communities. Production is highly seasonal and bottom-up control of the forage fish may be apparent. Upwelling and boreal food webs both have 'narrow waists' such that much of the productivity is filtered through a small number of forage fish species with large numbers of individuals.

In contrast, temperate food webs have a larger number of species with weaker levels of interaction. The predators are opportunistic and may feed at more than one trophic level. The interactions may become more apparent when species are aggregated into trophic guilds. Within the guilds, individual species may be interchangeable in their trophic roles. Temperate fish communities have less pronounced seasonal cycles, and bottom-up control of fish production is less evident than in boreal communities. Tropical fish communities are subject to even less seasonality and are even more species rich. Some degree of species aggregation is necessary for fitting multispecies population models. Habitat features are particularly important for structuring tropical fish communities. For example, on the north-west Australian shelf, composition of the demersal fish community is most strongly associated with the density of large epibenthos – sponges and gorgonian corals.

What are the implications of multispecies dynamics for the management and conservation of marine fish populations? The main conclusion is that there are trade-offs in the harvests of interacting species. In upwelling systems there may be large fisheries for anchovies or for sardines but not both simultaneously. The fisheries and fishery managers need to respond at the same timescales as the changes in the ocean environment that cause the population fluctuations.

The trade-offs in yield are influenced by the relative fishing pressure on interacting species. Even gradual changes in fishing effort can interact with ocean variability to cause rapid shifts in species dominance. Whether we are concerned with safe levels of harvesting or with maximizing the yield, fishing rates of predators and prey must depend on the abundance of the other species. The trade-off inherent in predator–prey complexes is whether to harvest a lower volume of the higher valued predator (e.g., cod) or a higher volume of the lower valued prey. Economically, the prey species may be more valuable as prey for the high-value predators. However, as the top predator populations have been depleted, fisheries have switched to harvesting prey species such as squid, sand lance and sprat. Industrial fisheries for forage fish can compete directly with piscivorous fish, seabirds and marine mammals. This global trend of 'fishing down the food web' may hinder efforts to rebuild stocks of depleted predator species.

See also

Coral Reef and Other Tropical Fisheries. Crustacean Fisheries. Demersal Species Fisheries. Marine Fishery Resources, Global State of. Molluskan Fisheries. Open Ocean Fisheries for Deep Water Species. Open Ocean Fisheries for Large Pelagic Species. Salmon Fisheries: Atlantic. Salmon Fisheries: Pacific. Seabirds and Fisheries Interaction. Small Pelagic Species Fisheries. Southern Ocean Fisheries.

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FISHERIES OVERVIEW

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Introduction

The long-standing importance of fishing as a human enterprise can be traced through the diversity of harvesting implements found in ancient archeological sites, artistic depictions throughout prehistory and antiquity, and the recorded history of many civilizations. Sustenance from the sea has been essential throughout human history and has formed the basis for trade and commerce in coastal cultures for millennia. The remains of fish and shellfish in extensive middens throughout the world attest to the prominence of these resources in the diets of early coastal peoples. In northern Europe, the fortunes of the Hanseatic League during the medieval period were linked to trade in fishery resources, demonstrating a dominant role of fisheries in the trade of nations that extends over many centuries. Today, the critical importance of food resources from the sea has been further highlighted by increased demand related to the burgeoning human population and the recognized benefits of seafood as a high quality source of protein.

The fishery resources of the oceans were long thought to be boundless and the fertility of fishes to render them impervious to human depredation. Thomas Henry Huxley, the pre-eminent Victorian naturalist wrote in 1884 '… the cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea-fisheries, are inexhaustible; that is to say that nothing we do seriously affects the number of fish … given our present mode of fishing. And any attempt to regulate these fisheries consequently … seems to be useless'. Although Huxley qualified his remarks and limited them to the harvesting methods of his day and to ocean fisheries, the paradigm of inexhaustibility was broadly accepted, shaping the attitudes of fishers, scientists, managers, and politicians and complicating efforts to establish effective restrictions on fishing activities. Experimental studies of the effects of fishing on marine populations were conducted in Scotland as early as 1886. In a decade-long study, areas open and closed to fishing were compared, demonstrating that harvesting did result in declines in the abundance and average size of exploited fishes. However, the results were deemed controversial and the debate concerning the impact of fishing on marine populations continued through the middle of the twentieth century. By the second half of the last century with the development of large-scale industrial fisheries and distant-water fleets, it was abundantly clear that humans have the capacity to outstrip the production capacity of exploited marine populations, resulting in resource depletion and loss in yield.

