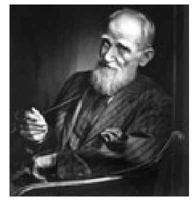
FISH and FISHERIES

FISH and FISHERIES, 2008, **9**, 316–327

Ghoti

Ghoti papers



Ghoti aims to serve as a forum for stimulating and pertinent ideas. Ghoti publishes succinct commentary and opinion that addresses important areas in fish and fisheries science. Ghoti contributions will be innovative and have a perspective that may lead to fresh and productive insight of concepts, issues and research agendas. All Ghoti contributions will be selected by the editors and peer reviewed.

Etymology of Ghoti

George Bernard Shaw (1856-1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

Consilience in fisheries science

Andrea Sáenz-Arroyo[1,2] *& Callum M Roberts*[2]

[1]Comunidad y Biodiversidad A.C., Boulevard Agua Marina # 297, Colonia Delicias C.P. 85420, Guaymas, Sonora, México; [2]Environment Department, University of York, York YO10 5DD, UK

Abstract

The failure of fisheries science to preserve life in the oceans is broadly recognized. Here, we argue that part of this failure is the result of the philosophical basis behind fisheries science. In the middle of the 20th century, synthesizing more than half a century of insights dealing with what they called the 'overfishing problem', British scholars gave birth to some of the first predictive fishery management tools. Although novel for their time, the main objective of the approach was to advise the fishing industry on how to maximize the exploitation of fish resources without jeopardizing the viability of fish populations. Half a century on from these first attempts, we need a wider historical perspective to understand species dynamics, both natural and anthropogenic. We are also aware that there are other benefits society obtains from the ocean than maximum sustainable catches and we need to understand the role of biodiversity in social welfare. Not only should fishing be regarded as an economic activity but also as a planetary-scale human experiment that requires experimental controls for a continuous evaluation of its performance and effects. Here, we present a philosophical approach to the problem, synthesizing material from the different disciplines that we consider should be addressed. A mix of insights may best help to deal with the 'overfishing problem.'

Keywords Ecosystem management, historical ecology, human ecology, philosophy of science

Correspondence:
Andrea Sáenz-Arroyo, Comunidad y Biodiversidad A.C., Boulevard Agua Marina # 297, Colonia Delicias C.P. 85420, Guaymas, Sonora, México
Tel.: 52 (622) 22 449 88
Fax: 52 (622) 22 24990
E-mail: asaenz@cobi.org.mx

Received 13 Nov 2007
Accepted 8 Feb 2008

Introduction

The sea is the only territory where humans still globally behave as hunter-gatherers. Using the most modern 21st century technology, fishers still go to the ocean with the same purposes, as our ancestors thousands of years ago: to hunt and bring food back home. The spectrum of technology employed for fishing ranges from the most sophisticated methods, such as those employed by the Australian deep-sea trawlers, to the traditional harpoons deployed from kayaks by Inuits for centuries in Greenland and that are still used today. Over time, this range of hunting activities has deeply transformed the marine environment and continues to do so today at an accelerating rate (Pauly *et al.* 1998; Hamilton 2001; Jackson *et al.* 2001; Pitcher 2001; Ruttenberg 2001; Baum *et al.* 2003; Christensen *et al.* 2003; Myers and Worm 2003; Pandolfi *et al.* 2003; Baum and Myers 2004; Sáenz-Arroyo *et al.* 2005a,b; Essington *et al.* 2006; Saenz-Arroyo *et al.* 2006). Our power to transform the sea has, however, increased exponentially over the last century, offering a unique opportunity to understand human effects on wild environments. While massive hunting on land occurred over thousands of years, its parallel in the sea began just a few centuries ago.

The collapse of commercial fish resources and the profound environmental transformations as a result of human hunting everywhere on the planet is no longer a topic of debate. Twentieth century fisheries' ecological crashes have become the rule instead of the exception. Tony Pitcher (2001) illustrates the dimension of fisheries management failures by saying that 'if this were engineering and we were dealing with bridge collapses, materials and methods would have been questioned long ago.' Here, we argue that one of the main reasons why fisheries science has had such evident failures is that we treat it as a single discipline aimed at answering specific questions. Instead, since its objective is to provide information to support decision-making towards the different alternatives we have for benefiting from ocean resources, it might not be seen as a unique discipline but as the need for a synthesis of knowledge.

Although not new in the fisheries-science argot (Cury and Cayre 2001; Pauly 2002), consilience, a word revived by Edward Wilson (1998) that calls for the unity of knowledge, might help craft a modern design of fisheries science. Consilience is defined by the psychologist and philosopher Steven Pinker (1998) in a very nice way 'literally jumping together, means the linking of facts and theory across disciplines into a single coherent system of explanation.' As Pinker states, although it can sound innocuous, it has a radical implication: 'that the divisions between nature and society, matter and mind, biology and culture, science and the humanities, arts and social sciences are obsolete.'

Major scientific advances are often the result of convergence among traditionally distinct disciplines. An extraordinary example used by Daniel Pauly (2002) to show the power of consilience is the insight used by a nuclear scientist, his geologist son and two chemists to the history of life on the planet (Alvarez *et al.* 1980). The team discovered the presence of extraterrestrial material in deep-sea limestone from Italy, Denmark and New Zealand and maintained that the Cretaceous/Tertiary mass extinction that took place 65 million years ago was the result of a large asteroid impact on earth (Alvarez *et al.* 1980). Their hypothesis suggested that the impact would have produced such a dust layer in the earth's atmosphere that photosynthetic processes were suppressed affecting entire ecosystems and eliminating, among other creatures, dinosaurs. Their perspective, later corroborated by other findings, offered a unique insight to improve our understanding of mass extinctions, a subject of great relevance today (Gould 2000).

This essay describes the disciplines and type of knowledge that might be tapped into to produce a better understanding of the role and effects of human hunting in the world's oceans. In doing so, we hope our synthesis could help us build a science able to advise society on the different alternatives and possible consequences of transforming the marine environments (Fig. 1). We suggest combining disciplines to construct a gentler, humbler and hopefully more successful scientific approach to deal with a difficult issue identified almost a 100 years ago by our peers: 'the overfishing problem.'

