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A New Look Back In Time

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PART I
Oceans Past

Chapter 1

Marine Animal Populations: A New Look Back in Time

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1.1 Introduction

Since around 1980, marine-capture fisheries have stagnated at around 90 million tonnes per year, despite massive technological investments and the opening up of distant and deep waters in the Southern hemisphere. The oceans will simply not yield more. In fact catches are of increasingly smaller fish of less economic value and total returns on investments are dwindling. On a global scale, capture fisheries are doomed to be of less importance as a source of protein to a growing human population, while the fishing pressure remains extremely high. There is no sign that the rise of aquaculture in recent decades has eased the pressure on wild resources. The fisheries crisis is part of a general health alert for the oceans. Marine habitats are under severe pressure as a side effect of trawling and directly by dredging, harbor development, the concretization of large stretches of coastline, and especially from eutrophication caused by both agriculture and aquaculture (Lotze & Worm 2009).

But what is the scale of change? What used to be in the sea before humans began impacting marine ecosystems and habitats? What are the major long-term effects of human extractions of marine life? Are the impacts of recent or ancient origin? In other words what are the baselines against which we may evaluate some of the findings of the Census of Marine Life field projects by 2010? Can we talk with confidence about the history of the sea, can we gauge how much has changed – and with what consequences to us humans? This was the grand challenge that was put to the scientific community some ten years ago when the Census endorsed the History of Marine Animal Populations (HMAP) Project to assess and explain the history of diversity, distribution, and abundance of marine life (Box 1.1).

Although the history of marine animal populations has long been one of the great unknowns, recent advances in scientific and historical methodology and new applications of existing methodology have enabled the HMAP teams to expand the realm of the known and the knowable (Holm 2002).

The analytical framework of HMAP embraces two basic premises, one concerning data, one concerning methodology. First, much of what we can know about the history of the oceans will be in the "human edges" of the ocean, those in the near shore and coastal zone. This is where humans most directly interacted with the sea in the past and therefore most historical records relate to these activities. However, in both the human edges and in the central oceanic waters there have been extensive fisheries for larger organisms, and the value of the organisms encouraged the creation and maintenance of archival material. As HMAP has evolved, new and unexpected data sources have been discovered, and we know now that vast repositories are still untapped.

Second, historical analysis must combine with ecological analysis in a truly interdisciplinary way. New insights are

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Box 1.1

Regional and Species Focus of HMAP

HMAP is a collaborative effort by some 100 researchers around the globe participating in several region- or species-specific research teams. Twelve are based on marine areas, as follows: southeast Australian Shelf; New Zealand Shelf; Caribbean Sea; Gulf of Maine; Newfoundland and Grand Banks; Baltic Sea; North Sea; Mediterranean Sea; Black Sea; White and Barents Seas; southwest African Shelf; and the biodiversity of nearshore waters. Three case studies focus on the following species: whales, cod, and mollusks and one on Northern European fish bone assemblages. In addition, several smaller case studies have been undertaken in areas such as the Philippine Seas, the Wadden Sea, and the seas of Indonesia and northern Australia.

due to the introduction of established marine science methodology to historical data, notably standardizing fishing effort (catch per unit effort) (see, for example, Poulsen & Holm 2007), biodiversity counts of historical fisheries (Lotze *et al.* 2005), statistical modeling of historical data (Klaer 2005; Rosenberg *et al.* 2005), etc. Perhaps the most surprising results have come simply from the data-mining effort in itself, which has revealed a wealth of documentation for historical fisheries previously neglected by historians. Examples of this are of catch records spanning two to four centuries (Holm & Bager 2001; Starkey & Haines 2001; Lajus *et al.* 2005; B. Poulsen 2010). HMAP has provided inspiration to glean important information from surprising and sometimes unlikely sources such as restaurant menus (Jones 2008) and snapshots of sports fishermen's catches (McClenachan 2009). Archaeological techniques have been deployed in conjunction with historical methods and stable isotope analysis to explore the character and composition of fish catches during early medieval times (Barrett *et al.* 2008), and many more unconventional approaches could be cited.

In many ways the complicated interplay between man and nature calls for a new type of historical research. Science is a challenge to historians who have had little statistics, not to speak of modeling, as part of their training. Historical source-criticism is a challenge to scientists who are used to hard data. Although academic history through the 1990s concentrated on narrative and deconstructing skills, environmental history also demands command of both statistical and scientific methods.

The need for historians and scientists to work together is not uncontroversial. Some historians assert that history would carry no lessons for the future as events are never repeated in exactly the same form. Some scientists doubt the validity of historical data that are by definition "dirty data" in the sense that they are relics of events, not signals of a recurrent phenomenon, or experiment, established in a controlled environment such as a laboratory. In the early part of the Census some skeptics doubted the role of environmental history in this mega-science program. Would such a program not by default perpetuate the divide between science and the humanities? Indeed, as one critic put it, would the marriage of history and science not lead to scientists simply appropriating data for their own use (Van Sittert 2005)?

HMAP is founded on the belief that the divide between history and science needs to be bridged. History will never repeat itself but like the child learns to walk based on experience so does society base decisions and preferences on past experience. The historian may indeed detect trends and patterns of behavior behind diverse and unique events. Emphatic statements on the validity of and need for the HMAP approach have been made by some historians (Anderson 2006; Bolster 2006, 2008). Conversely, if we reduce science to controlled experiments we would never understand the fundamental principles of natural selection. More urgently, contemporary concerns about global climate change, biodiversity, and scarcity of resources are based on perceived changes of nature and availability of natural resources. Therefore, the history of nature itself – and the dependency and impact of human society on nature – has become a prime social, economic, and political concern, and scientists and historians need to address these very real issues, or decisions will be based on assumptions.