In contrast to the long history of human harvest of the oceans, scientific endeavors in support of resource management (and the understanding of underlying basic ecological principles) are comparatively recent. Indeed, the term ecology (oecologie) itself was not coined until 1867, while written records of large-scale marine fisheries pre-date this landmark by several centuries. In many instances, fish and shellfish populations had already been substantially altered by fishing before the development of a scientific framework within which to evaluate these changes and true baseline conditions can only be inferred.

Because of their economic value and the scales over which fisheries operate, institutions dedicated to monitoring fisheries and resource species and providing scientific advice in support of management have been established. In western countries, many of these institutions were formed in the late nineteenth and early twentieth centuries. For example, the US Fish Commission was established in 1871 in response to concerns over declines in coastal fishery resources at that time. The Fishery Board of Scotland was established in 1883 and the International Council for Exploration of the Sea followed in 1902. These institutions and others such as the Marine Biological Association of the UK, established in 1884, approached the problem of understanding fluctuations of exploited fish and shellfish species from a broad scientific perspective, including consideration of the physical and biological environments of the organisms. Spencer Fullerton Baird, first US Commissioner of Fisheries wrote in 1872 that studies of fish '… would not be complete without a thorough knowledge of their associates in the sea, especially of such as prey upon them or constitute their food'. Baird further noted with respect to the importance of understanding the physical setting in the ocean that '… the temperature taken at different depths, its varying transparency, density, chemical composition, percentage of saline matter, its surface- and under-currents, and other features of its physical condition ... throw more or less light on the agencies which exercise and influence upon the presence or absence of particular fishes'. This broad multidisciplinary perspective remains an important component of fisheries investigations today, where the importance of an ecosystem perspective has been re-emphasized and efforts to understand the potential impact of climate change on fishery resources has assumed high priority.

Initial attempts to estimate the production potential of the seas based on a consideration of energy flow and transfer in marine systems indicated that the coastal ocean could sustain yields of approximately 100 million tons of fish and shellfish on a global basis. Subsequent estimates including the deep ocean basins and expansion to other species suggested higher levels of production. Within the last decade and a half, the yield from marine systems has approached the 100 million tonne level. Globally, 4% of the stocks for which information is available are estimated as having some capacity for increased harvest, 21% are moderately exploited, 47% are classified as fully exploited, 27% as overexploited or depleted, and 1% are listed as recovering (*see* **Marine Fishery Resources, Global State of**). It is clear that we are at or near the limits of production for many exploited populations and have exceeded sustainable levels for many others. Improved management does hold the promise of increasing production potential in overexploited and depleted populations, while carefully controlled increases in exploitation of currently underutilized species may also result in some increase in yield. As noted above, the pressures on fishery resources on a global basis are deeply interwoven with stresses related to increases in human population size and the resulting increased demand for protein from the sea. Furthermore, the recent emphasis on the health benefits of seafood consumption has resulted in increases in per capita consumption of fish in many western countries that traditionally had comparatively low consumption levels.

Fishing and Fishery Resources

The articles concerning fishery resources in this encyclopedia document the broad spectrum of species taken and modes of capture in fisheries throughout the world. The descriptions of fisheries for the species groups summarized in these articles are linked to the overviews of their biological and ecological features elsewhere in the encyclopedia. In this section, reviews are provided for major species groups supporting important fisheries. These reviews cover small-bodied fishes inhabiting the open water column (small pelagic fishes), larger-bodied pelagic fishes, near bottom organisms (demersal species), salmon, and shellfish (including crustaceans and mollusks). Regions (and associated species) requiring special consideration such as the vulnerable Antarctic marine ecosystem(s), coral reef habitats, and open-ocean deep-water habitats are accorded separate treatment. In addition, articles dealing with a number of overarching issues are included to provide a broader context for understanding the importance of fisheries to society and their impacts on natural systems. An overview of fishing methods and techniques employed throughout the world is provided, as are review articles on the global status of marine fishery resources, factors controlling the dynamics of exploited marine species, harvesting multiple species assemblages, and the ecosystem effects of fishing. Key considerations in the management of marine resources are documented and the intersection between human interests and motivations and resource management is explored.