The history of fisheries science

Mid-20th century marine scientists observed that as a result of fishing being prevented in European waters during the war years (1939–45), fish populations rebounded. They also recognized that within a few years of the resumption of fishing, over-exploitation rapidly became evident, as it had carried out after the First World War hiatus (Beverton and Holt 1954/1991). Aiming to counter this problem, Beverton and Holt (1954/1991)

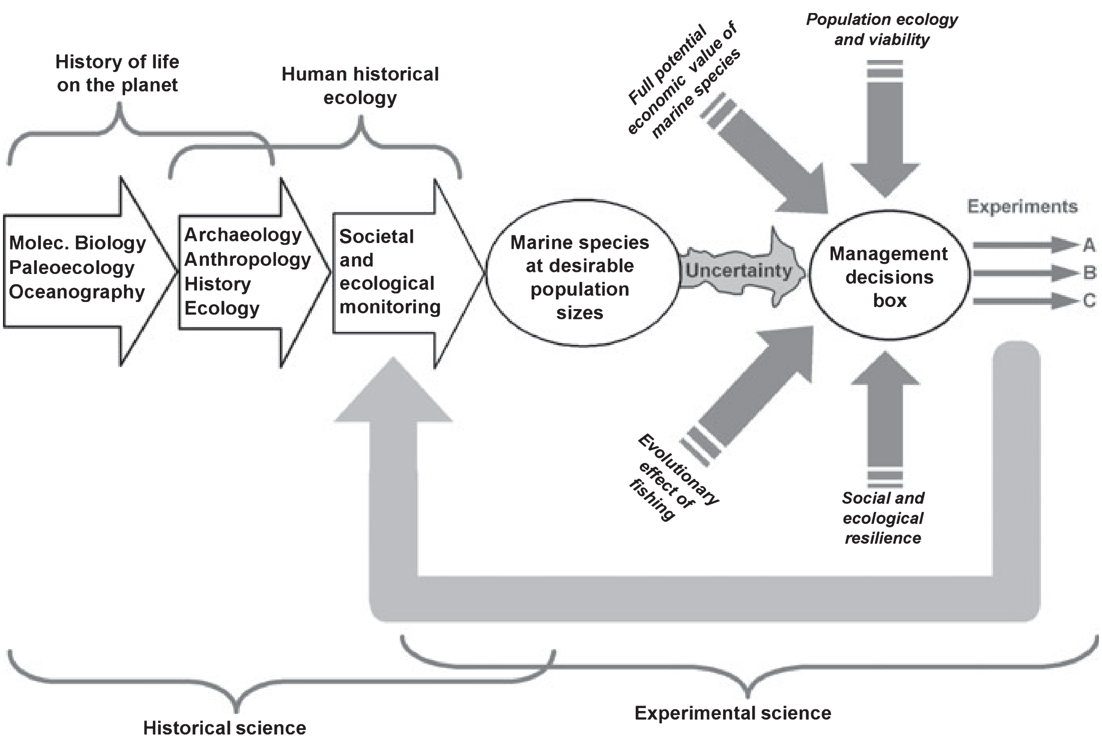


Figure 1 Different disciplines are needed to understand historical fluctuations of marine species. Society places different values on marine populations and each requires different fixed population sizes to optimize that objective. Designed management strategies (e.g. A, B, C) should be regarded as experiments to be continuously evaluated from different social and ecological points of views.

developed their famous work 'On the Dynamics of Exploited Fish Populations.' Their work was inspired by a fashionable post-war research method called 'operational research' (Goodeve 1948). Operational research was defined as 'a scientific method providing executive departments with a quantitative basis for decisions regarding the operations under their control' (Goodeve 1948). This method, motivated by tactics employed by war strategists, was a well-organized process to design models on how phenomena might behave using the best available data on past trends. As with today's models, these models were founded on periodical statistical observations of any phenomena's behaviour under different quantities of a defined variable. Operational research, as its author Sir Charles Goodeve (1948) described, was intended to deal with different branches of industry, from traffic to productivity to any type of technical problem. It is well described by a paragraph used as an epigraph by Beverton and Holt (1957/1993) '…one of the most common methods of operational research involves the setting up of one or more possible imaginary models, studying their expected characteristics and seeing which fits the data best.'

Beverton and Holt's work was an adaptation of this scientific method to deal with the different possibilities for confronting the overfishing problem. They recognized that much of the difficulty faced in managing wildlife populations was the lack of systems able to predict the possible effects of decisions before they were taken. In their view, the problem was that at the time, understanding the dynamics of wildlife populations was based on empirically isolated observations. Introducing some fundaments of their work in 1954, they wrote 'Southern (1948) has remarked that the blunders which man has made in the field of biological control can only be eliminated by a shift from hasty empirical methods to an attack on first principles…and like him, we have placed much emphasis on the fundamental study of populations in a steady state' (Beverton and Holt 1954/1991). By studying fish populations under fishing pressure and without fishing pressure during the world wars they identified parameters inherent to each species (growth, natural mortality, fishing mortality and recruitment) and modelled how each population might respond to different amounts of fishing pressure. Populations were treated by Beverton and Holt as independent entities, and biological processes reduced to their simplest fundaments to achieve tractable calculations in a world without computers.

Although Beverton and Holt's spirit was appropriate for their time, in a further half-century of scientific development we have amassed sufficient knowledge and experience to take fishery science to another stage. We now know that wildlife population dynamics in the marine realm are more complex than we can predict with the insights from short-term series data. We are beginning to understand that if suitable historical baselines are not properly addressed we run the risk of understanding only the dynamics of species at just a fraction of their original numbers (Pauly 1995; Baum *et al.* 2003; Myers and Worm 2003; Baum and Myers 2004; Sáenz-Arroyo *et al.* 2005a,b). We are also aware today that the effects of climate variation on wild populations are larger than formerly considered (Benson and Trites 2002; Chavez *et al.* 2003; Perry *et al.* 2005; Behrenfeld *et al.* 2006), and that human influences on marine food webs and ecosystem structure extend wider than previously thought (Pauly *et al.* 1998; Worm *et al.* 2006; Myers *et al.* 2007), potentially affecting aspects of ecological function that go far beyond the interests of conventional fisheries management. By now we also know that the decision-making process regarding how human actions might influence wildlife populations should not just consider the single objective of sustaining catches by the fishing industry. Instead, fisheries science should address objectives related to ecological functions of species (Daily 2000; Jackson *et al.* 2001; Frank *et al.* 2005; Myers *et al.* 2007) and the wide range of ecosystem services and benefits society receives from nature (Daily 1997, 2000; Worm *et al.* 2006). Without this interdisciplinary and broader definition of the goals of fisheries science, we run the risk of continuing to observe serial management failures and witnessing societal frustration at the rapid loss of qualities, they value within the marine environment.

