Rev Fish Biol Fisheries (2008) 18:1–16
DOI 10.1007/s11160-007-9058-6

RESEARCH PAPER

The 'shifting baseline' phenomenon: a global perspective

John K. Pinnegar · Georg H. Engelhard

Received: 17 July 2006 / Accepted: 12 March 2007 / Published online: 20 April 2007

Abstract In this paper we demonstrate that low level 'artisanal' fishing can dramatically affect populations of slow-growing, late-maturing animals and that even on remote oceanic islands, stocks have been depleted and ecosystems degraded for millennia. Industrialised fisheries have developed during different decades in different regions of the world, and this has almost always been followed by a period of massive stock decline. However, ecosystems were not pristine before the onset of industrial fishing and it is difficult to assess the 'virgin' state of a population given that it may have been subject to moderate or even high levels of fishing mortality for many centuries.

A wide range of information is available to help define or deduce historic marine population status. These include 'traditional' written sources but also less conventional sources such as archaeological remains, genetic analyses or simple anecdotal evidence. Detailed information, collected specifically for the purpose of determining fish stock biomass tends to exist only for recent decades, and most fishery assessments around the world (and thus time-series of biomass estimates), are less than 30 years long. Here we advocate using a wider range of multidisciplinary data sources, although we also recognise that it can be difficult to separate natural variability associated with changing climatic conditions from human-induced changes through fishing. We consider whether or not recovery of degraded ecosystems is ever possible and discuss a series of one-way ratchet like processes that can make it extremely difficult to return to a former ecosystem state.

Keywords Baseline · Historic · Archaeological · Fishing · Recovery

J. K. Pinnegar (✉) · G. H. Engelhard
Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK
e-mail: john.pinnegar@cefas.co.uk

G. H. Engelhard
e-mail: georg.engelhard@cefas.co.uk

Introduction: the 'shifting baseline' concept

In 1995, Daniel Pauly highlighted the inabilities of modern fisheries science to accommodate historical data, and the risks associated with a shifting perception of the status of stocks or the health of marine ecosystems. Essentially this treatise stated that each generation of marine scientist tends to accept as a baseline the stock-size and species composition that occurred at the beginning of their career, and uses this to evaluate subsequent changes, often assuming that inadequate data exist for earlier periods. This problem is compounded by the development of ever-more sophisticated modelling techniques and their associated greater demands for data. The result obviously is a gradual shift of the baseline perception, a gradual accommodation of the creeping disappearance of resource species, and inappropriate reference points for evaluating economic losses or for identifying targets for rehabilitation measures.

Humans have been impacting marine ecosystems for millennia and there are very few pristine systems anywhere in the world (Myers and Worm 2003). Lest we think that fish, for example, were at peak abundances 100 years ago—we need to think again (Carlton 1998). One hundred years ago both fishermen and scientists were also remembering ''back when'' themselves (Garstang 1900). As early as 1893 the UK parliament felt the need to convene a special 'Select Committee on Sea Fisheries', in response to fears of overfishing in the North Sea (see sources cited in Sims and Southward 2006).

Following Pauly's 1995 paper, interest in the phenomenon that he termed 'the shifting baseline syndrome' has soared (Sáenz-Arroyo et al. 2005a). Historical and archaeological research has shown that many species could have been much more abundant in pre-fishing times than previously appreciated. Modelling studies (e.g. Christensen et al. 2003; Jennings and Blanchard 2004), and analyses of genetic diversity (Roman and Palumbi 2003), have supported this view and help illustrate how relying only on modern ecological or fisheries data will always result in 'a shifted perception of the ocean' (Sáenz-Arroyo et al. 2005a).

Sheppard (1995) provided a slightly expanded view of Pauly's 'shifting baseline syndrome'. Often, in the absence of adequate historical data, it is necessary to compare the status of an impacted system with that of an un-impacted 'control' system around the corner or further down the coast. The problem is that each time this is done, the control areas used may have drifted further and further away from a 'true' pre-exploitation condition. There comes a point when the baseline area which is being used for a particular study has itself reached a condition which the original investigators, say 25 years earlier, might have recognized as being disturbed.

If baselines are shifting, then many ecological models which relate in some way to 'natural' conditions will assume erroneous starting points (Sheppard 1995). Within a fisheries context this might be particularly problematic. The emergence of precautionary management has resulted in greater emphasis on fisheries 'reference points' (Hilborn 2002). Chief among these precautionary reference points has been the biomass of the stock relative to assumed 'virgin stock size' (B_0). In most fisheries assessments, estimating virgin biomass (B_0) depends either on extrapolating back to well before we began to have reliable data or on taking estimates of annual recruitment and calculating what virgin biomass these would have produced in the absence of fishing pressure. All such calculations are highly subjective. If the stock has been subject to recruitment overfishing (i.e. the adult population reduced to the point that it no longer has the capacity to adequately replenish itself), using recent recruitments to estimate virgin biomass will lead to spurious underestimations (Hilborn 2002). Similarly, if environmental conditions have changed, that which was virgin biomass in the past will not necessarily be the same as could be achieved in the absence of fishing today (Jennings and Blanchard 2004).

Different time-horizons in different parts of the world?

It is a common misconception that the earliest evidence for the deleterious affect of fishing can be found in Europe or perhaps North America. The oldest fishing implements so far identified are sophisticated harpoons, found in the territory of the Congo (ex-Zaire), and dated to around 90,000 years (Yellen et al. 1995). Interestingly, these harpoons were found associated with the bones of a now extinct giant catfish. Fishing technology such as nets, hooks, and spears spread rapidly as early humans colonized the world. For example, characteristic ''flatfish'' fishing hooks and multipoint fishing spears are found both among Australian Aborigines (Flood 1995) and the coastal peoples of the North Pacific (Stewart 1977).

At one early settlement on Cyprus, middens dated at 8000 BP revealed that large specimens of certain species, notably sea breams (Sparidae) and groupers (Serranidae) are now much rarer than they were during the Neolithic (Desse and Desse-Berset 1993). Similarly, fish fauna diversity and size decreased over 12,000 years of fish remains in a Spanish cave (Morales et al. 1994). In middens on the Caribbean island of St. Thomas, the average size of individual reef fish (Scaridae, Acanthuridae, Serranidae and Labridae) declined sharply between 1500 BP when the island was first settled, and 560 BP. In addition it has been suggested that estimated reef-fish biomass also decreased markedly (Wing and Wing 2001). Together these patterns suggest that fish populations adjacent to occupied sites were heavily impacted, even in prehistoric times.

The relatively large impact of 'small-scale' fishing

It is now widely appreciated that even a small amount of 'artisanal' fishing can have a big impact on target fish populations (e.g. Fig. 1.). Jennings and Polunin (1996) assessed the biomass of large piscivorous fishes on 10 Fijian coral reefs varying 600-fold in terms of fishing pressure. The study found that the greatest changes in target fish biomass occurred at relatively low levels of artisanal fishing pressure (Fig. 1.), and hence that it is relatively easy for 'artisanal' fisheries to impact local fish resources. Similar observations have been made for fisheries in the Seychelles (Jennings et al. 1995) and in the Philippines (Russ and Alcala 1996). The implication is that low-level artisanal fisheries might have impacted fish stocks for millennia elsewhere in the world, well before the onset of intensive and industrialised fishing during the 19th and 20th centuries.

Hawkins and Roberts (2004) studied six Caribbean islands on which artisanal fishing pressure ranged from virtually none in Bonaire, increasing through Saba, Puerto Rico, St Lucia, and Dominica, and

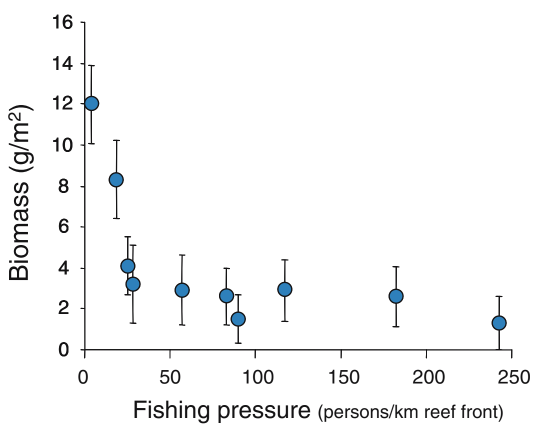

Fig. 1 Biomass of epinepheline groupers (genera *Anyperodon*, *Cephalopholis*, *Epinephelus*, *Gracila*, *Plectropomus* and *Variola*) assessed by underwater visual census in 10 Fijian traditional fishing-grounds (after Jennings and Polunin 1996)

reaching very high intensities in Jamaica. These authors showed that predatory fish biomass fell as fishing pressure increased. Similarly although the Galápagos Islands harbour some of the least impacted marine ecosystems in the tropics, there are indications that local artisanal fishing is affecting exploited marine resources at some sites (Ruttenberg 2001).