Environmental historians do not have to become biologists, nor do biologists need to become historians. However, we do need to understand enough of each other's language to exchange information and insight. Our experience of dialogue across the current divide of humanities and science has led to the emergence of the new scientific community of marine environmental history and historical marine ecology (Box 1.2).

Box 1.2

HMAP Outreach

HMAP has paved the way to establishing several new academic posts and trained graduate students at several participating universities. Marine environmental history and historical ecology is now taught at the undergraduate and doctoral level at universities in the USA (New Hampshire, Connecticut, Old Dominion (Virginia), Scripps Institution of Oceanography (California)), in Canada (Dalhousie (Halifax), Simon Fraser (Vancouver)), in Europe (Roskilde (Denmark), Hull (UK), Trinity College Dublin (Ireland), Södertörn (Sweden), Tromsø (Norway), Bremen (Germany), the St. Petersburg State University (Russia)), and in Australia (Murdoch (Perth)).

A total of 205 books and papers have been published up to September 2009 and the HMAP database (www.hull.ac.uk/hmap) holds approximately 350,000 records, with some 80% available through OBIS (see Chapter 17). By late 2010, it is anticipated that up to 1,000,000 records will be available on the HMAP website. With such a massive output it is obvious that any overview of major findings will be highly selective. In the following, we shall establish first the state of knowledge before the beginning of the Census in 2000, then focus on some of the highlights from the HMAP case studies. By way of conclusion, the chapter closes with observations on what we do not know, how we may get to know it, and why some questions will remain unanswerable.

1.2 The Background

Marine ecology was born as a scientific discipline by the late nineteenth century and derived often from a strong interest in the fisheries (Smith 1994). The question of human impact on marine life was central not only from the perspective of economic interest (for example where are the fish and how do we catch them?) but from the perspective of human impact (for example what is the effect of extracting thousands of tonnes of fish and what damage to the seabed may be caused by certain fishing technologies?).

The central question of the possibility of overfishing was raised at the World Fisheries Exhibition in London in 1884 and drew two opposing answers. One came from one of the leading scientific figures of the day, Thomas Henry Huxley, who concluded that "… probably all the great fisheries are inexhaustible; that is to say that nothing we do seriously affects the number of fish" (Huxley 1883). A more conservative note was struck by Ray Lankester, a young professor of zoology, that "the thousands of *apparently* superfluous young produced by fishes are not really superfluous, but have a perfectly definite place in the complex interactions of the living beings within their area" (Lankester 1890). To the credit of both men and to the academic community at the time the question of the possibility of harmful overfishing was put to the test. A rigorous series of trawls were undertaken in Scottish waters and were at first understood to support Huxley's view. In 1900, however, the tests were reanalyzed and further data from observations of commercial operations out of Grimsby were scrutinized. The conclusion by Walter Garstang was clear and had far-reaching implications: "… the rate at which sea fishes reproduce and grow is no longer sufficient to enable them to keep pace with the increasing rate of capture. In other words, the bottom fisheries are undergoing a process of exhaustion" (Garstang 1900; cf. Smith 1994, pp. 106–108).

This fundamental observation is at the heart of the question of human interaction with the oceans. Garstang established beyond scientific doubt that extractions might have an impact. Through the twentieth century, fisheries science concentrated on identifying optimal sustainable yields that would not extract more from the sea than marine life would be able to replenish. By the second half of the century, fisheries science had become highly sophisticated, equipped with research ships and advanced computer models. Scientific organizations like ICES, the International Council for the Exploration of the Sea, established in 1902 for the North Atlantic (Rozwadowski 2002), and a plethora of similar organizations for other ocean realms and migratory species, struggled to get both the science right and deliver management advice. Characteristically, fisheries studies were often based on very short time-series, although scientists were aware of long-term changes. The centennial variability of the Swedish Bohuslen herring fisheries provided a textbook example that fisheries may change dramatically over the long term. Nevertheless, perhaps because of the strong link with policy advice, the focus of cutting-edge science tended to be on recent data often obtained with new equipment, which by the very fact obliterated longer-term perceptions. Data observations over the long term were often discontinued for financial reasons. Few observation series are maintained today that span more than a few decades, the best-known of which is the Continuous Plankton Data Recorder survey, which has been maintained for the North Atlantic and North Sea since 1931 (Continuous Plankton Recorder 2009).

Marine science separated from fisheries science through the twentieth century as scientists developed the concept of ecology as a study of biodiversity, food webs, and biological processes and functions as a separate line of inquiry. To ecologists the ultimate question is not what is in nature for us, the humans, but how do we understand nature on its own, with the humans left out. Interest focused on biodiversity, the awesome richness of nature, and the exhilaration of understanding intricate and ingenious life-forms. By the 1960s ecologists did realize that ecosystems rarely remain steady for long, and "fluctuations lie in the very essence of the ecosystems and of every one of the … populations" (Margalef 1960 cited in Smith 1994, p. 33). Marine ecologists, however, perceived little or no need for history, with the exception of a few studies of correlations between contemporary and historical observations of animal populations and key environmental variables (Cushing 1982; Alheit & Hagen 1997; Southward 1995). Things were about to change, however, as demonstrated in a programmatic statement on the need to determine the historic structure of exploited ecosystems (Pitcher & Pauly 1998).

In a seminal study of the Caribbean ecosystem, Jeremy Jackson criticized ecologists for assuming that the natural or original condition is equal to the first scientific description of a phenomenon (Jackson 1997). Jackson turned to a concept developed a few years earlier by a fisheries scientist, Daniel Pauly, for a diagnosis of the problem, which was termed the shifting baseline syndrome (Pauly 1995). Pauly observed that equilibrium or steady-state models are based on a given dataset, often established by scientists within the past generation. However, what happens to equilibrium if older data are introduced? We cannot know from recent information the extent of the losses that have happened.