An ever-changing variety of life

Unlike the idea of fixed wallpaper providing the background to human life, biological diversity has always changed and will continuously change. It is, as defined by botanist Sandra Knaap (2003), 'an exciting ever-evolving variety of life.' Long before humans, climate, ecological and evolutionary forces shaped species' communities for at least four billion years (Gould 2000). In the last 100 000 years, and particularly since the Holocene, humans have joined environmental influences as some of the strongest forces that shape diversity on the planet (Martin and Wright 1967; Roberts 1998; Jackson *et al.* 2001). Separating the results of human actions from environmental fluctuations or determining how both forces blend together have been some of the trickiest challenges faced by environmental scholars. In fact, the vigorous debates on the causes of terrestrial megafaunal extinctions over the last 50 000 years or so, still ongoing, are based on the difficulty of separating these forces (Martin and Wright 1967; Jones 1995; Flannery 1999; Miller *et al.* 1999).

Different disciplines help us understand that marine communities were in the past and are still in the present profoundly influenced by environmental fluctuations. For example, paleoceanographic studies of past fish abundances revealed that fish populations, especially pelagic species, are extremely sensitive to environmental fluctuations (Finney *et al.* 2002). In the eastern Pacific, climate variations have driven populations of sardines, anchovies, salmon, Pacific herring and Pacific hake to clear multi-century abundance shifts in the last 2200 years (Finney *et al.* 2002). For example, from the third to the 13th century, sardines and anchovies were much more abundant in Alaska, California and the Gulf of California than they were from the 13th to the 19th century (Finney *et al.* 2002). Studies also demonstrate that pelagic species that compete for food resources show cyclical ups and downs over shorter time periods (Holmegren-Urba and Baumgartner 1993). The surprising appearance of the anchovy (*Engraulis mordax*, Engraulidae) in the central Gulf of California fisheries and the parallel collapse of the sardine (*Sardinops sagax*, Clupeidae) population during the 1980s, motivated researchers to explore the marine sediments for past abundances of both species (Holmegren-Urba and Baumgartner 1993). By looking at the scale deposition on the ocean floor they found that, although the anchovy was recently thought to be a species more restricted to temperate ecosystems, it did have an earlier peak of abundance in the Gulf of California in the mid-19th century. This was a period when sardine populations were coincidently very low. The same has been observed in a broader spatial scale and shorter time scale in the Pacific Ocean (Chavez *et al.* 2003). While the anchovy dominated the 1960's Peruvian catches it suddenly collapsed by the early 1970s. Simultaneous to this collapse, the sardine became more important until it collapsed again by the early 1980s when the anchovy started recovering (Chavez *et al.* 2003). Researchers explained these variations as resulting from warmer and cooler periods: the anchovy thrive in cooler periods, the sardine in warmer ones. Climate studies have improved our understanding of environmental variability in shaping marine communities enormously in the last few years (Perry *et al.* 2005; Behrenfeld *et al.* 2006; Doney 2006; Harley *et al.* 2006). For example, a recent study looked at the demersal community of the North Sea and found that half of the species studied shifted their boundaries northwards as the temperature increased (Perry *et al.* 2005). The analysis illustrated that when the temperature rises, fast-growing species with shorter-life cycles showed more adaptability to colder environments than large, slow-growing species (Perry *et al.* 2005).

Recent findings also suggest that human induced climate change has larger effects than those commonly thought and described above. For example, a recent review argues that increasing human emissions of CO_2 will acidify the world's oceans, and in turn decreasing minerals such as aragonite and calcite that are essential for calcifying organisms (Harley *et al.* 2006). If correct, this scenario might bring about dramatic consequences for the recruitment of species of interest for fisheries such as clams and reef builders like oysters and coral reefs. Furthermore, it could undermine ocean food webs by affecting the growth of plankton. A recent study also reveals global evidence that ocean productivity has shown an alarmingly declining trend since 1999 (Behrenfeld *et al.* 2006). According to this study, the oceans' algae contribute to roughly half of the planet's total CO_2 sequestration. If this trend continues, diminishing ocean phytoplankton productivity will not just reduce carbon sequestration but will affect entire fisheries' productivity (Behrenfeld *et al.* 2006). Evidence from the north Pacific, particularly in temperate systems, shows a clear link between ocean productivity and fisheries' production (Ware and Thomson 2005).

A strongly interacting omnivorous species

The sterile discussion of whether or not humans play a deep role in shaping natural communities vanishes when humans are considered as elements of natural ecosystems. Humans are a widespread, adaptable species that has succeeded in almost every earth environment (Knaap 2003). A concept that sheds light on the strength of our presence in natural communities is that of species 'interaction–strengths' (Paine 1992). This concept, developed by ecologists to understand how food webs work, basically calculates the effect of one species population on another as a function of time. A strongly interacting species is that which preys on species that in turn have strong interactions with other species within the food web. Theoretical and field ecologists have found that presence/absence and abundance of these types of strong-interactors changes the shape of the community dramatically (Sala and Graham 2002; Bascompte *et al.* 2005). For example, sharks account for 48% of the strength of interaction in the whole community in a coral reef (Bascompte *et al.* 2005). In temperate Pacific kelp forests, even small herbivores have been discovered to control 28% of the recruitment of the large seaweed Macrocystis (*Macrocystis pyrifera*, Phaeophyceae) (Sala and Graham 2002).