Aboriginal fishing in coral reef environments began at least 35,000 to 40,000 years ago in the western Pacific (Allen and Gosden White 1989; Dalzell 1998) but appears to have had only limited ecological impact. Recently however, coral reefs have experienced dramatic phase shifts in dominant species due to intensified human disturbance and global fish markets. The effects are most pronounced in the Caribbean but are also apparent on the Great Barrier Reef in Australia despite extensive protection over the past three decades (Jackson et al. 2001).

Certain fish species are more vulnerable to low-level exploitation or disturbance than others. Typically, large predatory animals such as sharks, rays, tuna, billfish and large groundfish (e.g. gadoids and groupers) are particularly susceptible. These species tend to possess low intrinsic population growth rates and hence they are easily depleted (Myers and Worm 2003). Recent estimates suggest that the global ocean has lost more than 90% of large predatory fishes over the past 50–100 years (Myers and Worm 2003), although such claims have been questioned by Hampton et al. (2005), Polachek (2006) and Walters (2003). Many shark populations have apparently been reduced to less than 10% of virgin biomass (e.g. Baum and Myers 2004). Several species of large skate seem to have become extinct at the global level (Casey and Myers 1998).

The industrialisation of world fisheries

The industrialisation of fisheries occurred at different times in different places throughout the world. The first purpose-built steam trawlers appeared in the North Sea in the 1880s and had an almost immediate effect on demersal fish stocks, catching four times as much as contemporary sailing trawlers (Garstang 1900; Mackinson 2001). By contrast, steam and motor vessels arrived in many African countries only recently, often in the form of outboard motors attached to traditional wooden canoes. Such development, over the last three decades, has resulted in a marked increase in the 'catching power' and increased ability to impact stocks (e.g. Laurans et al. 2004; Fig. 2).

In Australia steam trawling began in 1915 with the introduction of three vessels from England, and continued to expand until 1929. During this period catch rates of the main commercial species, tiger flathead *Platycephalus richardsoni*, latchet *Pterygotrigla poyommata* and leatherjacket *Nelusetta ayraudi* all declined severely and these species virtually disappeared from catches in later years (Klaer 2001, 2004).

A similar sequence of events occurred in kelp forests of the Gulf of Maine; new mechanized fishing technology in the 1920s set off a rapid decline in numbers and body size of coastal cod *Gadus morhua* (Steneck 1997). Formerly dominant predatory fish are now ecologically extinct and have been partially replaced by smaller and commercially less important species such as sculpins and dogfishes.

In recent years, fishing in deep waters (>400 m) has increased as traditional shallow-water stocks have declined (Devine et al. 2006). The target fish are often long-lived, late-maturing, slow-breeding (and hence vulnerable) species such as roundnose grenadier *Coryphaenoides rupestris* and orange roughy *Hoplostethus atlanticus*. Orange roughy can live to over 125 years of age and may not mature until 20 years old. Fishing by factory trawlers and modern long-line fleets started in the late 1960s. Analyses of several of the most important deep-sea fishes, using catch-per-unit fishing effort (cpue) data, have indicated a clear declining trend in abundance. For orange roughy in the NE Atlantic, the cpue in 1994 was only 25% of initial catch rates when the fishery commenced in 1991 (ICES 2003).

Fig. 2 Artisanal fishing boats (pirogues) at Kayar, Senegal. The artisanal marine fishery of Senegal is among the most important fisheries of West Africa, with more than 90,000 fishers and 12,000 canoes (90% of which are motorized). The catch (in excess of 300,000 t) contributes more than 70% of the nation's annual landings. Artisanal fishing on this scale can result in considerable impact on local fish stocks

Sources and types of information available?

A wide range of different data sources is available to help define or deduce historic marine population status, including 'traditional' written sources but also less conventional sources such as analysis of archaeological remains, genetic analysis or simple anecdotal evidence. Several authors (notably Jackson et al. 2001; Saénz-Arroyo et al. 2006; Dalzell 1998) have called for a wider appreciation of such data. They argue that retrospective data not only help to clarify underlying causes and rates of ecological change, but they also demonstrate achievable goals for restoration and management of coastal ecosystems that could not even be contemplated based on the limited perspective of recent observations alone (Jackson et al. 2001).

Fisheries data

Detailed information, collected specifically for the purpose of determining fish stock biomass, tends to exist only for recent decades. Most fishery assessments around the world, and thus time-series of biomass estimates, are less than 30 years long (Fig. 3). Understandably, fisheries scientists therefore tend to view the world through the window of the past 30 years, with little regard for what might have happened in the 'dark-ages' before they were able to gather sufficient data for a full stock assessment. Some authors have tried to push stock-assessments further back in time using whatever piecemeal data they could assemble (e.g. Pope and Macer 1996; Rijnsdorp and Millner 1996; Toresen and Østvedt 2000). Undoubtedly earlier data sources do exist but have thus far remained largely unutilised. Sometimes commercial catch-per-unit effort (cpue) data can extend back over considerable periods of time (e.g. Engelhard 2005; Godø 2003) and such data can be used to reconstruct historic biomass trajectories (e.g.

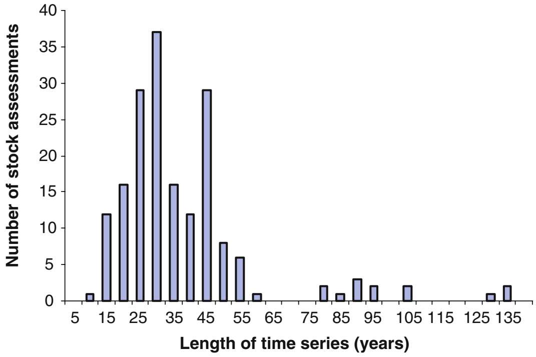

Fig. 3 The number of years included in 180 fishery stock assessments (data from most recent reports of ICES (Europe), NAFO (Canada, north-eastern US), ICCAT (Atlantic), NOAA (Alaska, US Gulf of Mexico, US Atlantic coast, US Pacific coast, coastal sharks), IPHC (north Pacific), IATTC (tropical Pacific), GFCM (Black Sea), MCM (South Africa)), defined as the number of years for which stock biomass estimates are available

Horwood 1993; Rose 2004; Godø 2003). Similarly, scientific survey estimates may exist (e.g., Greenstreet et al 1998; Rijnsdorp et al. 1996) and these too can yield valuable insights into historic ecosystem status, and include non-commercial as well as commercial species.

Other documentary information

Unlike scientific or fisheries data, detailed records of financial transactions or exports may extend back many decades or even centuries in some instances. For example, Ravier and Fromentin (2001) were able to reconstruct a 300-year (1650–1950) time-series of Mediterranean tuna catches based entirely on the records of bankers, financiers and tax collectors. Similarly, Øiestad (1994) constructed a 300-year (1550–1850) time-series of Norwegian cod and herring *Clupea harengus* catches using information from tithes (taxes) paid to the Norwegian king and Lutheran church, as well as export records from the port of Bergen. Similar tax and export records exist for many countries in Europe, for example MacKenzie et al. (2002) attempted to gather historic records from all countries around the Baltic Sea. Early records from England indicate that substantial quantities of herring, eels and other fish were paid as rents or taxes to the church even in the 11th century (Smylie 2004). Such records clearly indicate that substantial fisheries must have existed this far back.

Other documentary sources can yield valuable information, for example railway inventories for England and Wales indicate that fisheries landings in 1902 were much higher than today (Fig. 4). Japanese chronicles contain information on sardine *Sardinops melanostictus* outbursts for the last 400 years as well as documenting the development and collapse of various coastal fishing villages (Kawasaki 1994). Jónsson (1994) examined information contained within the ‘Icelandic annals’ and attempted an analysis of fisheries off Iceland between 1600 and 1900. Similarly Ogilvie and Jónsdóttir (2000) used early documents to explore the links between ice extent, sea temperatures, ocean currents and cod fishing around Iceland in the 18th and 19th centuries.