Jeremy Jackson, himself an American ecologist, son of a historian, used the British Empire trade statistics of the eighteenth century to learn of the trade in turtles from the Caribbean. When working out the numbers – hundreds of thousands of turtles killed in a single year – he realized that the ecosystem of the Caribbean would have looked very different to what conservation biologists supposed based on information from the past couple of decades (Jackson 1997). The lesson to ecologists of Jackson's historical analysis of Caribbean coral reefs was that textbook descriptions of reef ecosystems were limited by the fact that the systematic description by modern biology only began in the 1950s. Jackson put the case squarely to the ecologists: they needed to turn to historical sources and rediscover the world.

Another influential development in reinstating the historical dimension in science was the development of paleoecology and archaeoichthyology in the past 30–40 years. The preservation of fish scales in anoxic bottom sediments off the coast of California provided scientists the opportunity to reconstruct 1,600 years of pelagic abundances (Soutar 1967; Baumgartner *et al.* 1992; Francis *et al.* 2001). The field of paleozoology provided one of the first clear examples of scientists working across the cultural divides of historical and ecological analysis. Analysis of fish remains from archaeological sites provided a possible avenue to understanding biodiversity distribution and abundance. In the 1960s the Swedish scientist Höglund analyzed fish bones excavated from eighteenth century production sites for train oil and found that the Bohuslen herring was spent (namely post-spawning) herring from the sub-population of the North Sea Buchan herring (Höglund 1972). In the 1990s studies clearly demonstrated the potential of bringing the different lines of inquiry together (Muniz 1996; Enghoff 1999).

What about the historians? Environmental history has been a growth field in the USA since the 1970s and a little later in Europe, Asia, and Australia, and indeed, despite institutional problems, also in South America and Africa. However, the focus by leading American environmental historians was strongly on human agency and perception whereas ecological factors were rarely allowed to play an explanatory role. On top of that, the discipline developed out of a strongly narrative and qualitative approach to history that had little rapport with the quantitative approach of ecologists. The focus was very much on frontier cultures of the prairies, bushlands, savannahs, and steppes, whereas the oceans were strangely disregarded. Maritime historians on the other hand were firmly embedded in economic and social history with a preoccupation for naval and shipping matters and had little regard for environmental issues. The few fisheries historians often found their subject of marginal interest to mainstream historians and a bit fuzzy as the ecological context of fishing could not be disregarded but on the other hand was little understood. The few substantial overviews of fisheries published generally adopted a national, regional, or port perspective whereas environmental considerations were accidental at best. It was only as late as 1995 that the North Atlantic Fisheries History Association was established, but even then few papers dealt with the impact of harvesting on the seas (Holm & Starkey 1995–99).

Signs were in the air, however, that things were about to change. In the North Atlantic, Holm & Starkey (1998) reported the results of a workshop titled "Fishing Matters" that brought together historians, social scientists, biologists, oceanographers, and fisheries managers to examine multidisciplinary approaches to understanding the past and current scale and character of the fisheries. In the North Pacific, Pauly *et al.* (1998b) similarly documented the results of a workshop aimed at mathematically reconstructing the state of the Strait of Georgia, off Vancouver Island. Participants were even more varied, and the focus was broader in attempting "to provide a vision for rebuilding the Strait's once abundant resources."

1.3 The HMAP Projects

Such was the state of play when a preparatory workshop of the Census in 1998 called attention to the need of a historical backdrop – a baseline – to observations of ocean life (Anon 1998). The challenges were apparent: there was no shared or agreed set of methodologies and not even agreement as to which research questions needed to be raised. Before the project started the first step was therefore to bring together a workshop in February 2000 to identify the hypotheses that could be tested against historical data, to identify the various sources of data, and the methodologies that might yield plausible answers. The workshop agreed that historical data were only sporadically available and that there was an urgent need to build consistent time-series of extractions and fishing effort for at least the best documented operations such as whaling and large commercial fisheries. Participants identified 10 hypotheses to direct work in the early years of the project. The focus was first of all to investigate the proposition that validated historical, archaeological, and paleoecological records can be used to gauge long-term change in the abundance, spatial distribution, and/or diversity of marine animal populations. Secondly we wanted to identify the environmental and human forces that might condition fish mortality. Thirdly, we wanted to understand better the drivers of these forces themselves, be they related to geophysical or human activity.

In May 2000 a Steering Group of historians and marine scientists was charged by the Census' Scientific Steering Committee to lead a global inquiry into the history of marine animal populations. A series of regional projects was proposed while we set up annual training workshops through the summers of 2001–2003, well knowing that as nobody had ever received academic training as marine historical ecologists or marine environmental historians, there was a need to train a new generation of two dozen young researchers to understand enough of several disciplines. As the project grew, the Oceans Past conferences of 2005 and 2009 attracted more than 100 researchers while many more worked in the field.

The identification of a viable project was not just a question of a top-down process. Although the Steering Group wanted to get projects started in Japan and in the American Pacific, we were confronted with the reality of needing to find like-minded people who would undertake not only individual work but also lead a team for several years guided by an overarching research program. We were not always successful, but all projects that were begun proved viable. Although some were discontinued as the research was completed, other projects developed new agendas. A renewed focus on the evidence of archaeology brought new people and projects forward. By 2007 the focus shifted from data collecting to synthesis, both within projects and across projects. New collaboration with other Census projects emerged, in particular with Natural Geography in Shore Areas (NaGISA) for the History of the Near Shore project (see Chapter 2), which focused on providing historical data as baseline studies for ongoing fieldwork. In the following, we highlight selected research findings addressing two of the initial simple questions: what is the scale of change, and are changes of recent or ancient origin?

1.3.1 Mediterranean Sea and Black Sea

The Mediterranean and Black Seas are among the earliest heavily fished marine ecosystems in the world. Fish as a source of food was more important than meat in the ancient Mediterranean cultures (Fig. 1.1). Along the Nile, settlements with huge amounts of fish bones have been identified. Hundreds of full-time fishers were employed by the Lagash temple in Sumer around 2400 B.C. The fish was dried, salted, and stored. Babylonian sources from around 1750 B.C. show the importance of fishing. Greek merchants conducted an extensive fish trade from the Black Sea and the Russian rivers to the Greek and later the Roman market (Holm 2004).