Evidence from archaeological and historical studies shows that human societies strongly influenced coastal seascapes long ago. Marine environments, in turn, shaped their cultural habits and migration patterns. For example, archaeological studies show how even the most primitive cultures with very little means to fish were able to impact their surroundings causing wide community changes in the ecosystems (Jones 1995; Porcasi *et al.* 2000). Effects of aboriginal hunting of seals and sea lions have been well documented by archaeologists and ecologists in California and Alaska (Simenstad *et al.* 1978; Jones 1991, 1995; Porcasi *et al.* 2000). On the coast of California, for example, the exploitation of two species of sea lions (*Eumetopias jubata*, Otariidae), the Californian sea lion (*Zalophus californianus*, Otariidae) and two species of fur seals (*Callorhinus ursinus*, Otariidae and *Arctocephalus towsend*, Otariidae) were apparently so dramatic in the past that archaeologists refer to it as the 'prehistoric tragedy of the commons' (Jones 1995; Porcasi *et al.* 2000). Combining archaeological evidence with understanding of ecological attributes showed that large and protein rich species that breed on land, like sea lions and fur seals, were over-exploited in southern California in two waves, that of 6150–3970 BC and AD 1020–1400 (Porcasi *et al.* 2000). In a first wave of coastal exploitation, the large and vulnerable species appeared to be replaced by smaller species, with less parental time on land such as the harbour seal (*Phoca vitulina*, Phocidae) and the sea otter (*Enhydra lutris*, Mustelidae) in later periods. Centuries later, when ancient Californian cultures developed their watercraft, which allowed them to reach offshore islands such as San Clemente, sea lions and fur seals along with dolphins began to be exploited again in sites located close to offshore island breeding colonies (Jones 1995).

The effects of removing a keystone predator have wide ecosystem implications. For example, in Alaska ecologists point out that the removal of sea otters by early Aleutians may have promoted ecological shifts in coastal communities since prehistoric times (Simenstad *et al.* 1978). The comparison of middens' strata in Amchitka Island in the eastern north Pacific during the past 2500 years indicates a shift in the diet of the Aleutians from sea otters, harbour seals and fish in early periods (580–80 BC) to sea urchins and limpets in more recent times. By comparing modern communities with and without sea otters, the researchers concluded that past Aleutians reduced sea otter populations in ancient times, which in turn promoted a population increase in a key prey item, the sea urchin (*Strongylocentrotus polyacanthus*, Strongylocentrotidae) (Simenstad *et al.* 1978). In the absence of its predator, this invertebrate overgrazes seaweed causing loss of kelp forests (Dayton *et al.* 1995, 1998). The researchers argued that prompted by the overfishing of a strongly interacting species and not as a result of cultural changes as previously thought, Aleutians shifted their original diet to the abundant sea urchins and limpets that invaded the altered community (Simenstad *et al.* 1978).

Similar pieces of evidence can be found from archaeological research in other regions. For example, a study of fish bones up to 2000 years BP from the Caribbean revealed a shift from the ancient residents' diets of top predators in early times (mostly groupers), to a mix of species in lower trophic levels (parrotfishes, triggerfish surgeonfish and groupers) during the most recent periods (Wing and Wing 2001). In Santa Catalina Island, California, studies of coastal middens also revealed a shift from a proportion of 4:1 abalone species over mussels in the lower and older levels to an inverse proportion of 4:1 mussels over abalone in the more recent levels (Meighan 1959).

For many years, fisheries scientists have relied only on evidence from modern observations and suffer what has been called the 'shifting baseline syndrome' (Pauly 1995). The distribution of species, former numbers and ecological functions played by species in the past were inferred from only recent observations. The consequences of this syndrome are so problematic that the concept of the shifting baseline has gained much public attention (e.g. http://www.shiftingbaselines.org/news/photocont.html). To try to overcome this syndrome, a new wave of marine scientists addressing ecology from a historical perspective have shown great insight in the last years (Carlton *et al.* 1999; Jackson 2001; Jackson *et al.* 2001; Pitcher 2001; Pandolfi *et al.* 2003; Baum and Myers 2004; Lotze and Milewski 2004; Lotze 2005; Rosenberg *et al.* 2005; Sáenz-Arroyo *et al.* 2005a,b; Lotze *et al.* 2006; McClenechan *et al.* 2006; Saenz-Arroyo *et al.* 2006; Myers *et al.* 2007; Roberts 2007). Evidence from of all these studies shows that the transformation of coastal ecosystems started since early cultural periods and have expanded and deepened over time (Jackson 2001; Pandolfi *et al.* 2003; Lotze *et al.* 2006). In places with a long history of civilization such as the Mediterranean or the Adriatic, the extirpation of large vertebrates extends far beyond the Christian era (Lotze *et al.* 2006).

Compromised decisions: what god wants is not good for the devil

Up to now in cases of the depletion of the species, humans have adapted to abundance fluctuations whether these are natural or anthropogenic. In some cases, their societies collapsed and their survivors migrated to more productive environments (Porcasi *et al.* 2000; Diamond 2005). Today, we live sedentary lives while fishers explore the most remote ecosystems and deep habitats in search of seafood. Our appetite adapts and species that were regarded in the past as trash can become today's restaurant delicacies (Jacquet and Pauly 2007). This apparent adaptation gives us the illusion that technology will always provide solutions to overhunting. Fisheries science, conceived in an era of optimism when humans believed they had the power to control nature, considered overfishing problems as easily reversible. But these beliefs are illusory. In reality, what is happening is that with declining species and degrading habitats in the sea, society is losing environmental values that lacked the appropriate markets and disappeared before suitable incentives to preserve them are properly established.

The same year that Beverton and Holt published their seminal book on fisheries management in 1957, on the other side of the Atlantic Paul Sears (1954), an ecologist at Yale University argued for interdisciplinarity within ecology in his paper 'Human Ecology: A Problem in Synthesis.' In this paper, written more than half a century ago, he sharply identified one of the most fundamental problems we all face as ecologists: 'Once the ecologist expands his analysis of such phenomena as destruction of soil or native vegetation or of disturbance of the hydrologic cycle so that he sees them, not in the personal terms of foolish individuals or bad laws, but rather in terms of the basic structure and values of his society… When we as professionals learn to diagnose the total landscape, not only as the basis of our culture, but as an expression of it and to share our special knowledge as widely as we can, we need not fear that our work will be ignored and our efforts will be unappreciated' (Sears 1954). At the time, his paper made little impact, but it offers good advice for finding the path towards consilience in fisheries science.