Southward et al. (1988) assembled information on herring and pilchard (sardine *Sardina pilchardus*) fisheries in south-western England using ‘Port Books’ (customs and excise records) spanning 1597 to 1900. Pilchards were more abundant when climate was warmer (e.g. 1590 to 1640), whereas herrings were more abundant in cooler times (e.g. the ‘little ice age’ of the late 17th century). In some cases, surprisingly detailed information can be extracted from written historical sources. For example, based on an 18th century account of the English port of Lowestoft,

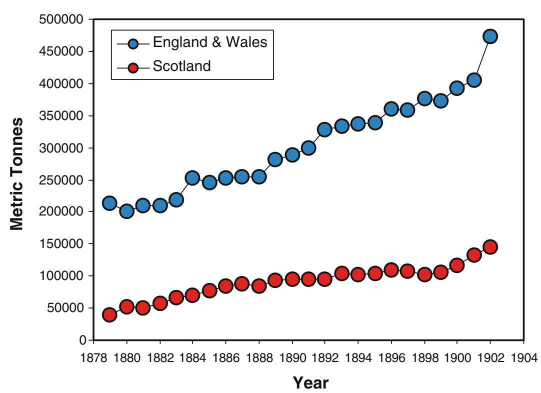

Fig. 4 The quantity of fish (in metric tonnes) transported inland by railway in England, Wales and Scotland (1879–1902). Note that the tonnage of fin-fish transported in England and Wales in 1902 (47,3274 metric tonnes) was 3½ times that landed at English and Welsh ports in 2002 (12,8300 metric tonnes)

Cushing (1968) was able to deduce the seven strongest year-classes of North Sea herring for the period 1750–1789.

Eyewitness accounts, written by early travelers to 'the new worlds' provide valuable insights into how seascapes once looked. Referring to the former abundance of green turtles *Chelonia mydas* nesting in the Caribbean, Jackson (1997) highlighted the difference between how we see the seascape today and how early Europeans visiting America witnessed it. Old hunting data from the Cayman Islands together with reports from early explorers and calculations of carrying capacity indicate that green turtle populations in the Caribbean may have declined by at least 99% since the arrival of Columbus in 1492 (Jackson 1997; Jackson et al. 2001).

Sáenz-Arroyo et al. (2006) provided a synthesis of 16th to 19th century travelers' descriptions of the Gulf of California and its marine wildlife. The diaries written by conquerors, pirates, missionaries and naturalists describe a place in which whales were 'innumerable,' turtles were 'covering the sea' and large fish were 'so abundant that they could be taken by hand'. Although all of these animals can still be seen in the Gulf of California, none of them exist in the numbers described by these early pioneers.

Sometimes accounts of historic voyages can yield useful information regarding the occurrence of vanished species. For example published accounts of Vitus Bering's expedition aboard the *St. Peter*, shipwrecked off the coast of Kamchatka in November 1741, provide us with one of the only reports of Steller's sea cow *Hydrodamalis gigas*, named after Georg Wilhelm Steller, the naturalist and physician on board the expedition. Steller was able to gather information on the habits of the sea cow as well as an extensive set of measurements of various parts of the sea cow's anatomy. 27 years after its discovery (in 1768) this species was declared globally extinct as a result of excessive hunting.

Records of historical catches from ship logbooks during the 18th and 19th centuries (e.g. Best 2006) are regularly used by the International Whaling Commission (IWC), to reconstruct the population dynamics of whales before, during and after exploitation (Baker and Clapham 2004). The historical trajectories for southern right whale *Eubalaena australis* for example, show a sharp decline during the mid 1800s, with a slow increase following international protection in 1931 and another decline resulting from illegal Soviet catches during the 1960s. The lowest point of population abundance was in 1920, when as few as 60 adult females were estimated to have survived.

In the Pacific Islands, ship manifests have provided a rich source of information on the volumes of marine harvests, in particular of high-value species such as bêche-de-mer (sea cucumber) and pearl oysters. Ward (1972) documents the comings and goings of bêche-de-mer trading vessels between 1803 and 1850 around Fiji. The author states that ''by 1834 the holothurian population of the reefs of western and northern Vanua Levu and Viti Levu had become depleted''. Also, that J.H. Eagleston had managed to fill his vessel, the '*Peru*' by calling at only two shore stations in 1831, but had required four stations in 1834 (to fill the vessel '*Emerald*'), and it took him over 12 months to obtain a comparable cargo for the '*Mermaid*' in 1837–1838.

Fisheries in art and literature

Sometimes art and literature can offer surprising insight into past conditions in the oceans, for example the John Steinbeck novel '*Cannery Row*' has been cited by scientists (Chavez et al. 2003) looking at the complex interplay between sardine and anchovy stocks in the eastern Pacific. MacIntyre et al. (1995) made use of anecdotes in Farley Mowat's book *'Sea of Slaughter'* to suggest that the biomass of fish and other exploitable organisms along the North Atlantic coast of Canada now represents less than 10% those available two centuries ago.

Stergiou (1999) has suggested that many Mediterranean top predators (e.g. dolphinfish *Coryphaena hippurus*) may have been all but 'fished out' in antiquity, since early fisheries, as depicted in Roman, Greek, or Minoan frescoes, tended to involve highly selective gears, and even small amounts of fishing pressure can deplete large predatory species (Fig. 5). Consequently it is possible that fishing-induced changes occurred long before scientific monitoring programmes and documentary evidence were in place. Highly accurate and clearly recognisable images of marine and freshwater fish exist from tombs, mosaics, frescos and pottery in ancient Rome, Greece and Egypt (see Moyle and Moyle 1991;

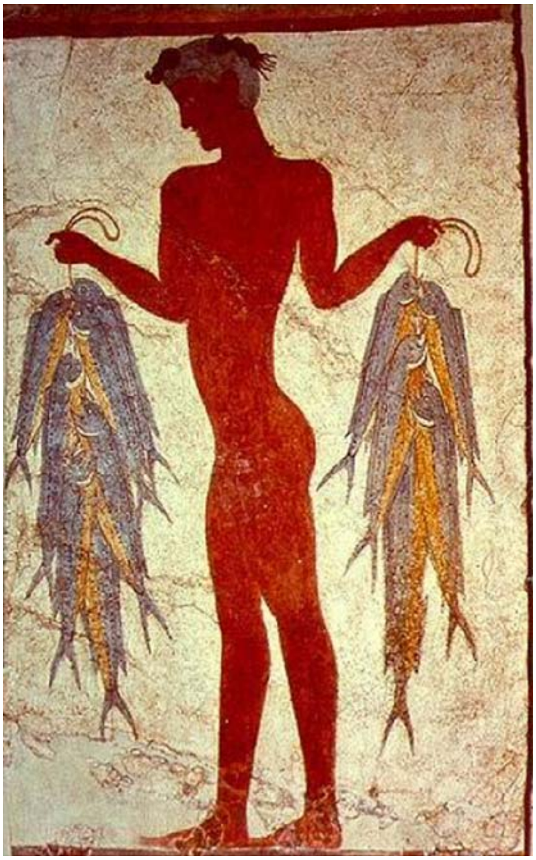

Fig. 5 The dolphinfish *Coryphaena hippurus* was widely exploited in the Aegean Sea as early as the Bronze Age (ca. 1500 B.C.) as evidenced from a Minoic fresco at Akrotiri ('the little fisher of Santorini'). This fresco shows a young man with a catch of over 20 kg of dolphinfish, a species probably much more abundant then compared to now (after Stergiou 1999) (Fresco in National Archaeological Museum, Athens)

Brewer and Friedman 1989), also in illuminated manuscripts in northern Europe (Fig. 6). These sources offer tantalising clues regarding the status of particular fish stocks 100s or even 1000s of years ago.