However, the problem with assessing the impact of fisheries on ecosystems is that ancient records are rarely quantifiable and often we are not able to identify the fish species mentioned. Even worse, until quite recently, historians have assumed that the ancient fisheries were of minimal importance, technology was simple, and nets were cast close to the shoreline. A full reversal of this perception was only achieved as a result of an analysis of the evidence matched by an understanding of modern impact studies of pre-industrial fisheries technology. The Graeco-Roman world had seagoing vessels for hook-and-line as well as net fisheries. Ancient technology was neither ineffective nor unproductive, and indeed produced such large catches that the limiting factor was preservation and storage (Bekker-Nielsen 2005). The main fisheries for bluefin tuna (*Thunnus thynnus*), mackerel (*Scomber scombrus*), and other pelagic species took place in narrow straits such as the Strait of Gibraltar, Sardinia, Sicily, and Crimea in the Black Sea (Curtis 2005; Gertwagen 2008).

One solution to the problem of conserving the fish was to dry and salt the fish, which was done extensively and accounted for much of the Greek imports from the Black

Fig. 1.1
Polychrome mosaic ("Catalogo di pesci") found in Pompeii, house VIII.2.16 and now in the National Archaeological Museum, Naples. Last century B.C. Size *ca*. 0.9 m × 0.9 m. Photograph courtesy of Professor Dario Bernal Casasola, University of Cádiz.

Sea. The most spectacular solution was, however, the reduction of fish to fish sauce, garum, essentially by throwing the catch into large containers to allow a fermenting process to result in a liquid that was then traded all around the Roman world to add flavor to the Roman cuisine. The large installations are especially found by the shores of the western Mediterranean and the Black Sea. They were probably privately owned commercial operations for export, and regularly had containers of several hundred cubic meters. The largest installation in present-day Mauretania had a capacity of over 1,000 cubic meters (Curtis 2005; Trakadas 2005).

As yet, there is no way to establish the quantities of catch, although evidently they will have been significant. One assessment of the distinctive amphora vessels for the oil, wine, and garum trades established that wine accounted for about 62% of relative volumes, whereas oil made up about 28%, and 10% contained garum. Fish sauce was sold all over the Roman Empire and was an essential part of the Roman dish, part of what made up Roman culture (Ejstrud 2005). There is no doubt that extractions will have been huge, and much will be learnt in coming years as this research continues.

Documentary records are especially rich for the Venetian lagoon and the Northern Adriatic Sea. Preliminary studies show that the marine system has been modified dramatically by human interventions since the medieval period. An ongoing project aims to reconstruct the dynamics of marine animal population in the Venetian Lagoon and in the Northern Adriatic Sea from the twelfth century up to the twenty-first century from historical and scientific sources (Gertwagen *et al.* 2008). Finally, the Catalan Sea has been studied carefully and data for twentieth-century fisheries have been made available for further study.

1.3.2 North Sea and Wadden Sea

The North Sea is another heavily fished and depleted marine system. The Mesolithic period about 6,000 years ago experienced a warm climate, which seems to have been conducive to extensive fisheries all over the Northern hemisphere. Many basic technologies for the fisheries were already developed by this time such as trap gear and fishing by hook-and-line from a boat. With domestication of animals and development of agriculture in the Neolithic period about 5,000 B.P., hunting and fishing became less important and settlements were no longer related to the seashore, and fishing seems to have been of minor importance through the Bronze and Iron Ages of Northern Europe. Rivers will have brought nutrition to the North Sea from the rich agricultural lands of Northern Europe already by the Bronze Age when major deforestation took place and increased the productivity of the sea (Enghoff 2000; Beusekom 2005).

Our knowledge of ancient fisheries is still deficient due to the lack of sieving of archaeological finds for small and easily overlooked fish bones. However, thanks to a thorough review of archaeological reports of dozens of medieval settlements we now know that the period *ca*. 950–1050 saw a major rise in fish consumption around the North Sea (Fig. 1.2) (Barrett *et al.* 2004, 2008). Early medieval sites are dominated by freshwater and migratory species such as eel and salmon, whereas later settlements reveal a widespread consumption of marine species such as herring (*Clupea harengus*), cod (*Gadus morhua*), hake (*Merluccius*), saithe (*Pollachius virens*), and ling (*Molva molva*). The "fish event" of the eleventh century reflected major economic and technological changes in coastal settlements and technologies, and formed the basis of dietary preferences that

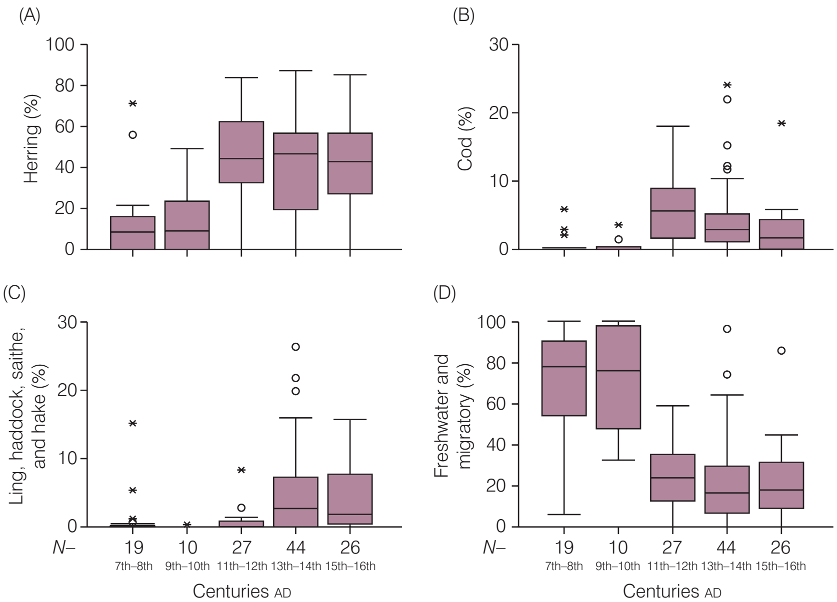

Fig. 1.2
Fish bones project: "Pristine" North Sea impacted *ca*. 950–1050, freshwater to marine species. Source: Barrett *et al*. (2004). Reproduced with permission.