The biological and ecological characteristics of the species sought in different fisheries and their behavioral patterns play a dominant role in harvesting methods, vulnerability to exploitation, and overall yields. The general strategies involved in fish capture include the use of entangling gears, trapping, filtering with nets, and hooking or spearing (*see* **Fishing Methods and Fishing Fleets**). Fishers use detailed information on distribution, seasonal movement patterns, and other aspects of behavior of different species in the capture process based on their experience and that of others gained over time. Recently, advances in electronic equipment ranging from sophisticated hydroacoustic fishfinders to satellite navigation systems have allowed fishers to refine their understanding of these characteristics, greatly increasing the efficiency of fishing operations and the consequent impact on fishery resources.

Small-bodied fish such as herring, mackerel, and sardines that characteristically form large schools are often taken by surrounding nets or purse seines in large quantities (*see* **Small Pelagic Species Fisheries**). These pelagic species typically inhabit mid- to near-surface water depths. Schooling behavior can increase the detectability of these species and therefore their vulnerability to capture, a problem which has resulted in overharvesting of small pelagic species in many areas. Similar considerations hold for larger-bodied pelagic fishes such as the tunas (*see* **Open Ocean Fisheries for Large Pelagic Species**). The harvesting pressure on these larger species is fueled by their high unit value and management is complicated by their extensive movements and migrations, necessitating international management protocols and agreements (*see* **Fishery Management**).

A diverse assemblage of fish typically inhabiting near-bottom or bottom waters support fisheries of long-standing importance such as the cod fisheries throughout the North Atlantic, halibut fisheries in both the Atlantic and Pacific, and many others (*see* **Demersal Species Fisheries**). The exploited demersal species exhibit a wide range of body sizes and life history characteristics that influence their response to exploitation. These species are often captured using nets dragged over the seabed, although traps, entangling nets, and other devices are also used. These fishing gears often capture many species not specifically targeted by the fishery and may also disrupt the bottom habitat and associated species. As a result, substantial concern has been expressed over both the direct and indirect effects of bottom-fishing practices with respect to alterations of food web structure and disturbance to critical habitat (*see* **Multispecies Fisheries Dynamics** and **Ecosystem Effects of Fishing**).

Species such as Atlantic and Pacific salmon spawn in fresh water but spend a substantial part of their life cycle in the marine environment (*see* **Salmon Fisheries:** Atlantic and **Salmon Fisheries:** Pacific). These species are potentially affected not only by harvesting but the effects of land and fresh water use practices affecting the part of the life cycle occurring in fresh water. Damming of rivers, deforestation, pollution, and overharvesting have all resulted in declines in these species in some areas. Salmon exhibit strong homing instincts and typically return to their natal river system to breed. The concentration of fish as they return to river systems and in the rivers and lakes themselves makes these species particularly vulnerable to capture. Pacific salmon differ considerably from most other fish species that support important fisheries in that they die after spawning once and it is essential that a sufficient number of adults escape the capture process to replenish the population. Artificial enhancement through hatchery programs has been very widely employed for salmon stocks in an attempt to maintain viable populations (*see* **Fishery Manipulation through Stock Enhancement or Restoration**). although concerns have been raised about effects on the genetic structure of natural stocks and the possibility of transmission of diseases from hatchery stocks.

Fisheries for shellfishes, including those for lobsters, crabs, and shrimp (*see* **Crustacean Fisheries**) and for clams, snails, and squids (as well as other cephalopods; *see* **Molluskan Fisheries**) are among the most lucrative in the world. Mollusks also are taken for uses other than food such as the ornamental trade in shells. Most shellfish live immediately on or near the seabed and are harvested by traps (lobsters, crabs, some cephalopods such as octopus, and some snails such as whelks), towed nets (e.g. shrimps, squid), and dredges (oysters, clams, etc.) among other devices. The ready availability of some types of shellfish in intertidal habitats has resulted in a very long history of exploitation by coastal peoples and a continuing importance for both commercial and recreational harvesters using very simple implements. The often high unit value of shellfish has meant that aquaculture is economically feasible to supplement harvesting of natural populations.