Anecdotal evidence

In Pauly's original 1995 description of the 'shifting baseline' phenomenon the author argued that fisheries science does not have adequate procedures for dealing with anecdotes (in contrast to various such programmes set up to collate physical and meteorological measurements). Pauly (1995) cited as an example the grandfather of a Danish colleague who

Fig. 6 Detail from an illuminated manuscript ('The Macclesfield Psalter') produced around AD 1330 in eastern England, showing an exceptionally large skate *Raja batis* (Fitzwilliam Museum, Cambridge). The common skate *Raja batis* may now be locally extinct in the southern North Sea (Dulvy and Reynolds 2002)

reported bluefin tuna *Thunnus thynnus* that entangled themselves in nets he was setting in the waters of the Kattegat in the 1920s, a population that subsequently disappeared in the 1950s (Tiews 1978). A recent study (MacKenzie and Myers in press), based on a range of data sources has attempted to quantify bluefin tuna catches in northern European waters between 1900 and 1950. The authors concluded that the species was an important part of the ecosystem and that commercial and recreational fisheries were well established before official ICCAT (International Commission for the Conservation of Atlantic Tunas) records began. Similarly, the abundance of bluefin tuna in the North Sea is evident from the activities of the British Tunny Club in the 1920s and 30s. The club was disbanded in the 1950s as the bluefin tuna catches declined (logbooks now held at the Scarborough Art Gallery, UK).

Such anecdotes are viewed by many scientists as possessing little empirical value and relevance for modern-day fisheries, yet anecdotal information has proved useful elsewhere. A study in western Mexico (the Gulf of California) involving naturalist's observations and systematic documentation of fisher's perceptions of trends in abundance of the Gulf grouper *Mycteroperca jordani* suggested that stocks collapsed in the early 1970s, long before official statistics started being collected. This study noted marked differences in the size and number of fish reported as being caught by three successive generations of fishermen, with older fishers recalling large catches in the 1940s and 1950s but much lower catch rates in the 1960s and especially in the 1990s (Sáenz-Arroyo et al. 2005a). Very little of the knowledge about marked declines appeared to have been passed on from the older to the younger generation, even if belonging to the same fishing families (Sáenz-Arroyo et al. 2005b).

Dulvy and Polunin (2004) surveyed fishers' remembrances of the giant humphead parrotfish *Bolbometopon muricatum* at 12 lightly exploited islands in the Lau group, Fiji. Fishers reported this parrotfish as being previously abundant, but it had not been caught at six islands since at least 1990 and was considered rare at another four islands. A compilation of giant humphead parrotfish records throughout the Indo-Pacific suggested that this fish has now become globally scarce.

Archaeological data

Using fish remains from archaeological excavations, researchers have attempted to demonstrate a reduction in the average size of fish caught through time (Amorosi et al. 1994; Jackson et al. 2001), and changes in fish growth rates that may be correlated with fishing intensity (Van Neer et al. 2002). Studies have also centered on changes in fisheries exploitation patterns in prehistory around the world.

Barrett et al. (1999) examined archaeo-ichthyological evidence from 40 sites in northern Scotland, Shetland and Orkney spanning the Neolithic (4500–2000 BC) to the Middle Ages (AD 1050–1468) and noted long-term changes in marine resource exploitation over the 6000-year period of occupation, and an intensification of fishing, corresponding with the arrival of the Vikings in around AD 800–1050.

In a further study Barrett et al. (2004) examined zooarchaeological evidence from 127 sites in eastern England. This study demonstrated marked changes in marine fishing activity around AD 1000 whereby large increases in catches of herring and cod were noticed. Surprisingly, this revolution pre-dated the documented post-medieval expansion of England's sea fisheries (Starkey et al. 2000) and coincided with the Medieval Warm Period—when herring and cod productivity was probably lower in the North Sea. The authors suggest that this discovery might be explained by the concurrent rise of urbanism and overexploitation of freshwater ecosystems during this period, and that the search for 'pristine' baselines regarding marine ecosystems will thus need to employ medieval palaeoecological proxies in addition to recent fisheries data and early-modern historical records.

Enghoff (2000) collated evidence from countries all around the southern North Sea (Denmark, Netherlands, Belgium, Germany, England) as well as the Baltic (Denmark, Germany, Poland and Sweden), spanning the 1st to the 16th century AD. The authors cite a chronological development in fishing practices, for example a tendency towards more distant-water fishing methods over time, and an increasing prevalence of offshore cod, haddock *Melanogrammus aeglefinus* and ling *Molva molva* in the fish bone assemblages of some countries (notably Belgium, England and Denmark)

Cooke (1992) examined marine fish bones at 14 sites in the eastern tropical Pacific (Costa Rica, Panama, and Ecuador). In Parita Bay, Panama, a comparison of fish faunas from Cerro Mangote (6000 B.P.) and Sitio Sierra (1800 B.P.) suggested that regional fishing strategies shifted between these dates from a shore-based, netless strategy to a more complex one that incorporated fine-meshed gill-nets and watercraft. Similarly, Kuang-Ti (2001) discussed prehistoric fishing activities as seen through archaeological remains from the area of Eluanbi in southern Taiwan. The excavations documented a continuous sequence of occupation beginning with initial settlement around 4000 BP and continuing until 2500 BP. Fifteen families of marine fish contributed to the ancient diet, and the most common taxa found in the fish assemblage were sail-fish, shark, mullet, and dolphinfish. Remains of fishing gear suggest that prehistoric settlers developed very effective fishing strategies. Through time, increased remains of offshore fish indicate a refined fishing strategy and an intensification of fishing as a subsistence activity.

In central Peru, Marcus et al. (1999) documented the existence of specialist fishing communities prior to the Inca conquest of AD 1470. These communities were primarily devoted to procuring large quantities of anchovy and sardine for shipment to inland agricultural communities. In addition, some 20 species of larger coastal fish were caught using nets (e.g. *Anisotremus scapularis* and *Sciaena deliciosa*); the more prestigious varieties showing up mainly in residential compounds occupied by elite families.

Dalzell (1998) reviewed the archaeological information on coastal fisheries at seven Pacific Island sites in Papua New Guinea, Tonga, Cook Islands, Solomon Islands and the Caroline Islands. It is clear that Pacific island reef and lagoon fisheries resources have been continuously exploited for many centuries, and in Western Melanesia for periods of between 20 and 30 millennia. Mollusc resources appear to have been extremely important as a food source for early Pacific Island human populations. In some instances, declines in mollusc resources forced early human populations to increase exploitation of other marine resources, and to rely increasingly on agriculture. Similar depletions of coastal and intertidal resources by small-scale human foraging has occurred all around the world (Mannino and Thomas 2002).

Genetics data

A recent study by Roman and Palumbi (2003) used genetic variation in the mitochondrial DNA sequence of North Atlantic whales and suggested pre-exploitation population sizes of approximately 240,000 humpback, 360,000 fin, and 265,000 minke whales. Estimates for fin and humpback whales were far greater than those previously calculated for prewhaling populations and 6–20 times higher than present-day population estimates. Such discrepancies with estimates obtained through analysis of log books from whaling vessels, suggested to the authors the need for a quantitative reevaluation of historical whale populations and a fundamental revision in our conception of the natural state of the oceans.

Natural (climate) vs. human-induced changes

When considering long-term changes in marine communities it can often be very difficult to separate natural variability associated with changing climatic conditions from human-induced changes through fishing. There are many written sources which indicate that cod and herring stocks in Europe for example, were severely affected by excessively warm or cold periods during the middle ages (Fagan 2002), and there has been much recent debate concerning whether warmer temperatures, rather than excessive fishing in the North Sea may be a contributory factor leading to the poor status of cod populations. Similarly sardine populations in the Santa Barbara basin, California are known to have undergone at least nine major collapses and subsequent recoveries over the past 1700 years determined overwhelmingly by climatic conditions (Baumgartner et al. 1992). Counts of Pacific sardine *Sardinops sagax* and northern anchovy *Engraulis mordax* scales in cores taken from anaerobic sediments, showed that the collapse of the sardine stock in the latter half of the 20th century which had been attributed to industrial-scale fishery exploitation, may actually be part of a coherent cycle that operates over a period of about 120–140 years (Baumgartner et al. 1992).

Fish scales in sediment cores have also been examined for the upwelling zone off central Peru (Devries and Pearcy 1982) and in an upwelling region along the coast of South Africa/Namibia (Struck et al. 2002; Shackleton 1987). Abundance and type of scales at different sediment depths have indicated dramatic fluctuations over the past 3200 years as well as changes in oceanographic and ecological conditions in the Benguela Current ecosystem.

In Europe, sardine (*Sardina pilchardus)* stocks are also known to fluctuate widely, and there is strong evidence that this variability is linked to climatic cycles (Southward et al. 1988). Moura and dos Santos (1984) demonstrated a strong lagged correlation between solar activity, as evinced by sunspots, and production of sardine off the Portuguese coast between 1901 and 1981. Spectral analysis revealed 10.4-year cycles for both sunspots and sardine catches, with high catches of sardines following 1–2 years after a low in solar activity.