were to last into the seventeenth century. In particular, the evidence of traded cod, "stock fish", which begins to show up in Northern European towns by the middle of the eleventh century, is clear evidence of the rise of commercial fisheries (Fig. 1.3). Barrett's group combines an osteological study of fish bones with analysis of their stable isotope signatures. The project has now identified traded cod in medieval settlements from Norway, England, Belgium, Germany, Denmark, Sweden, Poland, and Estonia. The evidence also supports a hypothesis that seagoing vessels were in wide use by the thirteenth century catching fishes at depths of 100–400 m such as ling. Commercial fisheries were well established by the high middle ages to feed a European population that had developed religious practices of fasting and abstinence of red meat in favor of fish on certain weekdays and through the 40 weekdays of Lent (Hoffmann 2004).

The first estimate of total removals of one species from the North and Baltic Seas comes from the sixteenth-century Danish inshore fisheries for herring in Scania and Bohuslen. Annual catches regularly reached a level of 35,000 tonnes (Holm 1999, 2003). By the late sixteenth century, the Dutch had taken the lead in Northern European herring fisheries with seagoing *buysen*, which harvested the rich schools off the coasts of Scotland and the Orkneys. They landed catches of 60,000–75,000 tonnes every year in the first quarter of the seventeenth century, and total removals with English, Scottish, and Norwegian landings amounted to upwards of 100,000 tonnes. Catches declined to about half by 1700, and only increased to about 200,000 tonnes in the late eighteenth century owing to Swedish and Scottish progress (B. Poulsen 2008).

By 1870 total removals reached a level of 300,000 tonnes, which equals the recommended Total Allowable Catch for 2007 for herring in the North Sea (ICES 2006). In the twentieth century, total catches repeatedly amounted to well over a million tonnes annually, causing collapses of herring stocks and the closure of fisheries for one or two decades to allow populations to rebuild.

This evidence demonstrates how fishermen in the age before steam and trawl were able to remove large quantities of biomass from the sea. The technologies of wind power and driftnets were practically unchanged in the Dutch fisheries from the seventeenth to the nineteenth centuries. There are indications that removals even at the much lower level than that recommended by modern standards had an effect on abundance. One study standardized the fishing power of North Sea herring fishing vessels across the technological divide from sail to motor-powered vessels from the sixteenth to the twentieth centuries. Even by a conservative estimate the returns of catch per unit effort indicated that stock abundance was ten times higher in the 1600s than in the 1950s, and already by the 1800s, well before the big technological change, it had dropped to 50–60% of the level of the 1600s (B. Poulsen 2008). The effects of early removals may therefore have been larger than we would have assumed.

The catches of two other commercially important species, ling (*Molva molva*) and cod (*Gadus morhua*), were abundant in the nineteenth century whereas the stocks showed signs of depletion by World War I. Detailed historical data are available from the Swedish fishery in the northeastern North Sea and Skagerrak, which make up about one-sixth of the entire North Sea. Minimum total biomass of cod in 1872 was estimated at about 47,000 tonnes for

Fig. 1.3
Map of the pound nets in Sebberlaa area of the Limfjord. The district bailiff, Thestrup, drew the map in 1741, where hundreds of pound nets, each 70 meters long, were in use in this very narrow stretch of water. In the right hand bottom of the map, Thestrup has drawn a pound net scaled next to a tree and row of dried fish. Source: Royal Library, Copenhagen, Ny Kgl. Saml. 409d, fol.

this portion of the North Sea, but it may have been much higher, whereas the total biomass of ling was estimated at a total of 48,000 tonnes. These were very healthy stocks if the levels are compared with the modern biomass estimate for cod of 46,000 tonnes for the entire North Sea, Skagerrak, and Eastern Channel, whereas for ling no modern biomass estimate is available as the species is caught too infrequently. The cod population is today considered severely depleted throughout the North Sea, and the ling population may be considered commercially extinct from the region that once produced the major catches (R.T. Poulsen *et al.* 2007).

Ecosystem theory emphasizes the importance of top predators for the entire food web. Top predators play a controlling and balancing role for the abundance of other species further down the food chain, and an abundance of top predators is a sure sign of biodiversity (Baum & Worm 2008; Heithaus *et al.* 2008). Human hunting tends to focus on top predators as the big fish are of highest commercial value. When we take out the largest specimens, we remove one of the controls on the ecosystem. The mature fish are also highly important for the reproduction of the population as their eggs have been shown to be healthier and more plentiful than the spawn of younger and smaller specimens

(O'Brien 1999). Because the fish continues to grow through its entire life, a decline in the length of specimen caught is a clear indication that the fishery is changing the age structure and viability of the stock. Analysis has shown that whereas the average length of northeastern North Sea ling in the mid- to late nineteenth century was about 1.5 m, it had decreased to about 1.2 m by World War I, and ling caught today is less than 1 m on average (R.T. Poulsen *et al.* 2007). A century ago, cod landed from the North Sea was usually 1–1.5 m long whereas today it is only about 50 cm. This means that although cod used to live to an age of 8 or 10 years, today it is caught at less than three years of age; for example in 2007, 87% of the catch in numbers were aged two years or younger. As cod only spawns at the age of three years, this fishing pattern is inhibiting the population from maintaining itself and delaying recovery (ICES 2008).