Fisheries prosecuted in some habitats and environments require special considerations. For example, in the waters off Antarctica the need to protect the potentially vulnerable food web, encompassing endangered and threatened marine mammal populations, has led to the development of an ecosystem-based approach to management that is unique (*see* **Southern Ocean Fisheries**). Harvesting of krill populations, a preferred prey of a number of whale, seal, and sea bird populations, is regulated with specific recognition of the need to avoid disruption of the food web and impacts on these predators. In coral reef systems, the very high diversity of species found and the sensitivity of the habitat to disruption has highlighted the need for an ecosystem approach to management in these systems (*see* **Coral Reef and Tropical Species Fisheries**). Growing concern over destructive fishing practices using toxins and explosives has highlighted the need for effective management in these areas. In deepwater habitats, many of the species exhibit life history characteristics such as slow growth and delayed maturation that make them particularly vulnerable to exploitation (*see* **Open Ocean Fisheries for Deepwater Species**). The vulnerability of deep-sea habitats to disturbance by fishing gear is also a dominant concern in these environments.

Issues in Fishery Management

Fishery management necessarily entails consideration of resource conservation, the economic implications of alternative management strategies, and the social context within which management decisions are effected (*see* **Fishery Management**). The relative weights assigned to these diverse considerations can vary substantially in different settings, resulting in very different management decisions and outcomes. The setting of conservation standards is tied directly to understanding of basic life history characteristics such as the rate of reproduction at low population levels, growth characteristics, and factors affecting the survivorship from the early life stages to the age or size of vulnerability to the fishery (*see* **Dynamics of Exploited Marine Fishery Populations**). The choice of particular harvesting strategies and levels holds both economic and social implications. Fishery management is ultimately a political process and decisions concerning allocation of fishery resources often engender intense debates as noted in **Fishery Management, Human Dimension**). These debates are often set within the context of differing perspectives on fishing rights and privileges. In many societies, fishing is viewed as a basic right open to all citizens and fishery resources are often viewed as a form of common property.

Formal designation of fishery resources as *res nullia* (things owned by no one) can be traced to Roman law where ownership was conferred by the process of capture. Traditions of open access to fishery resources in many western countries persist and remain a principal factor in the global escalation of fishing pressure. This legacy has led to excess capacity and overcapitalization of world fishing fleets, resulting in conflicts between conservation requirements and the social and short-term economic impacts of implementing rational and effective management. Gareth Harding's influential statement of the 'Tragedy of the Commons' – a resource owned by no one is cared for by no one – has been applied to fishery resources and further honed to reflect considerations of the importance of well defined property rights and attendant responsibilities in natural resource management. Today this issue remains at the heart of many problems in resource management.

Failures in fishery management can often be traced to conflicting goals and objectives in the conservation, economic, and social dimensions. For example, the needs for conservation can be compromised by desires to maintain full employment opportunities in the fishing industry if this leads to political pressure to permit high harvest levels. In the longer term, actions taken to ensure the sustainability of fishery systems also ensure the viability of the industries dependent on these resources. However, the short-term impacts (or perceived impacts) of fisheries regulations on fishers and fishing communities are often dominant considerations in whether particular regulations will be put in place.

Emerging Issues in Fisheries and Fisheries Science

Although substantial research efforts have been directed toward understanding the broader ecological setting within which fisheries are conducted, management has been traditionally implemented on a species by species basis. The global escalation in fishing pressure and recognition of the potential environmental impacts of fishing activities have led to increased interest in and emphasis on ecosystem-based management. Ecosystem-based management seeks to ensure the preservation of ecosystem composition, structure, and function based on an understanding of ecological interactions and processes required for ecosystem integrity. As noted above, ecosystem principles guide the management of marine resources off Antarctica (*see* **Southern Ocean Fisheries**) and broader application of ecosystem-based management approaches is under development in many other regions. The work entails consideration of interactions among species (*see* **Fisheries:** Multispecies Dynamics) and evaluation of effects of fishing on habitat and nontarget organisms (*see* **Ecosystem Effects of Fishing**). The interest in ecosystem-based management has led to a re-evaluation of management tools and an increased emphasis on the use of strategies such as the development of marine protected areas in which harvesting and other extractive activities are strongly controlled. Areas in which all extractive practices are banned hold the potential to reduce overall exploitation rates, protect sensitive habitats and associated biological communities, and preserve ecosystem structure and function. Used in concert with other measures that restrain fishing activities in areas open to fishing, no-take marine protected areas can be a highly effective component of ecosystem-based management strategies.