Rose (2004) attempted a 500-year reconstruction of cod landings and biomass by linking records of catches and exports from published sources in the Newfoundland archives, and tree ring data for 1600–1974. These tree-ring data represent annual temperatures for northern North America, based on growth chronologies of white spruce (*Picea glauca*) and white cedar (*Thuja occidentalis*). The model was able to mimic the much documented history of Newfoundland cod, including declines during the Little Ice Age (mid- to late 19th century) and the stock collapses of the late 20th century. This model suggests temporal differentiation between fishing and climate effects, including: (i) declines during the Little Ice Age (1800–1880) caused by lower productivity, (ii) collapses in the 1960s caused by overfishing, (iii) collapses in the late 1980s caused by both, and (iv) rebuilding now hindered by depensatory effects of low numbers.

Archaeological excavations sometimes yield large numbers of fish bones from particular species that no longer live in the area or are considered to only inhabit warmer waters. Zohar and Dayan (2001) describe fish processing during the early Holocene (8140–7550 BC) at a site in coastal Israel. Fish bone assemblages were overwhelmingly dominated (97%) by grey triggerfish *Balistes capriscus*, a species no longer present in local waters. Similarly the bones of warm water species such as red mullet *Mullus surmuletus* have been recovered from excavations in northern Europe. This species has only recently returned to the North Sea in reasonable numbers, but was apparently widely available during the Roman (AD 64–400) period (Barrett et al. 2004). Enghoff (2000) lists a number of occurrences of warm water species (e.g. seabass *Dicentrarchus labrax*, anchovy *Engraulis encrasicolus*, red mullet and seabream) among bone assemblages from northern Europe, these records also include meagre *Argyrosomus regius* in the Netherlands and Germany during the 4th century BC–3rd century AD. The author reasoned that this species may have occurred further north during this time.

Undoubtedly some unusual occurrences may have resulted from trade and the transportation of fish from elsewhere in the Roman Empire. This would explain the occurrence of a north African catfish *Synodontis* in Roman deposits at Dragonby in eastern England (Jones 1996), and the presence of barracuda *Sphyraena sphyraena* at a Roman site in the Netherlands (Enghoff 2000). Other species such as the burbot *Lota lota* which are found among archaeological remains throughout the United Kingdom (Barrett et al. 2004) are now completely extinct in this country probably as a result of pressure on habitats.

Discussion: is there any way back?

If we accept that marine ecosystems all around the world have been impacted for millennia, and that even very low levels of artisanal fishing can have a serious impact on vulnerable species, then the question logically follows as to whether it is ever possible to recover natural systems and whether or not we would recognize a 'recovered' ecosystem when we see one.

A recent paper by Maxwell and Jennings (2005) set out to explore the power of a large-scale annual monitoring programme to detect decline and/or recovery of species that are vulnerable to fishing (elasmobranchs, cod, etc.). Even though this survey (the English North Sea bottom trawl survey) is one of the largest and best resourced in the north Atlantic, the power to detect declines and/or recovery on time scales of less than 10 years was very low. This raises the question as to whether marine species might go extinct (or recover) without people really noticing. Casey and Myers (1998) suggested that several large species of skate may have become extinct 25 years before the phenomenon was actually reported. Only through examining historical information, however derived, might we know what marine resources we have lost and also what we might expect to regain (in some circumstances) should fishing pressure be removed or significantly reduced.

There is evidence that fish stocks can sometimes recover when exploitation is halted, for example during the 1st and 2nd world-wars when intensive fishing was effectively halted (Pope and Macer 1996) and/or in marine protected areas (MPAs). Stock 'recovery plans' (Caddy and Agnew 2004) and closed spatial areas remain at the forefront of efforts to achieve a more ecologically considerate approach to fisheries. Inherent in both approaches however, is the explicit anticipation that populations and ecosystems will recover once the pressure has been removed, and that they have not been irreversibly and fundamentally damaged during the period of exploitation.

Pitcher (2001) suggested several ratchet-like processes that contribute to the erosion of biodiversity and make it very difficult to return to a situation which looks broadly similar to that experienced in the past. Pitcher listed only three such processes, but many more exist, and these are discussed here.

Fishing is a selective force on ecosystems by removing long-lived, slow-growing individuals in favor of those with higher turnover rates (Borisov 1978; Law 2000). When species (or genotypes) become totally extinct, the past becomes virtually impossible to restore, short of 'Jurassic-Park' style cloning technology to recreate vanished species or to introduce lost genes. Local extinctions may perhaps be reversed by reintroductions and restocking, but these tend to be very expensive operations (e.g. Burton 2001). Pitcher (2001) called this inability to recover lost animals ''Odum's ratchet'' recognizing Eugene P. Odum's concerns regarding human-caused extinctions.

There can be many economic factors which make it difficult to reverse trends in species depletion and over-exploitation. ''Ludwig's ratchet'', named after the study by Ludwig et al. (1993), refers to the generation of additional fishing power through financial loans that can only be repaid by sustained catches that, on account of stock depletion, can only be generated by further investment in fleet technology (hence 'technological creep'). The catching power of the world fishing fleet continues to expand even though the number of vessels has declined; and it is this overcapacity that drives serial depletion of species (e.g., Orensanz et al. 1998). Reversing Ludwig's ratchet has baffled fisheries economists for decades, and down-sizing of the world fishing fleet can only be achieved through draconian regulatory instruments including continued and compulsory decommissioning schemes and a halting of all subsidies for building new fishing vessels.

Given population trends and the global market for fishery products, the question remains as to whether fishing pressure can ever be reduced and healthy ecosystems regained. A single big-eye or blue-fin tuna (*Thunnus obesus* and *T. thynnus*) destined for the Japanese sashimi market, may fetch over $10,000, and thus there are strong incentives to comb the oceans and catch every last individual. As populations of these species decline, prices on the world market continue to grow (Fromentin and Powers 2005). In the Pacific, most non-tuna fishery exports are to China, including shark fin, bêche-de-mer, trochus, pearl oyster, and live reef fish. As China's economy continues to grow and its people become wealthier, demand for such products is likely to increase. A recent study by the WorldFish Centre (Delgado et al. 2003) predicted that inhabitants of the 'developing world' (including China) will likely increase their total consumption of food fish over the next 20 years by as much as 34 million tonnes, whereas consumption will remain relatively static in the 'developed world'. Hence, the 'race for fish' will become ever-more intense. Many fisheries are viewed as common property and some are entirely open-access. As such, there is little to be gained by one fisher trying to conserve fish because the same animal will simply be caught by someone else. The elucidation of this problem in general ecological terms is often associated with Hardin and his well-known article ''The Tragedy of the Commons'' (Hardin 1968).

There can be a great many socio-cultural factors which make it difficult to return to a historic situation, including the understandable wish to avoid high unemployment rates and associated social problems in coastal communities. Indeed, throughout the world recommendations to curtail excessive fishing effort in order to conserve stocks or ecosystems have been ignored and/or actions deferred in order to protect vulnerable fishing communities (Mace 2004; Rosenburg 2003). The wholesale loss of fishing fleets has been seen as politically unacceptable and hence ecosystems continue to be degraded.

Pollnac and Poggie (2006) have argued that those individuals who participate in fishing seem to have a psychological need for 'a certain level of adventure and its accompanying risks'. It has been observed that fishers resist changing to alternative sources of income even when their catches fall to the point where it would make economic sense to do so. Job satisfaction has been related to individual attributes such as mental health and longevity; as well as social problems such as family violence, absenteeism and job performance. Given the important impacts of job satisfaction in human well-being, several researchers have suggested that it must be accounted for in fishery management policy, particularly since fishing appears to select individuals with relatively unique socio-cultural characteristics. This being said, in many countries there has been an overall trend of younger fishers leaving the industry to pursue less physically demanding, better-paid jobs, for example to join the oil and gas sectors in the UK and Canada (OECD 2006), or towards jobs in the city in some remote oceanic islands such as Palau (Johannes 1981). This in itself, may create problems, in his book 'Words of the Lagoon', the late Robert Johannes bemoaned the fact that expert fishermen were now less inclined to share their traditional knowledge with a disinterested younger generation

(Johannes 1981). Prior to the arrival of industrialised fishing practices and global fish markets, a strong 'conservation-ethic' existed in many oceanic island communities—whereby the right-to-fish in a particular area was tightly controlled by the local chief given some understanding of the ecosystem's overall 'carrying capacity', and there were strong incentives not to catch more fish than could be consumed. With the loss of the traditional ''knowledge-base'', such practices are being rapidly eroded, and in some places stocks have dwindled (Johannes 1981). Once destroyed, traditional tenure-based management systems may prove very difficult to resurrect (Johannes 1978).