When looking at humans as part of the planetary system there is little possibility to ignore the fact that the human population explosion has changed and is still profoundly changing the marine environment. The discussion really lies in what local, regional and global societies are losing by tolerating this transformation (Table 1). Consequently, we need decision-making tools that help us systematize the costs and benefits (whether they can be represented in monetary terms or not) of exploiting fish populations to certain levels from different social, cultural, evolutionary, economic and biological points of view (See Fig. 1). Economist Guissepe Munda *et al.* (1994) provided a possible solution to deal with these trade-offs. Recognizing that any problem related with the environment is essentially a conflictive one, he states that we should not expect to have straightforward unambiguous solutions. This means that we will always be dealing with a compromised solution that chooses a set of deliberated objectives. Consequently, he suggests, multicriteria tools are one of the best choices to evaluate decisions regarding the environment (Munda *et al.* 1994). As implied in their name, multicriteria decision tools enable the evaluation of courses of actions from different points of view (Munda *et al.* 1994).

The rapid evolution of ecological economics, a discipline that analyses human economies in the context of their dependence on natural ecosystems, shows that the elimination of a commercial fishery is not the sole economic cost to society when fish populations are over-exploited (Balmford *et al.* 2002; Worm *et al.* 2006; Table 1). When a commercial species collapses, societal impacts run from the obvious losses of employees

Table 1 Potential values of marine diversity.

Values with potential monetary significance		Values with little potential to be assessed in monetary units	
Direct use		Bequest values	Sacred and insight values
Goods	Services	Future values	
Seafood Food for humans Food for cattle Attractive places for tourism Juveniles and breeders for aquaculture Medicine Art and handcrafts Chemical products (e.g. agar) Minerals, gas, petroleum	Physical energy from winds and currents Buffer for the coastal zone from hurricanes and storms. Stable food webs. Recycling of nutrients Climate regulation	Option value Resilient ecosystems for future generations Potential undiscovered goods (medicines, new fisheries, etc.)	Local cultural and/or sacred values Insight of places free of human hunting for science development

Adapted from Costanza *et al.* (1997) and Pearce and Moran (1994).

and rural sources of income to the disappearance of cultural identity and social bonding. Meanwhile a set of complex environmental functions – still poorly understood – vanished also. An extraordinary example is the collapse of the north Atlantic cod, a fishery that shaped for centuries European meals and inspired the creation of an entire culture in eastern North America (Kurlansky 1999). Its collapse not only caused the ruin of a multi-million dollar industrial fishery, but it also caused the loss of a symbol of cultural identity for north Atlantic human communities. It also signified the ecological switch of a large ecosystem from cod-dominance to absence of this broad-spectrum predator (Frank *et al.* 2005).

Coral reefs are also a good example to illustrate the economic consequences of overfishing. While it is calculated that coral reefs generate US$220 per hectare per year of fish products annually, society harvests potential benefits from a broad range of environmental services of approximately US$6075 per hectare (Costanza *et al.* 1997). Among these services are the protection offered by reef structures to coastal villages from hurricanes or storms and their role in climate regulation. It has also been calculated that the annual income generated by recreational activities to the tourism industry is in the range of US$3000 per hectare (Costanza *et al.* 1997). However, a simple problem of overfishing might dismantle all these coral reef functions, taking with them the benefits society receives from this ecosystem. In Jamaica, for example, by the early 1970s, top predators such as groupers, snappers, jacks or even trigger fish were apparently so rare, that fishing concentrated on herbivorous fishes, and also trapped many fish below their minimum reproductive size (Hughes 1994). The artisanal fishery so reduced herbivorous populations that by the early 1980s the main species that controlled algae from overgrowing corals was the long spined sea urchin (*Diadema antillarum*, Diadematidae). However, in 1983, sea urchins suffered a mass mortality killing 99% of the population. After a subsequent hurricane that reduced coral cover, algae rapidly flourished in the absence of herbivore control, killing many of the remaining live corals illustrating how as a consequence of overfishing communities become much more vulnerable to natural fluctuations (Mumby *et al.* 2007). After the hurricane the ecosystem then rapidly shifted from 50% of coral cover to one with <5%, and from 4% benthic macroalgae to up to 92% (Hughes 1994).

Beware of the idols of the mind

Reductionism has brought great insight on how to word correctly our hypotheses. But if these hypotheses are not also suitably placed in their societal and historical context, we run the risk of making just sophisticated mistakes. The 17th century philosopher Francis Bacon, considered the father of inductive reasoning, alerted scientists to what he called the idols of the mind (Wilson 1998). His worries illustrated the faith we have placed in recent modern data without considering its historical context. Bacon's thoughts are nicely described by E.O. Wilson (1998) in Consilience: 'Beware, he said, of the idols of the mind, the fallacies into which undisciplined thinkers most easily fall. They are the real distorting prisms of human nature. Among them, idols of the tribe assume more order than exists in chaotic nature; those of the imprisoning cave, the idiosyncrasies of individual belief and passion; of the marketplace, the power of mere words to induce belief and misleading demonstrations. Stay clear of these idols, he urged, observe the world around you as it truly is, and reflect on the best means of transmitting reality as you have experienced it; put in to it every fiber of your being.'

Although mostly concerned with terrestrial ecosystems, a nice example of Bacon's idols of the mind is the publication and assaulting popularity of Bjorn Lomborg's (2001) book *The Skeptical Environmentalist*. Published for the first time in 2001, by 2003, this book was in its 11th reprint. The book claimed to use 'the best statistical information from internationally recognized research institutes' to argue that environmentalists have made selective and misleading use of scientific evidence and created 'imagined' problems. By using this evidence, Lomborg refutes one by one some of the most important statements that sustain the ecological crisis faced in the 20th century. Lomborg's views were widely used by politicians to support their case that the earth was in good shape and no action was needed to tackle some of the most evident environmental problems, including climate change (Sachs 2004). A few years after this popular book was published, little doubt remains that human induced climate variation is a fact and that it strongly threatens societal welfare (Giles 2007).

