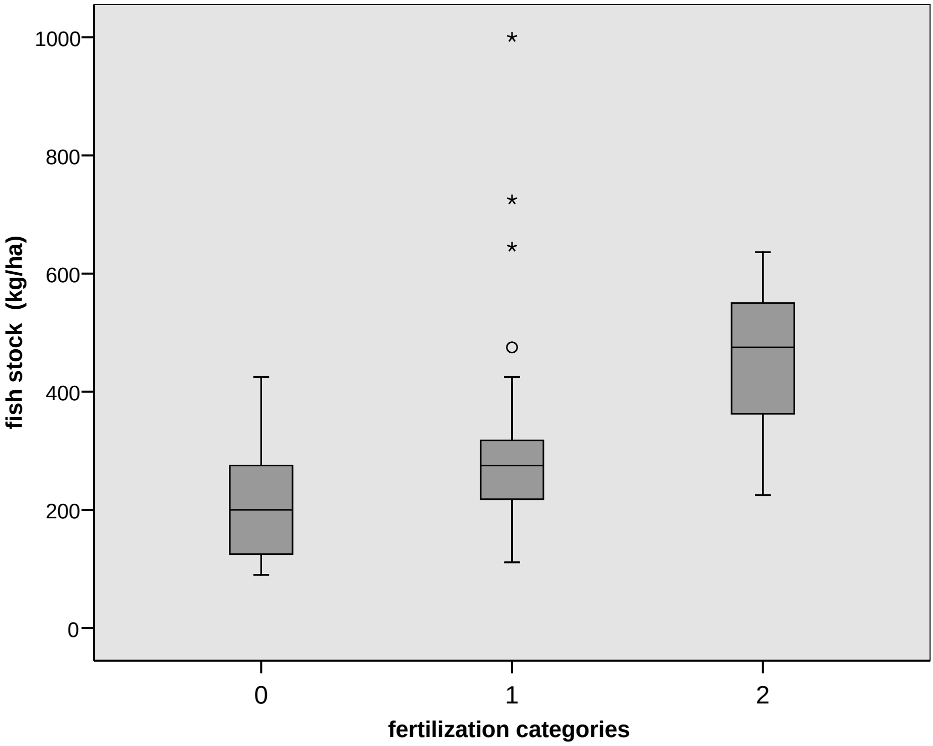

Figure 1. Box plot showing fish stock variation across fertilization categories (0: unfertilized n=17, 1: organic or inorganic manure n=31, 2: organic and inorganic manure n=11) (Brenne, France, 1999-2001).

Data Analysis

The objective of the study was to analyse correlative variations across fertilization categories, of fish stock density, invertebrate biomass density in macrophytes, duck brood density and brood size variation throughout the rearing period. We analysed brood density of all species pooled considering that ducklings always depend heavily on the consumption of invertebrates as a source of protein during their first weeks of life (Sugden 1973, Cox et al. 1998). Brood size variations with age however was only monitored in the pochard which is the most abundant breeding duck in Brenne, with broods spending usually more time outside the emergent vegetation cover than dabbling duck broods and, hence, being more easily observed.

The variations between F0, F1 and F2, in fish stock density and duck brood density and size were studied by one-way ANOVA. When differences were significant, each pair-wised comparison between fertilization categories was then tested post-hoc by using the Bonferroni method. Only significant results ($p \leq 0.05$) will be indicated thereafter. Data on invertebrate biomass density in macrophytes however were heteroscedastic and we used non parametric methods (Mann-Whitney U-tests). Since we found no difference between the 3 years for all studied variables, the data were pooled prior to analysis.