Globally, the number of fishers has increased considerably over the last two decades. Fisheries have emerged as one of the last refuges of the impoverished. With reduced opportunities and incomes in other sectors of the economy, fishing has been viewed as an attractive option, and this has contributed significantly to the overexploitation of marine resources and the deterioration of the coastal environment (Tietze et al. 2000). For example, in Tanzania a policy of creating communal villages in the 1970s and 1980s disrupted farming activities inland and led many peasants to abandon their established farms of permanent crops such as cashew nuts and coconuts and turn to fishing. Similar difficulties in the agriculture sector, led to increases in small-scale fisheries in the Philippines and in Senegal during this period (Tietze et al. 2000). Even in the 'developed world' there may be a link between poverty and increased pressure on marine resources. It is noteworthy that during the early 1980s in England when unemployment surpassed 3 million, there was a distinct and significant upsurge in illegal fishing and poaching as noted by the author Jonathon Raban in his book 'Coasting' (Raban 1986).

As more and more people enter fisheries, so they are faced with declining catches. Lacking any alternative source of income, the fishers initiate wholesale destruction of the resource-base to maintain their livelihood. This may involve the use of very damaging fishing gears (including explosives and poisons in some tropical reef systems) that kill non-target organisms or damage habitats, thereby compromising any possibility of sustaining yields in the future. Such fishing was termed 'Malthusian overfishing' (Pauly et al. 1989) after the Reverand I.R. Malthus (1766–1834) the 'prophet of doom', who described problems of feeding an exponentially growing human population.

Other ratchet-like processes include a phenomenon whereby a predator expands and prevents a particular prey from recovering. This arises where a particular predator 'switches' among focal prey, such that whenever the depleted prey increases slightly the predator switches back, thereby preventing further recovery. Otherwise known as a 'predator pit' (Hilborn and Walters 1992), the most widely discussed example of this phenomenon concerns the collapsed cod populations of eastern Canada and the huge harp seal *Phoca groenlandica* populations which have become established in the region (see Shelton and Healy 1999).

The introduction of exotic species may also act to change the system irreversibly, for example the planned and accidental introduction of reef fish and small pelagic species into Hawaii (Randall 1987). One of these, the bluestripe snapper (*Lutjanus kasmira*) has been extremely successful, and is found in large quantities throughout the archipelago, while other endemic species have tended to decline from overfishing. Despite its palatability and consumption in other Pacific Islands this snapper is almost universally disliked in Hawaii (Randall 1987) and will likely never be eradicated, in which case the ecosystem is changed irrevocably. The same is also true of the tilapia species in many Pacific Islands, where they have invaded reef and lagoon habitats (De Silva et al. 2004).

The opening of the Suez Canal in 1869 allowed entry into the eastern Mediterranean of Indo-Pacific and Red Sea biota, where these so-called Lessepsian migrants now dominate the community structure (50–90% of fish biomass). The process has accelerated in recent years associated with a warming trend of the seawater. Record numbers of newly discovered non-native species have been observed, leading to the creation of a human-assisted Erythrean (Red Sea) biotic province in the Eastern Mediterranean (Goren and Galil 2005).

In spite of these one-way ratchet-like processes, Pitcher (2001) argues the case for ecosystem 'rebuilding' as a goal of fisheries management. As part of this, the establishment of no-take marine reserves is viewed as the first practical element of the marine restoration process (also by Worm et al. 2006). The size and placement of these MPAs will be critical in determining whether or not ecosystem restoration is successful. Of the 1,306 MPAs surveyed world-wide by Kelleher et al. (1995), only 31% were thought to be fully achieving their management objectives. The optimal size of marine reserves will depend on conservation needs and goals, quality and amount of critical habitat, and the particular characteristics of species or biological communities (Gerber et al. 2003). For highly migratory species, MPAs may not be very effective unless extensive proportions of their range can be closed to fishing (Lauck et al. 1998; Murawski et al. 2000). For sessile or more sedentary species, including crustaceans and some reef fish, even small, effectively protected areas are likely to increase survivorship, abundance and mean size.

Almost all existing MPAs are small; the median size of MPAs worldwide is $\sim$160 km^2 (Kelleher et al. 1995). In June 2006 however, the US President, George W. Bush, announced the creation of the world's largest MPA, the Northwestern Hawaiian Islands (NWHI) Marine National Monument. The monument covers 140,000 square miles (360,000 km^2), or two-thirds of the waters of Hawaii. The NWHI archipelago is home to more than 7,000 marine species—a quarter of which are found nowhere else on Earth. The new MPA is also home to nearly 1,400 Hawaiian Monk Seals—*Monachus schauinslandi* virtually the entire population of this endangered species. In essence, the NWHI has been subject to minimal amounts of fishing over the past few decades and is acknowledged to be mostly in a pristine state, in contrast to the populated islands (Hawaii, Maui, Oahu, Kauai, Molokai) where many fishery resources are chronically overfished (Friedlander and DeMartini 2002).

Jennings and Blanchard (2004) point out that the unexploited biomass of a community (the 'carrying capacity') is not necessarily the same as the historically observed state, because climate and primary productivity may have changed over time. Indeed it is highly unlikely that ecosystems today would always revert to historic levels even if fishing were stopped. Restoring an ecosystem to its 'virgin' state is a romantic but probably unrealistic notion (Pitcher 2001). However, ecosystem 'restoration' remains at the forefront of international commitments such as those agreed in Johannesburg 2002 at the World Summit on Sustainable Development.

Since Pauly put forward his ideas in 1995, the 'shifting baseline' phenomenon has received much attention. Zeller et al. (2005) argued the financial and scientific case for recovering historical data, and as evidenced by the international 'History of Marine Animal Populations' (HMAP) programme, involving more than 100 researchers from 20 countries, there is now considerable interest in this subject.

Acknowledgements We are particularly grateful to David J. Starkey, Simon Jennings, Kostas Stergiou and James H. Barret whose work provided much of the inspiration for this manuscript. The work was funded by the European Union under work-package 2 (shifting baselines) of the Framework VI project INCOFISH (INCO project number 003739) and the UK Department of Environment, Food and Rural Affairs (Defra) contract MF0323.

References

Allen JC, Gosden White JP (1989) Human Pleistocene adaptations in the tropical island Pacific: recent evidence from New Ireland, a Greater Australian outlier. Antiquity 63:548–561

Amorosi T, McGovern TH, Perdikaris S (1994) Bioarchaeology and cod fisheries: a new source of evidence. ICES Mar Sci Symp 198:31–48

Baker CS, Clapham PJ (2004) Modelling the past and future of whales and whaling. Trends Ecol Evol 19:365–371

Barrett JH, Locker AM, Roberts CM (2004) The origins of intensive marine fishing in medieval Europe: the English evidence. Proc R Soc Lond B 271:2417–2421

Barrett JH, Nicholson RA, Cerón-Carrasco R (1999) Archaeo-ichthyological evidence for long-term socio-economic trends in northern Scotland: 3500 BC to AD 1500. J Archaeol Sci 26:353–388

Baum JK, Myers RA (2004) Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. Ecol Lett 7:135–145

Baumgartner TR, Soutar A, Ferreira-Bartrina V (1992) Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. CalCOFI Rep 33:24–40

Best PB (2006) The presence of right whales in summer on the west coast of South Africa: the evidence from historical records. Afr J Mar Sci 28:159–166

Borisov VM (1978) The selective effect of fishing on the population structure of species with a long life cycle. J Ichthyol 18:896–904

Brewer DJ, Friedman RF (1989) Fish and fishing in Ancient Egypt. The Natural History of Egypt: volume II. Arts and Phillips, Warminster, UK

Burton CA (2001) The role of lobster (*Homarus* spp.) hatcheries in ranching, restoration and remediation programmes. Hydrobiol 465:45–48

Caddy JF, Agnew DJ (2004) An overview of recent global experience with recovery plans for depleted marine resources and suggested guidelines for recovery planning. Rev Fish Biol Fisher 14:42–112