The power of statistics to lead us to the wrong conclusions can also be illustrated through several examples in fisheries: either because fleets tend to misreport their catches (Watson and Pauly 2001), because catch data is often not species specific (Dulvy *et al.* 2000), because bycatch is usually not reported (Casey and Myers 1998), or just because of a lack of historical baselines (Baum and Myers 2004; Sáenz-Arroyo *et al.* 2005a,b). The fallacy that testing a hypothesis with sophisticated techniques will result in indisputable knowledge was illustrated by the 18th century Scottish philosopher David Hume (Huxham 2000). He recognized that even testing an event millions of times did not mean that this behaviour will endure forever, illustrating his rationale with a funny example (Huxham 2000). He states that even if we test several times that flames burn our hands we have no logical grounds to state that they will always do in the future: 'Tomorrow, flames might not burn hands if the hands belong to a mystic, who can happily walk on burning coals' (Huxham 2000). More than 200 years later, concerned by the same issues, philosopher Karl Popper (1963) identified a method to deal with this problem. He recognized, as Hume did, that scientific hypotheses are sometimes difficult to accept even when we can repeatedly collect evidence in their support. He was also aware that some hypotheses, even though gaining support from multiple tests, could still be rejected, even with a solitary piece of evidence. He also states that since science is a continuous process of enlarging human knowledge, error is implicit in its nature. These three main attributes were the basis for his proposal of science as a process of falsification, by which we can recognize the difference among metaphysics and science by designing hypotheses so they are able to be rejected in the future (Popper 1963). Irrefutability, in his words, was 'not a virtue of a theory (as people often think) but a vice' (Popper 1963). He finally recognized that although some hypotheses can still not be ranked as scientific because of the difficulty of refuting them, they are still valuable since they can lead scientists to reformulate them in a manner whereby they can be easily falsified in the future (Popper 1963).

A nice example of an important hypothesis that was placed originally in a manner difficult to falsify is 'biophilia.' The hypothesis, originally coined by Erich Fromm and then described by Wilson (1984), sustained that we have a innate tendency to focus on life and lifelike processes, rooted in our origin in the African Savannas. That is why – he explains – most societies are willing to create green gardens surrounding their homes. Put in this way this hypothesis, although tremendously important was difficult to refute (we could even offer plenty of evidence to confirm it). Nevertheless, addressing the concept of culturally variable senses of sacredness and morality (Haidt 2006, 2007) and placing biophilia in the context of our love of nature, this concept can be framed as a scientific hypothesis (e.g. 21st century people from Baja California might have placed a sacred value over grey whales (*Eschrichtius robustus*, Eschrichtiidae), open to be confirmed or refuted by future scientists.

A continuous experiment

Consilience in fisheries science will occur when we fully integrate humans as part of natural ecosystems: recognizing our pervasive long-term interactive strength as an abundant omnivorous predator. Most of the recurrent queries we have in fisheries management belong to our obsessive desire to predict what will happen if we intervene in one way or another in a highly complex and largely human influenced environment. We should keep making these attempts by improving our modelling skills and methods. Nevertheless, there will probably be no more valuable insight than to test our predictions empirically through large-scale time networks of unexploited marine protected areas. These networks will provide 'experimental controls' for the large-scale experiment we are undertaking with the planetary environment through fishing, and will help us understand human impacts in an every-day more fluctuating environment. Although this approach might sound faith-based (Hilborn 2006), it is indeed just a sensible way to learn more about human influence in the sea and the social and economic consequences of 'the overfishing problem.'

In the future design of university marine science education programmes, it would be worth teaching young students the fact that humans have transformed the natural environment for millennia; that our societies are more vulnerable to climate fluctuations than we previously believed during the 20th century, and that recent scientific approaches have been shaped by some lack of understanding of the degree of human impact on natural systems. We should include guidance for young scientists on how to pick up ideas, anecdotes and arguments to tackle the overfishing problem with a broad perspective. They need to understand how little we know about the human impact on the planet and learn to combine historical information with that coming from experiments or recent social and ecological monitoring. Furthermore, they should learn to place their hypotheses in a suitable historical context. We should teach them the clear concept that societies do not lose just 'sea food' by over-exploiting natural systems. They need to address the variety of goods and services society receives from the natural ecosystem and the emotional values we all place on them. In the future, we should be much more open to construct our arguments, as Bacon advised more than four centuries ago, from a wide range of disciplines and types of knowledge, from poetry to economics, from oral tradition to physics, oceanography and chemistry, and from mathematics to social science. To work towards consilience in wildlife management disciplines and to draw our conjectures in ways that they can be falsified in the future, as the natural process of building science requires.

Acknowledgements

The authors would like to thank the Consejo Nacional de Ciencia y Tecnología – México (CONACYT) for supporting A. Sáenz-Arroyo during her postgraduate studies at the University of York. S. Menzel's help in constructing the figure and V. Perez-Cirera's comments were invaluable. We would also like to thank A. Waller for proof reading the text. The observations and art input made by the team of Fish and Fisheries' editors and by three anonymous reviewers were of great help for the final manuscript.

References

Alvarez, L.W., Alvarez, W., Asaro, F. and Michel, H.V. (1980) Extraterrestrial Cause for the Cretaceous-Tertiary Extinction. *Science* **208**, 1095–1108.

Balmford, A., Bruner, A., Cooper, P. *et al.* (2002) Economic Reasons for Conserving Wild Nature. *Science* **297**, 950–953.

Bascompte, J., Melian, C.J. and Sala, E. (2005) Interaction strength combinations and the overfishing of a marine food web. *PNAS* **102**, 5443–5447.

Baum, J.K. and Myers, R.A. (2004) Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. *Ecology Letters* **7**, 135–145.

Baum, J.K., Myers, R.A., Kehler, D.G., Worm, B., Harley, S.J. and Doherty, P.A. (2003) Collapse and conservation of shark populations in the Northwest Atlantic. *Science* **299**, 389–392.

Behrenfeld, M.J., O/'Malley, R.T., Siegel, D.A. *et al.* (2006) Climate-driven trends in contemporary ocean productivity. *Nature* **444**, 752–755.

Benson, A.J. and Trites, A.W. (2002) Ecological Effects of Regime Shifts in the Bering Sea and Eastern Pacific Ocean. *Fish and Fisheries* **3**, 95–113.