The prospect of global climate change and its implications for terrestrial and marine systems is one of the most pressing issues facing us today. The potential impacts of global climate change in the marine environment are receiving increased attention as higher resolution forecasting models are developed and oceanographic features are more fully represented in general circulation models. The projected climate impacts with respect to changes in temperature, precipitation, and wind fields hold important implications for oceanic current systems, mesoscale features such as frontal zones and eddies, stratification and thermal structure. In turn, these impacts will affect marine organisms dependent on the physical geography of the sea for dispersal in currents, the size and location of feeding and spawning grounds, and basic biological considerations such as temperature effects on metabolism. Shifts in distribution patterns of fishery resource species, changes in vital rates such as survivorship and growth, and in the structure of marine communities can be anticipated. Persistent changes in environmental conditions can affect the production characteristics of different systems and the production potential of individual species (*see* **Fisheries and Climate**). In particular, a shift in environmental states can interact synergistically with fishing pressure to destabilize an exploited population. Exploitation rates that are sustainable under a favorable environmental regime may not remain so if a shift to less favorable conditions occurs (*see* **Dynamics of Exploited Marine Fish Populations**).

Large-scale research programs such as the Global Ocean Ecosystem Dynamics (GLOBEC) Program have now been implemented throughout the world to assess the potential effects of global climate change on marine ecosystems, including impacts on resource species.

Collectively, the problems of overexploitation, habitat loss and degradation, alteration of ecosystem structure, and environmental change caused by human activities point to the need to fully consider humans as part of the ecosystem and not somehow apart and to manage accordingly. Wisely managed, fisheries can continue to meet important human needs for food resources from the sea and our obligations to future generations can be met.

See also

Coral Reef and Other Tropical Fisheries. Crustacean Fisheries. Demersal Species Fisheries. Marine Fishery Resources, Global State of. Molluskan Fisheries. Open Ocean Fisheries for Deep Water Species. Open Ocean Fisheries for Large Pelagic Species. Salmon Fisheries: Atlantic. Salmon Fisheries: Pacific. Seabirds and Fisheries Interaction. Small Pelagic Species Fisheries. Southern Ocean Fisheries.

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FISHERY MANAGEMENT

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The world's fisheries are significant from many perspectives: biological, economic, cultural, and political. Fisheries may be measured in terms of biological yield; economic returns and contributions to economic value, income and jobs; production of food; cultural dependence; recreation; relationship to the ecosystem and the environment; and domestic and international trade.

Total fisheries production is reviewed elsewhere in this volume (*see* **Marine Fishery Resources, Global State of**). The focus of this article is not on the fisheries themselves or the production from them, but rather the institutions of fisheries management. A broad definition of fisheries management will be used – a set of rules that govern who can fish and how fishing is conducted. Fishery management cuts across all the perspectives mentioned above and provides the bridge to human governance of fishery harvesting and processing.

An understanding of fisheries management is useful in interpreting trends in production, and changes in fleets, revenue, jobs, and income. More importantly, however it is largely the actions of fishery managers that will determine the dynamics and likely future of the world's fisheries.

Introduction

Fisheries management is based on a number of goals. In general, managers seek to maximize long-term production from the fishery. Foremost among the formal concepts of management is the principle of maximum sustainable yield (MSY). MSY is derived from the fact that increasing application of effort will result in increasing catch (yield) up to a point at which additional effort will lead to decreased stock size and, subsequently, reductions in total yield.

It's not only important to maximize total sustainable production, however. Managers should also seek to maximize the total value of fisheries. This brings into consideration economic returns, costs, and profitability; social and cultural considerations such as jobs, income and preserving a way of life; and the value of the resource as food, the focus of recreational activity, etc. Maximizing the value of the fishery, however measured, is known as managing for optimum yield (OY). Again management systems around the world tend to manage for Optimum Yield, either directly or indirectly.