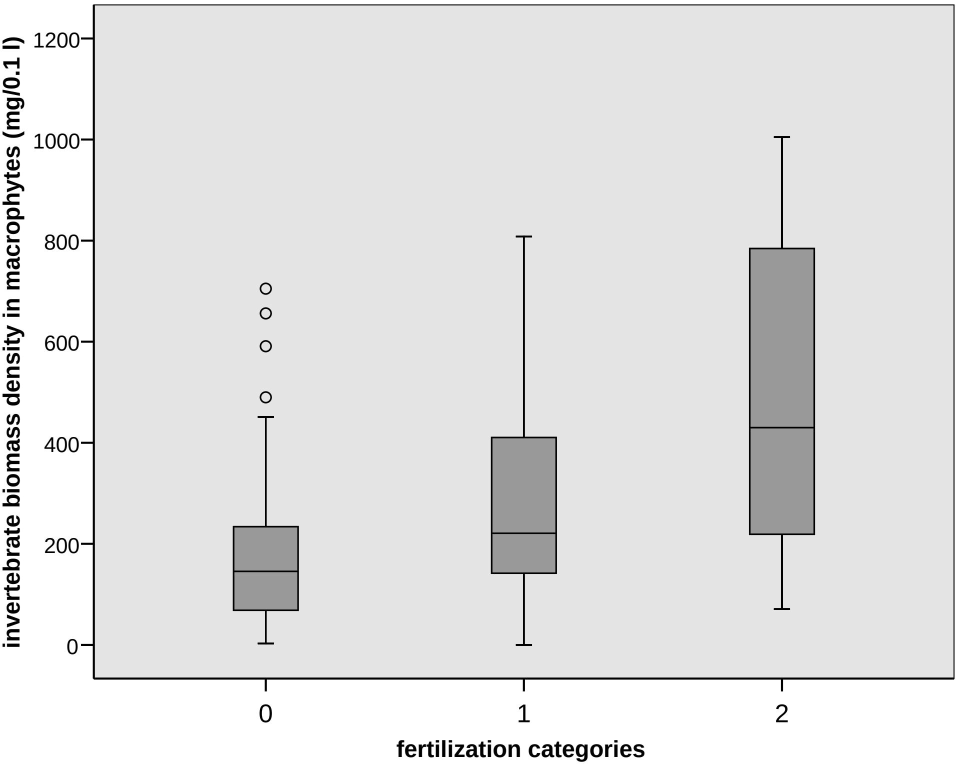

Figure 2. Box plot showing the variation of invertebrate biomass density in macrophytes across fertilization categories (0: unfertilized n=19, 1: organic or inorganic manure n=15, 2: organic and inorganic manure n=7) (Brenne, France, 2000-2001).

RESULTS

Fishpond Characteristics According to Fertilization Categories

Fertilization obviously depended on pond surface area, fertilized ponds (F1 or F2) being smaller (F0 : 16.7 ha (SE=2.0); F1 : 7.0 ha (SE=0.8); F2 : 8.2 ha (SE=1.1)). Fish stock density increased with fertilization (F0 : 215.9 kg.ha^{-1} (SE=23.8); F1: 309.7 kg.ha^{-1} (SE=32.8); F2 : 441.9 kg.ha^{-1} (SE=41.2); $F_{2.56}$ = 7.114, p = 0.002).(Fig.1)

Invertebrate biomass density in macrophytes was higher in F2 than in F0 (Z = -2.342, p = 0.019), but did not significantly differ between F1 and F0 or between F1 and F2 (Fig.2). However, macrophytes were neither more nor less abundant in F2 than in F0 (Fig.3).

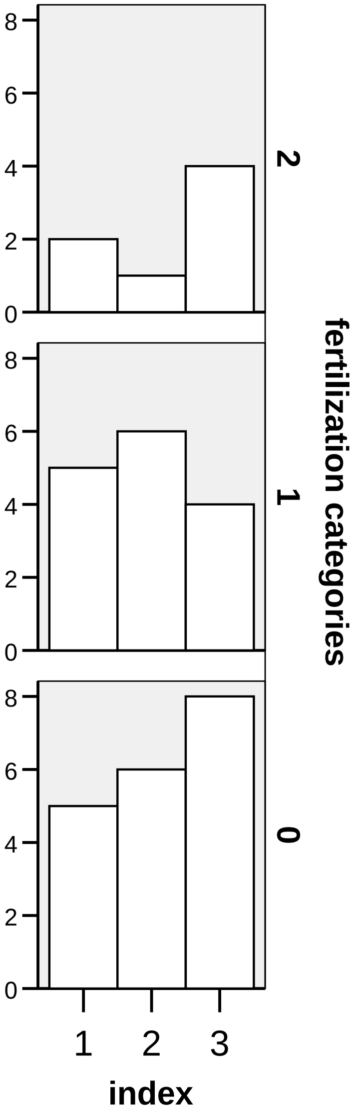

Figure 3. Fishpond distribution within 3 classes of macrophyte abundance (index 1: macrophyte cover ≤ 10% of total pond area, index 2 = 10-30%, index 3: ≥ 30%) according to fertilization categories (0: unfertilized, 1: organic or inorganic manure, 2: organic and inorganic manure) (Brenne, France, 2000-2001).