Beverton, R.J.H. and Holt, S.J. (1954/1991) *On the Dynamics of Exploited Fish Populations*. Chapman & Hall, London, 533 pp.

Beverton, R.J.H. and Holt, S.J. (1957/1993) *On the Dynamics of Exploited Fish Populations*. Chapman & Hall, London, 533 pp.

Carlton, J.A., Geller, J.B., Reaka-Kudla, M.L. and Norse, E.A. (1999) Historical Extinctions in the Sea. *Annual Review of Ecology and Systematics* **30**, 515–538.

Casey, J.M. and Myers, R.A. (1998) Near extinction of a widely distributed fish. *Science* **281**, 690–692.

Chavez, F.P., Ryan, J., Lluch-Cota, S.E. and Niquen, C.M. (2003) From anchovies to sardines and back: multidecadal change in the Pacific ocean. *Science* **299**, 217–221.

Christensen, V., Guenette, S., Heymans, J.J., Walters, C., Zeller, D. and Pauly, D. (2003) Hundred-year decline of North Atlantic predatory fish. *Fish and Fisheries* **4**, 1–24.

Costanza, R., d'Arge, R., Groot, R.D. *et al.* (1997) The value of the world's ecosystem services and the natural capital. *Nature* **387**, 253–260.

Cury, P. and Cayre, P. (2001) Hunting became a secondary activity 2000 years ago: marine fishing did the same in 2021. *Fish and Fisheries* **2**, 162–169.

Daily, G.C. (1997) *Nature's Services. Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC, 392 pp.

Daily, G.C. (2000) Management objectives for the protection of ecosystem services. *Environmental Science & Policy* **3**, 333–339.

Dayton, P.K., Thrush, S., Agardy, M.T. and Hofman, R.J. (1995) Environmental effects of marine fishing. *Aquatic Conservation-Marine and Freshwater Ecosystems* **5**, 205–232.

Dayton, P.K., Tegner, M.J., Edwards, P.B. and Raiser, K.L. (1998) Sliding baseline, ghosts and reduced expectation in kelp forest communities. *Ecological Application* **8**, 309–322.

Diamond, J. (2005) *Collapse. How Societies Choose to Fail or Survive*. Allen Lane, London, 575 pp.

Doney, S.C. (2006) Oceanography: Plankton in a warmer world. *Nature* **444**, 695–696.

Dulvy, N.K., Metcalfe, J.D., Glanville, J., Pawson, M.G. and Reynolds, J.D. (2000) Fishery stability, local extinctions and shifts in community structure in skates. *Conservation Biology* **14**, 283–293.

Essington, T.E., Beaudreau, A.H. and Wiedenmann, J. (2006) Fishing through marine food webs. *Proceedings of the National Academy of Sciences of the United States of America* **103**, 3171–3175.

Finney, B.P., Gregory-Evans, I., Douglas, M.S.V. and Smol, J.P. (2002) Fishery productivity in the northeastern Pacific Ocean over the past 2200 years. *Nature* **416**, 729–733.

Flannery, T.F. (1999) Debating extinction. *Science* **283**, 182–183.

Frank, K.T., Petrie, B., Choi, J.S. and Leggett, W.C. (2005) Trophic Cascades in a Formerly Cod-Dominated Ecosystem. *Science* **308**, 1621–1623.

Giles, J. (2007) Special report: from words to action. *Nature* **445**, 578–579.

Goodeve, C. (1948) Operational research. *Nature* **161**, 377–384.

Gould, S.J. (2000) *Wonderful Life*. Vintage, London, 347 pp.

Haidt, J. (2006) *The Happiness Hypothesis. Finding Modern Truth in Ancient Wisdom*. Basic Books, Cambridge, MA, 297 pp.

Haidt, J. (2007) The New Synthesis in Moral Psychology. *Science* **316**, 998–1002.

Hamilton, R.J. (2001) *The Role of Indigenous Knowledge in Depleting a Limited Resource. A Case Study on the Bumphead Parrotfish Bolbometopon muricatum Artisanal Fishery in Rovina Lagoon, Western Province, Solomon Islands*. Putting Fishers' Knowledge to Work, Fisheries Centre University of British Columbia, Vancouver, BC, pp.68–77.

Harley, C.D.G., Randall Hughes, A., Hultgren, K.M. *et al.* (2006) The impacts of climate change in coastal marine systems. *Nature* **9**, 228–241.

Hilborn, R. (2006) Faith-based fisheries. *Fisheries* **31**, 554–555.

Holmegren-Urba, D. and Baumgartner, T.R. (1993) A 250-year history of pelagic fish abundances from the anaerobic sediments of the central Gulf of California. *CalCOFI Reports* **34**, 60–68.

Hughes, T.P. (1994) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science* **265**, 1547–1551.

Huxham, M. (2000) Science and the search for truth. In: *Science and Environmental Decision Making* (eds M. Huxham and D. Summer). Essex Pearson Education, Prentice Hall, pp. 1–32.

Jackson, J.B.C. (2001) What was natural in the coastal oceans? *Proceedings of National Academy of Science* **98**, 5411–5418.

Jackson, J.B.C., Kirby, M.X., Berger, W.H. *et al.* (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629–637.

Jacquet, J.L. and Pauly, D. (2007) The rise of seafood awareness campaigns in an era of collapsing fisheries. *Marine Policy* **31**, 308–313.

Jones, T.L. (1991) Marine-resource value and the priority of coastal settlement: a California perspective. *American Antiquity* **56**, 419–443.

Jones, T.L. (1995) Reasserting a prehistoric tragedy of the commons: reply to Lyman. *Journal of Anthropological Archaeology* **14**, 78–98.

Knaap, S. (2003) Dynamic diversity. *Nature* **422**, 475.

Kurlansky, M. (1999) *Cod. A Biography of the Fish that Changed the World*. Vintage, London.

Lomborg, B. (2001) *The Skeptical Environmentalist. Measuring the Real State of the World*. Cambridge University Press, Cambridge, 515 pp.

Lotze, H.K. (2005) Radical changes in the Wadden Sea fauna and flora over the last 2,000 years. *Helgoland Marine Research* **59**, 71–83.