The bluefin tuna (*Thunnus thynnus*) generally escaped human hunting activity until the twentieth century owing to its rapidity and superior strength, which made its capture difficult. By the 1920s superior hook-and-line technology was available and brought tuna within the reach of fishermen. Even more importantly, harpoon guns and purse-seining methods, eventually implemented with hydraulic winches, were developed in the 1930s and rapidly increased catches to thousands of individuals per year. By 1960, however, tuna catches were falling and ceased to be of commercial importance after the mid-1960s. Climate change and prey abundance seem unlikely causes for the sudden decline, and it seems now likely that the commercial extinction of bluefin tuna from the North Sea was caused by the heavy onslaught by humans in the mid-twentieth century (MacKenzie & Myers 2007).

In the southern North Sea, the haddock (*Melanogrammus aeglefinus*) fishery was of substantial size in the sixteenth and first half of the seventeenth centuries. The fishery declined in the later seventeenth into the eighteenth century, but by the 1770s the fishery was on the increase again. We have evidence of an abundant haddock fishery by German and Danish hand liners in the German Bight and along the Jutland coast in the late eighteenth century and first half of the nineteenth century. Statistics show substantial catches by 1875 declining rapidly in the last quarter of the century to nil around 1910. It would seem that the southern North Sea haddock stocks were rendered commercially extinct by the intensive German and Fanø-Hjerting fisheries of the late nineteenth century. Today, haddock is prevalent mainly in the northernmost part of the North Sea and in the Skagerrak (Holm 2005), whereas its former widespread presence in the southern part of the North Sea was not generally recognized by marine science until its regional history was revealed.

Major changes to the inshore habitats of the North Sea and thus to marine wildlife occurred in the Middle Ages. Hunting and fishing took its toll on the rich wildlife of the inshore areas of the Wadden Sea, a large intertidal zone off the coasts of the Netherlands, Germany, and Denmark. Dikes, traps, and other inshore coastal uses changed the wide mud flats. By the late nineteenth century industrial and chemical pollution began to build up in the sea. However, the major change to the ecosystem is likely to have come from direct effects of removals of animals by fishing and hunting (Beusekom 2005). Some marine species have been extirpated from the Wadden Sea such as pelicans (*Pelicanus crispus*), which disappeared about 2,000 years ago (Prummel & Heinrich 2005), the Atlantic gray whale (*Escherichtius robustus*), which went extinct not only from the nearshore habitats of the North Sea but as a species sometime in the late medieval period (Mead & Mitchell 1984), and the great auk (*Pinguinus impennis*), which disappeared from the North Sea by the medieval period before extinction from the North Atlantic by the nineteenth century (Meldgaard 1988). Several species have been so much reduced in numbers that they are considered regionally extinct or at least so rare that they have lost their ecosystem importance, and their previous commercial importance to the human economy. Sturgeon (*Acipenser sturio*) was previously caught in vast quantities and marketed in the hundreds, for instance at the Hamburg fish auction. By 1900, however, the fishery declined rapidly both because of river and inshore pollution and fisheries. As late as the 1930s sturgeon was still caught regularly in the northern Danish part of the Wadden Sea but is now extremely rare (Holm 2005).

A general survey of extirpations in the Wadden Sea concluded that major impacts occurred by the turn of the twentieth century, well before the introduction of modern industrial fishing technologies to this region. The major causes for species decline and indeed extirpations were associated with removals and habitat destruction whereas factors such as pollution, eutrophication, and climate change have been late and minor factors so far (Lotze *et al.* 2005).

1.3.3 Baltic Sea

One of the early research questions of HMAP was posed by fisheries scientists about Baltic cod (MacKenzie *et al.* 2002). In the absence of historical records before 1966, they wondered if the record high cod stock in the Baltic Sea in the late 1970s to early 1980s was a unique occurrence or likely to occur at regular intervals. The question was unequivocally answered by the work of the Baltic team.

Through the recovery of historical data back to 1925 we know now that abundant cod stocks corresponded to a favorable combination of four key drivers in the late 1970s: incursions of saline water to the brackish Baltic and hydrographic conditions allowing successful reproduction, low marine mammal predation, high productivity environment fuelled by nutrient loading, and reduced fishing pressure.

A similar situation did not occur at any other time in the twentieth century. The cod biomass in the 1920s–1940s was likely restricted by high abundance of marine mammals and low ecosystem productivity; and in the 1950s–1960s by high fishing pressure. Periods of deteriorated hydrographic conditions occurred throughout the twentieth century and were most pronounced in the past 20 years, thereby restricting cod recruitment (Eero *et al*. 2008).

Today, cod rarely ventures into the very brackish northern Baltic waters between Stockholm and the Gulf of Riga. In the late sixteenth and early seventeenth centuries the presence of a large cod fishery off southwest Finland indicates that cod abundance must have been very large. The abundance is all the more remarkable because the population of top predators such as seals would have been much larger than today (MacKenzie & Myers 2007). Climate clearly impacted fish distribution but there are some surprises which underline that some fish are quite resilient to change. Archaeological evidence of fish fauna in the Atlantic warm period (*ca*. 7000–3900 B.C.) shows many fish species in waters around Denmark that we would today expect to find in warmer waters. Indeed, comparison with contemporary data from surveys and commercial landings shows that many of these species are now re-appearing as temperatures rise. However, cod was very abundant in the Stone Age, even though temperatures were 2–4 °C warmer than late twentieth century temperatures. This finding suggests that commercially important cod populations can be maintained in the North Sea–Baltic region, even as temperatures rise due to global warming, provided that fishing mortalities are reduced (Enghoff *et al*. 2007).