Variation in Duck Brood Density

Brood numbers were positively correlated with pond surface area, whereas brood density1, i.e. 'brood number/pond surface area', was negatively correlated with pond surface area. Brood numbers were therefore divided by the square root of pond surface area (= brood density2) to allow comparison between ponds of different sizes (absence of correlation with pond area). The general negative correlation between brood density1 (number/surface area) and pond surface area, nevertheless, was influenced by fertilization with higher brood densities in surface areas less than 5 hectares in fertilized ponds, but a virtual absence of relationship between brood density and surface area in unfertilized ponds (Fig.4).

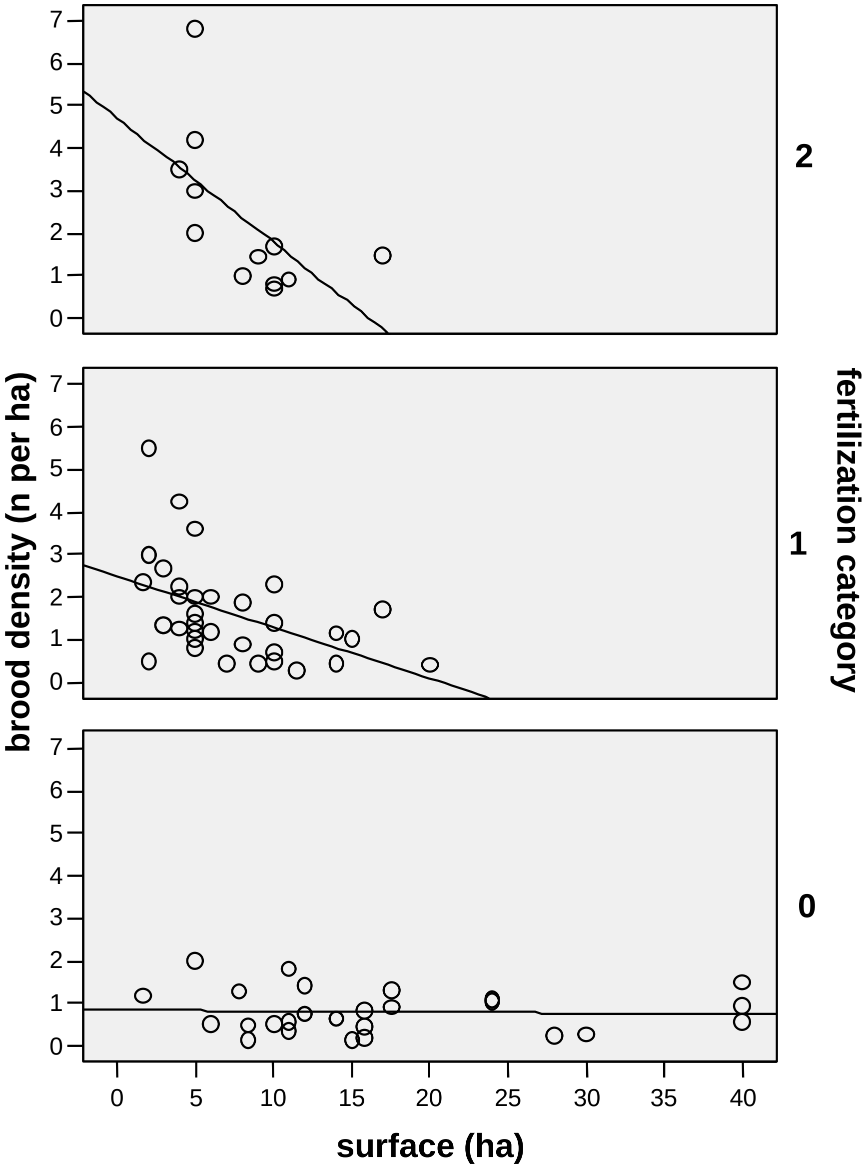

Figure 4. Variation with pond surface area of duck brood density1 (n.ha^{-1}) according to fertilization categories (0: unfertilized, 1: organic or inorganic manure, 2: organic and inorganic manure)) (Brenne, France, 1999-2001).