Lotze, H.K. and Milewski, I. (2004) Two centuries of multiple human impacts and successive changes in a North Atlantic food web. *Ecological Applications* **14**, 1428–1447.

Lotze, H.K., Lenihan, H.S., Bourque, B.J. *et al.* (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* **312**, 1806–1809.

Martin, P.S. and Wright, H.E. (1967) *Pleistocene Extinctions. The Search for a Cause*. Yale University Press, New Haven and London, 441 pp.

McClenechan, L., Jackson, J.B. and Newman, M.J. (2006) Conservation implications of historic sea turtle nesting beach loss. *Frontiers in Ecology and the Environment* **4**, 290–296.

Meighan, C.W. (1959) The little harbor site, Catalina Island: an example of ecological interpretation in archaeology. *American Antiquity* **24**, 383–405.

Miller, G.H., Magee, J.W., Johnson, B.J., Fogel, M.L., Spooner, N.A., McCulloch, M.T. and Ayliffe, L.K. (1999) Pleistocene extinction of Genyornis newtoni: human impact on Australian megafauna. *Science* **283**, 205–208.

Mumby, P.J., Hastings, A. and Edwards, H.J. (2007) Thresholds and the resilience of Caribbean coral reefs. *Nature* **450**, 98–101.

Munda, G., Nijkamp, P. and Rietveld, P. (1994) Qualitative multicriteria evaluation for environmental management. *Ecological Economics* **10**, 97–112.

Myers, R.A. and Worm, B. (2003) Rapid Worldwide depletion of predatory fish communities. *Nature* **423**, 280–283.

Myers, R.A., Baum, J.K., Shepherd, T.D., Powers, S.P. and Peterson, C.H. (2007) Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science* **315**, 1846–1850.

Paine, R.T. (1992) Food-web analysis through field measurement of per capita interaction strength. *Nature* **355**, 73–75.

Pandolfi, J.M., Bradbury, R.H., Sala, E. *et al.* (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science* **301**, 955–958.

Pauly, D. (1995) Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution* **10**, 430.

Pauly, D. (2002) Consilience in oceanographic and fishery research: a concept and some digressions. In: *The Gulf of Guinea Large Marine Ecosystem* (eds P.C.J.M. McGlade, K.A. Koranteng and N.J. Hardman-Mountford). Elsevier Science, Amsterdam, pp. 41–46.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. and Torres, F. (1998) Fishing down marine food webs. *Science* **279**, 860–863.

Pearce, D. and Moran, D. (1994) *The Economic Value of Biodiversity*. World Conservation Union (IUCN), Gland, Switzerland. Biodiversity Programme, 172 pp.

Perry, A.L., Low, P.J., Ellis, J.R. and Reynolds, J.D. (2005) Climate change and distribution shifts in marine fishes. *Science* **308**, 1912–1915.

Pinker, S. (1998) The theory of everything. E.O. Wilson explains how all knowledge fits together. *Slate Magazine* **2004**. http://slate.msn.com/id/3057/.

Pitcher, T.J. (2001) Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. *Ecological Applications* **11**, 601–607.

Popper, K. (1963) *Science as Falsification. Conjectures and Refutations*. Routledge and Keagan Paul, London and New York, pp. 33–39.

Porcasi, J.F., Jones, T.L. and Raab, L.M. (2000) Trans - Holocene marine mammal exploitation on Clemente Island, California: a tragedy of the commons revisited. *Journal of Anthropological Archaeology* **19**, 200–220.

Roberts, N. (1998) *The Holocene, an Environmental History*. Blackwell Publisher Inc, Oxford, 315 pp.

Roberts, C. (2007) *The Unnatural History of the Sea*. Shearwater Books, Washington, 435 pp.

Rosenberg, A.A., Bolster, W.J., Alexander, K.E., Leavenworth, W.B., Cooper, A.B. and McKenzie, M.G. (2005) The history of ocean resources: modeling cod biomass using historical records. *Frontiers in Ecology and the Environment* **3**, 84–90.

Ruttenberg, B.I. (2001) Effects of artisanal fishing on marine communities in the Galapagos Islands. *Conservation Biology* **15**, 1691–1699.

Sachs, J.D. (2004) Seeking a global solution. *Nature* **430**, 725–726.

Saenz-Arroyo, A., Roberts, C.M., Torre, J., Carino-Olvera, M. and Hawkins, J.P. (2006) The value of evidence about past abundance: marine fauna of the Gulf of California through the eyes of 16th to 19th century travellers. *Fish and Fisheries* **7**, 128–146.

Sáenz-Arroyo, A., Roberts, C.M., Torre, J. and Cariño-Olvera, M.M. (2005a) Fishers' anecdotes, naturalists' observations and grey reports to reassess marine species at risk: the case of the Gulf grouper in Gulf of California, México. *Fish and Fisheries* **6**, 121–133.

Sáenz-Arroyo, A., Roberts, C.M., Torre, J., Cariño-Olvera, M.M. and Enríquez-Andrade, R. (2005b) Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society of London Series B-Biological Sciences* **272**, 1957–1962.

Sala, E. and Graham, M.H. (2002) Community-wide distribution of predator-prey interaction strength in kelp forests. *PNAS* **99**, 3678–3683.

Sears, P.B. (1954) Human ecology: a problem in synthesis. *Science* **120**, 959–963.

Simenstad, C.A., Estes, J.A. and Kenyon, K.W. (1978) Aleuts, sea otters and alternate stable-state communities. *Science* **200**, 403–411.

Ware, D.M. and Thomson, R.E. (2005) Bottom-up ecosystem trophic dynamics determine fish production in the northeast Pacific. *Science* **308**, 1280–1284.

Watson, R. and Pauly, D. (2001) Systematic distortion in world fisheries catch trends. *Nature* **414**, 534–536.

Wilson, E.O. (1984) *Biophilia: The Human Bond with Other Species*. Harvard University Press, Cambridge, 145 pp.

Wilson, E.O. (1998) *Consilience*. Vintage Books, London, 332 pp.

Wing, S.R. and Wing, E.S. (2001) Prehistoric fisheries in the Caribbean. *Coral Reefs* **20**, 1–8.

Worm, B., Barbier, E.B., Beaumont, N. *et al.* (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science* **314**, 787–790.