Carlton JT (1998) Apostrophe to the ocean. Conserv Biol 12:1165–1167

Casey JM, Myers RA (1998) Near extinction of a large, widely distributed fish. Science 281:690–692

Chavez FP, Ryan R, Lluch-Cota SE, Miguel Ñiquen C (2003) From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science 299:217–221

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

Cooke R (1992) Prehistoric nearshore and littoral fishing in the eastern Tropical Pacific: An ichthyological evaluation. J World Prehist 6:1–49

Cushing DH (1968) The East Anglian herring fishery in the eighteenth century. J Cons Int Explor Mer 31:323–329

Dalzell P (1998) The role of archaeological and cultural-historical records in long-range coastal fisheries resources management strategies and policies in the Pacific Islands. Ocean Coast Manage 40:237–252

Delgado CL, Wada N, Rosegrant MW, Meijer S, Ahmed M (2003) Fish to 2020: supply and demand in changing global markets. International Food Policy Research Institute and World Fish Centre, Manilla

De Silva SS, Subasinghe RP, Bartley DM, Lowther A (2004) Tilapias as alien aquatics in Asia and the Pacific: a review. FAO Fish Tech Pap 453, 65 pp

Desse J, Desse-Berset N (1993) Pêche et surpêche en Méditerranée: le témoignage des os. In: Desse D, Audoin-Rouzeau F (eds) Expoitation des animaux sauvages a travers le temps, vol 13. Recontres Internationales d'Archéologie de d'Histoire d'Antibes, Editions APDCA, Antibes, pp 332–333

Devine JA, Baker KD, Haedrich RL (2006) Fisheries: deep-sea fishes qualify as endangered. Nature 439:29

Devries TJ, Pearcy WG (1982) Fish debris in sediments of the upwelling zone off central Peru: a late Quaternary record. Deep-Sea Res 28:87–109

Dulvy NK, Polunin NVC (2004) Using informal knowledge to infer human-induced rarity of a conspicuous reef fish. Anim Conserv 7:365–374

Dulvy NK, Reynolds JD (2002) Predicting extinction vulnerability in skates. Conserv Biol 16:440–450

Engelhard GH (2005) Catalogue of Defra historical catch and effort charts: six decades of detailed spatial statistics for British fisheries. Cefas Science Technical Report No. 128, 42 pp

Enghoff IB (2000) Fishing in the southern North Sea region from the 1st to the 16th Century AD: evidence from fish bones. Archaeofauna 9:59–132

Fagan B (2002) The Little Ice Age: how climate made history 1300–1850. Basic Books, New York

Flood J (1995) The archaeology of the dreamtime. Angus and Robertson, Sydney, Australia

Friedlander AM, DeMartini EE (2002) Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Mar Ecol Prog Ser 230:253–264

Fromentin JM, Powers JE (2005) Atlantic bluefin tuna: population dynamics, ecology, fisheries and management. Fish Fisher 6:281–306

Garstang W (1900) The impoverishment of the sea. J Mar Biol Assoc UK 6:1–69

Gerber LR, Botsford LW, Hastings A, Possingham HP, Gaines SD, Palumi SR, Andelman S (2003) Population models for marine reserve design: a retrospective and prospective synthesis. Ecol Appl 13:S47–S64

Godø OR (2003) Fluctuation in stock properties of north-east Arctic cod related to long-term environmental changes. Fish Fisher 4:121–137

Goren M, Galil BS (2005) A review of changes in the fish assemblages of Levantine inland and marine ecosystems following the introduction of non-native fishes. J Appl Ichthyol 21:364–370

Greenstreet SPR, Spence FE, McMillan JA (1998) Fishing effects in northeast Atlantic shelf seas: patterns in fishing effort, diversity and community structure. V. Changes in the structure of the North Sea groundfish species assemblage between 1925 and 1996. Fish Res 40:153–183

Hampton J, Sibert JR, Kleiber P, Maunder MN, Harley SJ (2005) Decline of Pacific tuna populations exaggerated? Nature 434:E1–E2

Hardin G (1968) The tragedy of the commons. Science 162:1243–1248

Hawkins JP, Roberts CM (2004) Effects of artisanal fishing on Caribbean Coral Reefs. Conserv Biol 18:215–226

Hilborn R (2002) The dark side of reference points. Bull Mar Sci 70:403–408

Hilborn R, Walters CJ (1992) Quantitative fisheries stock assessment. Chapman and Hall, New York, New York

Horwood J (1993) The Bristol Channel sole (*Solea solea* (L.)): a fisheries case study. Adv Mar Biol 29:215–368

ICES (2003) Report of the working group on biology and assessment of deep-sea fisheries resources. International Council for the Exploration of the Sea, ICES CM 2003/ACFM:25 Ref. G

Jackson JBC (1997) Reefs since Columbus. Coral Reefs 16:S23–S32

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629–638

Jennings S, Blanchard JL (2004) Fish abundance with no fishing: predictions based on macroecological theory. J Anim Ecol 73:632–642

Jennings S, Polunin NVC (1996) Effects of fishing effort and catch rate upon the structure and biomass of Fijian reef fish communities. J Appl Ecol 33:400–412

Jennings S, Grandcourt EM, Polunin NVC (1995) The effects of fishing on the diversity, biomass and trophic structure of Seychelles' reef fish communities. Coral Reefs 14:225–235

Johannes RE (1978) Traditional marine conservation methods in Oceania and their demise. Ann Rev Ecol Syst 9:349–364

Johannes RE (1981) Words of the lagoon: fishing and marine lore in the Palau district of Micronesia. University of California Press, Berkeley, 245 pp