During the Little Ice Age of the late seventeenth century, coldwater marine fish (herring, flounder (*Platichthys flesus*), and eelpout (*Zoarces viviparous*)) were of major importance in the Baltic Sea fisheries and the fishing season for the major pelagic fish was substantially later in the year compared with the present, much warmer conditions (Gaumiga *et al*. 2007). Similarly, catches of herring and other coastal fish (for example perch (*Perca fluviatilis*) and ide (*Leuciscus idus*)) near Estonia in the mid- and late nineteenth century varied, probably owing to climatic fluctuations, when fishing effort and methods were stable (Kraikovski *et al*. 2008). A major hydrographic event increased the salinity of the Limfjord in 1825; the saltwater intrusion destroyed the habitat for the freshwater whitefish (*Coregonus lavaretus*), but created conditions for saltwater species such as plaice (*Pleuronectes platessa*) (B. Poulsen *et al*. 2007).

Overall, fishing pressure was quite low in the inner parts of the Baltic. During the late seventeenth century, removals of fish biomass from the Gulf of Riga were at least 200 times less than at the end of the twentieth century, and most fisheries concentrated on the rivers. Migratory fish species, such as sturgeon, Atlantic salmon, brown trout, whitefish, vimba bream, smelt, eel, and lamprey were the most important commercial fish in the area, because they were abundant, had high commercial value, and were easily available. Over time, however, the main fishing areas moved downstream and to the sea. Owing to intensive fishing, populations of many migratory species, first of all sturgeon and Atlantic salmon, considerably declined and lost their commercial significance. Marine fish, especially Baltic herring, gained increased importance in the nineteenth century (Kraikovski *et al*. 2008).

1.3.4 Grand Banks, Gulf of Maine, and Scotian Shelf

Although the fisheries in the Northeast Atlantic developed later than in Northern Europe, they were no less intense in the past few centuries. The Grand Banks fishery for northern cod is a well-known example of the effects of sustained high fishing pressure ending in a sudden collapse of the stock (Myers *et al*. 1997). The HMAP research focused on correcting the historical landings statistics and showed that the combined efforts of British and French fishermen on the Grand Banks off Newfoundland yielded between 204,000 and 275,000 metric tonnes of cod in the years 1769–1774 (Starkey & Haines 2001), or two to three times higher than previous estimates, and at a level that was only eclipsed by the late nineteenth century when catches were on the order of 300,000 tonnes (Cadigan & Hutchings 2001). This level proved unsustainable and catches were only half as much in the 1940s. This finding underscores that – as happened in the North Sea herring fishery – extractions using pre-industrial technology could be similar to or indeed above modern levels. When the fishery finally collapsed in 1992, landings had reached a decadal peak of 268,000 tonnes only four years earlier.

Because of the open nature of the Grand Banks fishery, the data will always be incomplete. To understand the dynamics of the fisheries fully, we need to know how many people and boats participated in a particular fishery. The focus in the later stages of HMAP has therefore been on the Gulf of Maine and Scotian Shelf fisheries closer to the American mainland that were largely conducted by local vessels through the nineteenth and twentieth centuries. Luckily, these fisheries are exceptionally well documented thanks to a bounty that required fishing captains to keep and hand in their logbooks through the period 1852–1866. Thousands of these logbooks have been digitized and analyzed for content by a team at the University of New Hampshire.

The fishermen consistently removed 200,000 tonnes of live fish per year through the 1850s. For example, in 8.5 months during 1855, the hand-lining fishermen in 43 schooners from Beverly, Massachusetts, caught a little over 8,000 tonnes of cod on the Scotian Shelf, whereas in 15 months during 1999–2000 a total of just 7,200 tonnes of cod was extracted from the same waters by the entire

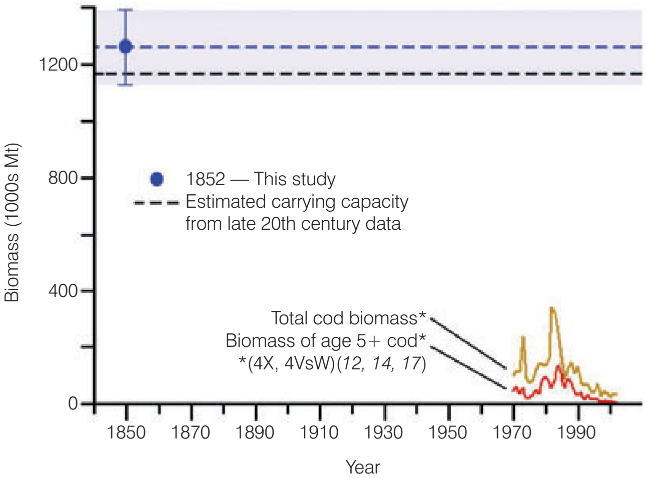

Fig. 1.4
Reduction of cod biomass, Scotian Shelf – estimated and historical. Source: Rosenberg *et al*. (2005). Reproduced with permission of ESA.

Canadian mechanized fishing fleet and fell short of the full Total Allowable Catch by 11%, a comparison that points to a profound change in cod abundance on the Scotian Shelf over the past 150 years (Fig. 1.4) (Rosenberg *et al*. 2005).

Abundant as fish were, the fishermen perceived reductions in stock sizes sufficient to change to fishing grounds further at sea. By the end of the 1850s catches had declined sufficiently for many ships to undertake the longer voyage to the Gulf of St. Lawrence and the Grand Banks. Similar processes of moving from fishing ground to fishing ground in a relentless effort to earn marginal benefit are well-known for modern fisheries and well-documented for many historical fisheries, perhaps best of all for the mid-nineteenth century fishery off the Labrador coast (Myers 2001). This is a fishing strategy that is known as serial depletion and may be recognized again and again in historical records from all over the world.