Brood density2 differed between the 3 fertilization categories ($F_{2.72}$ = 5.336, p = 0.007; post-hoc tests were significant between F2 and F0 : p = 0.005 and between F2 and F1 : p = 0.032), increasing from F0 to F2 (Fig.5).

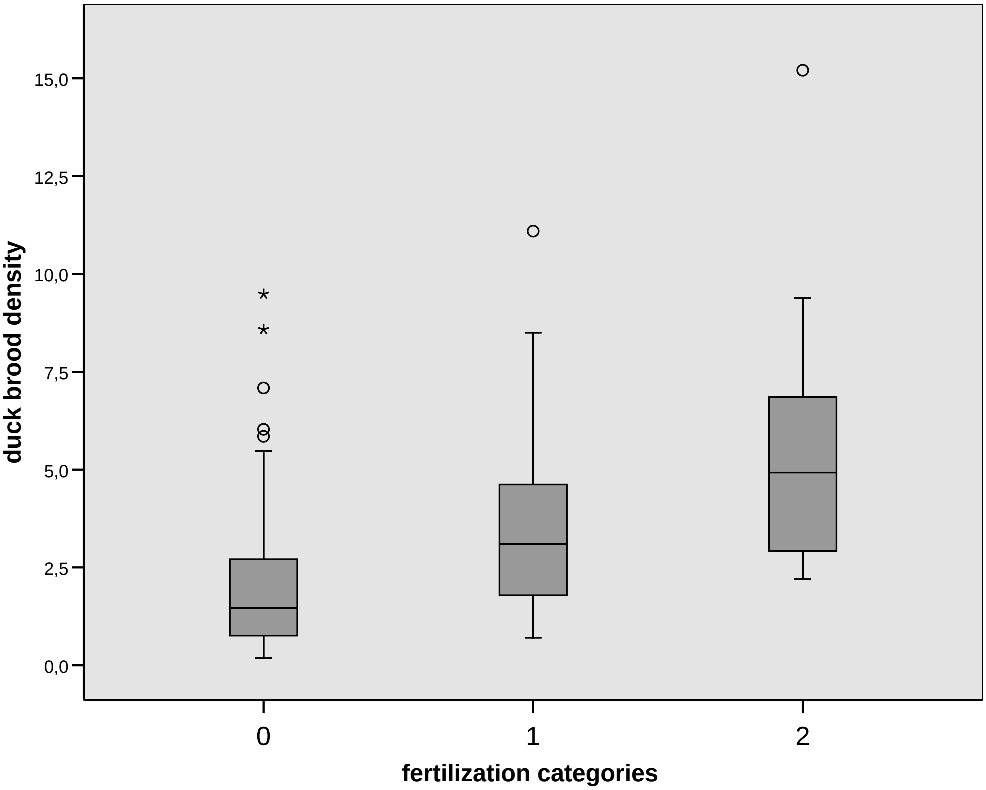

Figure 5. Box plot showing the variation of duck brood density2 (n: square root of pond surface area) across fertilization categories (0: unfertilized n=28, 1: organic or inorganic manure n=35, 2: organic and inorganic manure n= 12) (Brenne, France, 1999-2001).

Size Variation with Age in Pochard Broods

Pochard brood number at different ages remained roughly stable in our sample between 1 and 3 weeks, and then decreased as ducklings grew older (3.0 broods.10ha^{-1} at 3 weeks, 1.5 broods.10ha^{-1} at 5 weeks). Lower abundance in F0 could be linked to the larger size of fishponds (see above). Differences were small between F1 and F2 (except for 1 week old broods whose density was lower in F1) (Table 1).

Brood size did not significantly differ across fertilization categories from the 1st to the 4th weeks (Fig.6). At the age of 5 weeks however, the difference was significant ($F_{2.120} = 3.155$, p = 0.046, with 1 duckling more on average in F2 than in F1. This difference could be explained by a better persistence of the largest broods (≥ 4 ducklings) in F2 (n broods with ≥ 4 ducklings *vs*. n broods with ≤ 3 ducklings, F1 *vs* F2: 1-3 weeks: $\chi^2 = 0.7943$, $p > 0.25$; 5 weeks: $\chi^2 = 5.056$, $p < 0.025$) (Fig.7).

Table 1. Variation according to brood age (1-5 weeks) of pochard brood number (n.10ha^{-1}) recorded in sampled fishponds of 3 fertilization categories (F0: unfertilized, F1: organic or inorganic manure, F2: organic and inorganic manure) (Brenne, France, 1999-2001).