Jones AKG (1996) Fishes. In: May J (ed) Dragonby: report on excavations at an Iron Age and Romano-British settlement in north Lincolnshire, vol 1. Oxbow Monograph 61, 395 pp
Jónsson J (1994) Fisheries off Iceland, 1600–1900. ICES Mar Sci Symp 198:3–16
Kawasaki T (1994) A decade of the regime shift of small pelagics. B Jpn Soc Fish Oceanogr 58:321–333
Kelleher G, Bleakley C, Wells S (1995) A global representative system of marine protected areas: volume I. The World Bank, Washington, DC
Klaer NL (2001) Steam trawl catches from south-eastern Australia from 1918 to 1957: trends in catch rates and species composition. Mar Freshwater Res 52:399–410
Klaer NL (2004) Abundance indices for main commercial fish species caught by trawl from the south-eastern Australian continental shelf from 1918 to 1957. Mar Freshwater Res 55:561–571
Kuang-Ti L (2001) Prehistoric marine fishing adaptation in Southern Taiwan. J East Asian Archaeol 3:47–74
Laurans M, Gascuel D, Chassot E, Thiam D (2004) Changes in the trophic structure of fish demersal communities in West Africa in the three last decades. Aquat Living Resour 17:163–173
Lauck T, Clark CW, Mangel M, Munro GR (1998) Implementing the precautionary principle in fisheries management through marine reserves. Ecol Appl 8:S72–S78
Law R (2000) Fishing, selection, and phenotypic evolution. ICES J Mar Sci 57:659–668
Ludwig D, Hilborn R, Walters C (1993) Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17–18
Mace P (2004) In defence of fisheries scientists, single species models and other scapegoats: confronting the real problems. Mar Ecol Prog Ser 274:285–291
Mackinson S (2001) Representing trophic interactions in the North Sea in the 1880s, using the Ecopath mass-balance approach. In: Guenette S, Christensen V, Pauly D (eds) Fisheries impacts on North Atlantic ecosystems: models and analyses. Fisheries Centre Research Reports, vol 9, no. 4, pp 35–98
MacIntyre F, Estep KW, Noji TT (1995) Is it deforestation or desertification when we do it to the ocean? NAGA (the ICLARM Quarterly) 18(3):7–8
MacKenzie BR, Awebro K, Bager M, Holm P, Lajus J, Must A, Ojaveer H, Poulsen B, Uzars D (2002) Baltic Sea Fisheries in previous centuries: development of catch data series and preliminary interpretations of causes of fluctuations. ICES CM 2002/L: 02
MacKenzie BR, Myers RA (in press) The development of the northern European fishery for north Atlantic bluefin tuna *Thunnus thynnus* during 1900–1950. Fish Res
Mannino MA, Thomas KD (2002) Depletion of a resource? The impact of prehistoric human foraging on intertidal mollusk communities and its significance for human settlement, mobility and dispersal. World Archaeol 33:452–474
Marcus J, Sommer JD, Glew CP (1999) Fish and mammals in the economy of an ancient Peruvian kingdom. Proc Natl Acad Sci USA 96:6564–6570
Maxwell D, Jennings S (2005) Power of monitoring programmes to detect decline and recovery of rare and vulnerable fish. J Appl Ecol 42:25–37
Morales A, Rosello E, Canas JM (1994) Cueva de Nerja (prov. Malaga): a close look at a twelve thousand year ichthyofaunal sequence from southern Spain. In: van Neer W (ed) Fish exploitation in the past. Annales du Musee Royale pour L'Afrique Centrale, Tervuren, Belgium, pp 253–262
Moura O, dos Santos GA (1984) Relating pilchard abundance to solar activity. ICES CM 1984/H:48
Moyle PB, Moyle MA (1991) Introduction to fish imagery in art. Env Biol Fish 31:5–23
Murawski SA, Brown R, Lai H-L, Rago PJ, Hendrickson L (2000) Large-scale closed areas as fishery-management tool in temperate marine systems: the Georges Bank experience. B Mar Sci 66:775–798
Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. Nature 423:280–283
OECD (2006) Expert meeting on the human side of fisheries adjustment: the real cost of diminishing fishing effort in the European Union. Organisation for Economic Co-operation and Development (OECD), Report AGR/FI/HAS(2006)7, 14 pp
Ogilvie AEJ, Jónsdóttir I (2000) Sea ice, climate, and Icelandic fisheries in the eighteenth and nineteenth centuries. Arctic 53:383–394
Øiestad V (1994) Historic changes in cod stocks and cod fisheries: Northeast Arctic cod. ICES Mar Sci Symp 198:17–30
Orensanz JM, Armstrong J, Armstrong D, Hilborn R (1998) Crustacean resources are vulnerable to serial depletion-the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Rev Fish Biol Fisher 8:117–176
Pauly D (1995) Anecdotes and the shifting baseline syndrome in fisheries. Trends Ecol Evol 10:420
Pauly D, Silvestre G, Smith IR (1989) On development, fisheries and dynamite: a brief review of tropical fisheries management. Nat Res Mod 3:307–329
Pitcher TJ (2001) Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. Ecol Appl 11:601–617
Polacheck T (2006) Tuna longline catch rates in the Indian Ocean: did industrial fishing result in a 90% rapid decline in the abundance of large predatory species? Mar Pol 30:470–482
Pollnac RB, Poggie JJ (2006) Job satisfaction in the fishery in two southeast Alaskan towns. Hum Org 65:329–339
Pope JG, Macer CT (1996) An evaluation of the stock structure of North Sea cod, haddock, and whiting since 1920, together with a consideration of the impacts of fisheries and predation effects on their biomass and recruitment. ICES J Mar Sci 53:1157–1169
Raban J (1986) Coasting. Collins-Harvill, London
Randall JE (1987) Introductions of marine fishes to the Hawaiian Islands. Bull Mar Sci 41:490–502
Ravier C, Fromentin JM (2001) Long-term fluctuation in the eastern Atlantic and Mediterranean bluefin tuna population. ICES J Mar Sci 58:1299–1317
Rijnsdorp AD, Millner RS (1996) Trends in population dynamics and exploitation of North Sea plaice (*Pleuronectes platessa* L.) since the late 1800s. ICES J Mar Sci 53:1170–1184

Rijnsdorp AD, van Leeuwen PI, Daan N, Heessen HJL (1996) Changes in abundance of demersal fish species in the North Sea between 1906–1909 and 1990–1995. ICES J Mar Sci 53:1054–1062

Roman J, Palumbi SR (2003) Whales before whaling in the North Atlantic. Science 301:508–510

Rose GA (2004) Reconciling overfishing and climate change with stock dynamics of Atlantic cod (*Gadus morhua*) over 500 years. Can J Fish Aquat Sci 61:1553–1557

Rosenburg AA (2003) Managing to the margins: the overexploitation of fisheries. Front Ecol Environ 1:102–106

Russ GR, Alcala AC (1996) Marine reserves; rates and patterns of recovery and decline in abundance of large predatory fish. Ecol Appl 6:947–961

Ruttenberg BI (2001) Effects of artisanal fishing on marine communities in the Galápagos Islands. Conserv Biol 15:1691–1699

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

Sáenz-Arroyo A, Roberts CM, Torre J, Cariño-Olvera M, Enríquez-Andrade RR (2005b) Rapidly shifting environmental baselines among fishers of the Gulf of California. Proc R Soc Lond B 272:1957–1962

Sáenz-Arroyo A, Roberts CM, Torre J, Cariño-Olvera M, Hawkins JP (2006) The value of evidence about past abundance: marine fauna of the Gulf of California through the eyes of 16th to 19th century travelers. Fish Fisher 7:128–146

Shackleton LY (1987) A comparative study of fossil fish scales from three upwelling regions. S Afr J Mar Sci 5:79–84

Shelton PA, Healey BP (1999) Should depensation be dismissed as a possible explanation for the lack of recovery of the northern cod (*Gadus morhua*) stock? Can J Fish Aquat Sci 56:1521–1524

Sheppard C (1995) The shifting baseline syndrome (editorial). Mar Pollut Bull 30:766–767

Sims DW, Southward AJ (2006) Dwindling fish numbers already of concern in 1883. Nature 439:660

Smylie M (2004) Herring: a history of the silver darlings. Tempus Publishing, Stroud, 224 pp

Southward AJ, Boalch GT, Maddock L (1988) Fluctuations in the herring and pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th Century. J Mar Biol Assoc UK 68:423–445

Starkey DJ, Reid C, Ashcroft N (2000) England's sea fisheries: the commercial sea fisheries of England and Wales since 1300. Chatham Publishing, London, 272 pp

Steneck RS (1997) Fisheries-induced biological changes to the structure and function of the Gulf of Maine ecosystem. In: Wallace GT, Braasch EF (eds) Proceedings of the Gulf of maine ecosystem dynamics scientific symposium and workshop. Regional Association for Research on the Gulf of Maine, Hanover NH, pp 151–165

Stergiou KI (1999) Fisheries impacts on marine ecosystems. In: Pauly D, Christensen V, Coelho L (eds) EXPO'98 conference on ocean food webs and economic productivity. ACP-EU Fisheries Research Report No. 5, Lisbon, Portugal, pp 29–30

Stewart H (1977) Indian fishing: early methods on the Northwest coast. University of Washington Press, Seattle, Washington, USA

Struck U, Altenbach AV, Emeis KC, Alheit J, Eichner C, Schneider R (2002) Changes of the upwelling rates of nitrate preserved in the δ^{15}N signature of sediments and fish scales from the diatomaceous mud belt of Namibia. Geobios-Lyon 35:3–11

Tietze U, Groenewold G, Marcoux A (2000) Demographic change in coastal fishing communities and its implications for the coastal environment. FAO Fish Tech Pap 403, 151 pp

Tiews K (1978) On the disappearance of Bluefin Tuna in the North Sea and its ecological implications for herring and mackerel. Rapp P-V Reun Cons Int Explor Mer 172:301–309

Toresen R, Østvedt OJ (2000) Variation in abundance of Norwegian spring-spawning herring (*Clupea harengus*, Clupeidae) throughout the 20th century and the influence of climatic fluctuations. Fish Fisher 1:231–256

Van Neer W, Ervynck A, Bolle L, Millner RS, Rijnsdorp AD (2002) Fish otoliths and their relevance to archaeology: an analysis of medieval, post-medieval and recent material of plaice, cod and haddock from the North Sea. Environ Archaeol 7:61–76

Walters C (2003) Folly and fantasy in the analysis of spatial catch rate data. Can J Fish Aquat Sci 60:1433–1436

Ward RG (1972) The Pacific bêche-de-mer trade with special reference to Fiji. In: Ward RG (ed) Man in the Pacific Islands. Oxford University Press, London, pp 91–123

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

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314:787–790

Yellen JE, Brooks AS, Cornelissen E, Mehlman MJ, Stewart K (1995) A middle stone-age worked bone industry from Katanda, Upper Semliki Valley, Zaire. Science 268:553–556

Zeller D, Froese R, Pauly D (2005) On losing and recovering fisheries and marine science data. Mar Policy 29:69–73

Zohar I, Dayan T (2001) Fish processing during the early holocene: a taphonomic case study from coastal Israel. J Archaeol Sci 28:1041–1053