	Age (weeks)				
	1	**2**	**3**	**4**	**5**
F0 (468 ha)	2.3	2.4	2.5	1.9	1.3
F1 (245 ha)	2.8	3.4	3.6	2.8	1.8
F2 (99 ha)	4.1	3.7	3.8	2.9	2.1
TOTAL	**2.7**	**2.8**	**3.0**	**2.3**	**1.5**

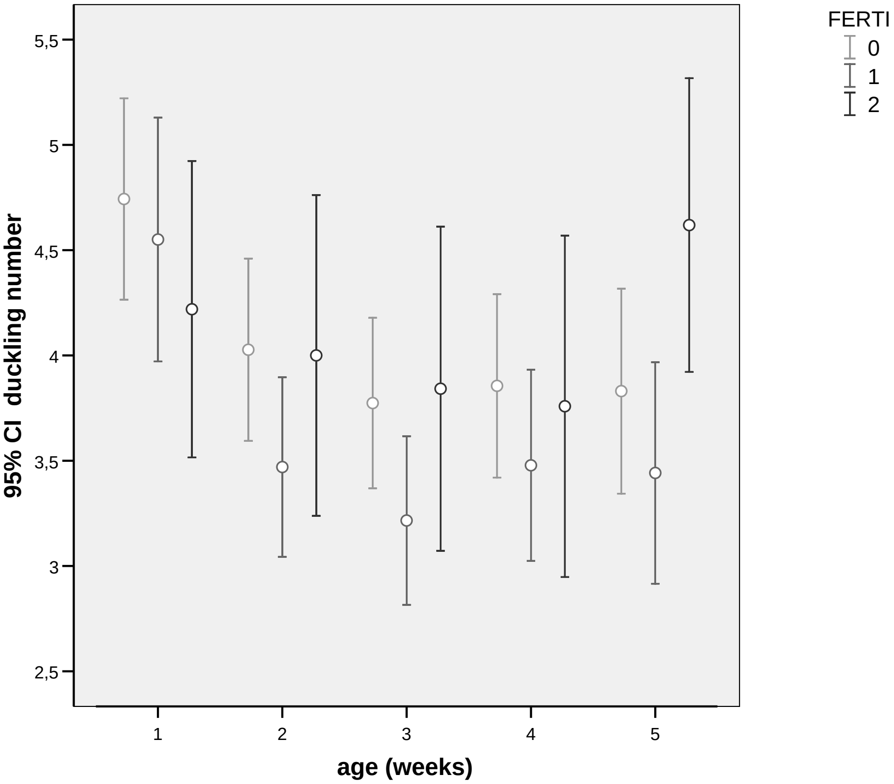

Figure 6. Variation with brood age (1-5 weeks) of pochard brood size (mean and 95% confidence interval) according to fertilization categories (0: unfertilized, 1: organic or inorganic manure, 2: organic and inorganic manure)) (Brenne, France, 1999-2001).

Discussion

In Brenne, duck brood density was higher in ponds with both organic and inorganic manure than in unfertilized ones and in those fertilized with either organic or inorganic manure. In fertilized ponds, invertebrate biomass density in macrophytes was also higher than in unfertilized ones. Furthermore, we did not find evidence that macrophyte abundance differed obviously between the most fertilized and the unfertilized ponds. The decrease of duck brood number per hectare with increasing surface area observed in fertilized ponds could possibly be linked to the fact that fertilizers could be more easily spread in small ponds (< 5ha), as shown by the larger size of unfertilized ones.

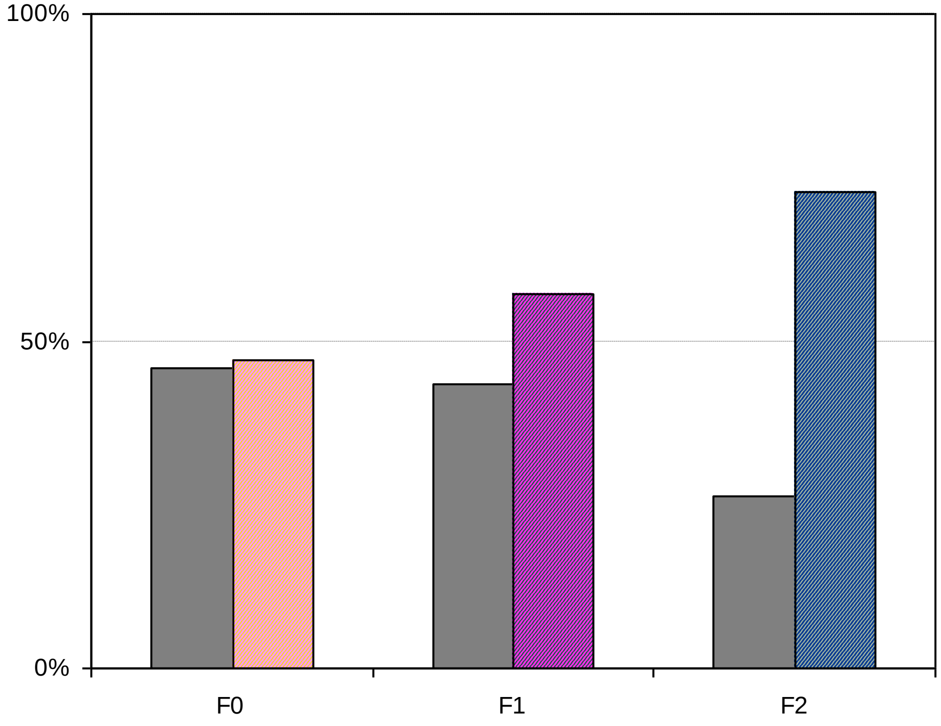

Figure 7. Persistence from the age of ≤ 3 weeks to the age of 5 weeks of pochard broods ≤ 3 ducklings (shaded) and ≥ 4 ducklings (hatched) in 3 fertilization categories (F0: unfertilized n=28, F1: organic or inorganic manure n=35, F2: organic and inorganic manure n=12) (Brenne, France, 1999-2001).

Pochard brood size did not vary significantly across fertilization categories until the age of 4 weeks but 5-week old brood size was higher in ponds where both organic and inorganic manure had been sprayed than in those with either organic or inorganic manure. This difference was related to a better persistence of large broods (≥ 4 ducklings) and a lower persistence of small ones (≤ 3 ducklings) in the most fertilized ponds. A general decrease in pochard brood size was observed after the first week of life, which could be explained by the high duckling mortality usually observed in the first 10 days of life (Korschgen et al. 1996, Mc Auley & Longcore 1988). Later, brood densities decreased from the 4th week onwards. It could be postulated that competition for food resources had become stronger with increased food requirements. Accordingly, the higher persistence of large broods in the most fertilized ponds could have been the consequence of a better trophic environment. Both higher fish stock and duck brood densities characterized therefore the most fertilized ponds in which we found higher invertebrate biomass density in macrophyte beds.

In this study, organic fertilizers usually amounted to 500 kg.ha^{-1} of animal manure, as it is traditionally the case in French fishpond systems (Bérard 1982). Inorganic fertilization corresponded generally to 20-35 kg.ha^{-1} of nitrogen, which is very similar to the average quantity sprayed in Czech fishponds between 1970 and 1990 (Pechar 1995). Despite that, fish stock mean density in Czech fishponds was above 800 kg.ha^{-1} in the 1980s (Pechar 1995 *op. cit.*), whereas in this study mean fish harvesting in the most fertilized ponds was only 442 kg.ha^{-1}. The difference in fish productivity between fertilized French and Czech fishponds could be possibly explained by other aspects of fish farming intensification: increased water volume after littoral scraping, intensive artificial carp feeding, etc. The impact of carps on submerged macrophytes has been experimentally assessed by Crivelli (1983) who found a 20% decrease in their dry weight when carp biomass density was 400-500 kg.ha^{-1}, rising to 45% when carp biomass density amounted to 700 kg.ha^{-1}. This result confirms that the turning point in the balance between negative effects (i.e. the impact of carps on macrophytes) and possible positive effects (the influence of fertilization on food resources) of fish-farming intensification is probably not far above the 400 kg.ha^{-1} threshold.

We conclude that artificially increasing fish stock density in fishponds is not necessarily antagonistic with duck breeding provided that: i) shore vegetation is preserved to secure safe nesting habitats, ii) fish stock density does not exceed an optimal threshold (about 400 kg.ha^{-1} or slightly above), iii) manure application does not result in a shift from clear to turbid water in which macrophytic vegetation tends to disappear (Moss 1990, Hargeby et al. 1994).

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