Declining catches were offset by new technology. French fishermen introduced tub trawls to the Scotian Shelf fishery, and soon the Americans no longer used the traditional hand lines with two to four hooks per man but upwards of 400–500 hooks per crewman. Thus the catchment area of one boat increased immensely. Unfortunately, although catches went up in the short run, in a matter of a few years the fish stock was showing clear depletion signals, being caught at a smaller size and catch per unit effort of the fishermen declining. In the 1850s, based on the fishing effort, the adult cod biomass may be estimated to have been of the order of 1.26 million tonnes. The comparable estimate was of 50,000 tonnes in the 1990s (Rosenberg *et al*. 2005). The reduction in abundance is obvious and even starker than the decline of the cod and ling in the North Sea.

The American waters of the nineteenth century were incredibly rich and are today impoverished to a degree that present-day managers would not realize without historical research. It would be naive to suggest that restoration targets may simply be based on historical values. If an ecosystem regime shift has occurred, the ecosystem may never be able to rebuild to past abundance levels. However, analysis of the age structure of modern cod populations indicates that conservation measures in recent years have helped to rebuild a stock of older and better spawners, resembling the stock of the 1860s (Alexander *et al.* 2009).

An even more short-lived success than cod was the Atlantic halibut fishery, which became severely depleted owing to a rapidly developing taste for the halibut fins among American consumers from the 1840 to 1880s. This fishery has never regained its former strengths (Grasso 2008).

1.3.5 Southeast Australia

The Australian southeast shelf region was the first HMAP case study to be completed and the first case study to apply catch rate standardization methods rigorously, single species population models, and the Ecopath ecosystem modeling approach to historical data. Compared with other HMAP case studies, the Australian southeast shelf data set is of particularly high quality. It is comparatively short in duration, beginning only in 1915 with some years missing, but it was collected in a systematic manner since the beginning of the fishery and has data for a considerable number of species. The fishery was initially set up by the government and records kept to convince private enterprise of the profitability of the industry.

What the evidence allows us to see are the effects of a trawl fishery on a pristine marine ecosystem, or as untouched by humans as was ever documented (Klaer 2005). Indigenous fishing in the Sydney region was mainly concentrated on the snapper, which lives in nearshore waters, and the indigenous fishery may have impacted the population. European settlers in Sydney added problems of pollution and disturbance. However, the southeast Australian shelf and slope marine animal populations may largely be considered to have been in a pristine state until the Australian government began fisheries experiments with a single trawler at the turn of the century. The main impact and the start of historical documentation came with the arrival of three British trawlers, purchased to begin commercial fisheries for a state company by May 1915. The operation was privatized in 1923 and peaked with 17 steam trawlers in 1929. Danish seine vessels were brought in through the 1930s but during World War II activities almost came to a halt. Catches were resumed after the war. The fishery was primarily in shelf waters between 50 and 200 m depth. It targeted tiger flathead (*Neoplatycephalus richardsoni*), jackass morwong (*Nemadactylus macropterus*), and redfish (*Centroberyx affinis*) until the 1970s.

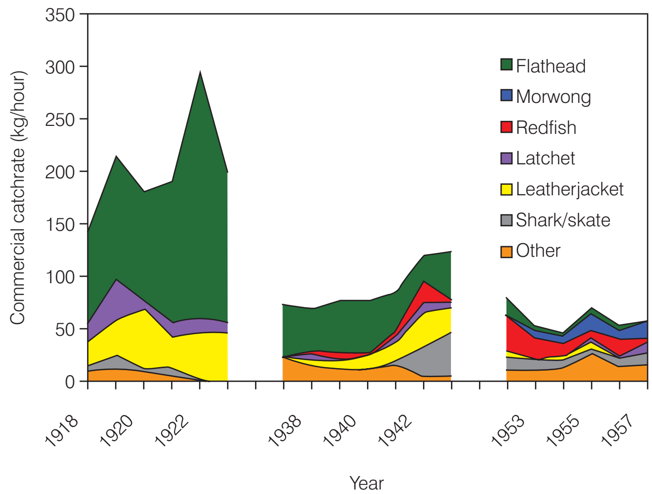

Fig. 1.5
Ecosystem effects of early trawling. Commercial catch rates by species on the southeast Australian continental shelf. Contribution per species to the total commercial catch per unit effort by year. Source: Klaer (2001), Fig. 10. Reproduced with permission.

The unique collection of 65,000 individual haul records, vessel logbooks, and landings data were used by Neil Klaer to develop relative indices of abundance for the major commercial fish species, to estimate the biomass of those species, and to examine ecosystem changes in the southeast Australian shelf over the period since the start of commercial fishing (Fig. 1.5). The results showed an overall decline in yields per haul over the history of steam trawling. Although initially the ships experienced larger catches as the men got acquainted with the new fishing grounds, the catch per hour trawled during 1937–43 was much lower than that of 1920–23. The fishing fleet moved further afield and into deeper waters as catch rates declined. In the early years, Botany Bay off Sydney yielded excellent catches of fish "very large and bursting with roe" and fishermen even talked of the "Botany Glut" from September to early December. However, by 1926 the glut failed to occur and by the 1930s the Botany Bay ground was no longer visited for commercial operations. As described for the Labrador coast, the Sydney fishermen began a mining operation that took them further up and down the coast and to deeper grounds. As the flathead was fished out, new, previously discarded fish began to be landed for the market. World War II gave a temporary reprieve for the stocks and the available biomass increased slightly, but catches quickly reduced the available biomass further.

Despite the substantial changes in the relative biomass of the main commercial species from 1915 to 1961, there were no great changes to relative biomass at lower trophic levels (megabenthos and lower). The biomass density of all large fish (flathead, latchet, other large fish, leatherjacket, redfish, and morwong) decreased by 73% from 1915 to 1961, whereas the biomass density of invertebrates at the same time decreased by only 6% (Klaer 2004). In other words, the effect of the southeast Australian trawl fishery was a fishing down the food web, as described by Pauly *et al.* (1998a), resulting in fewer of the large fish, while the small fish, plankton, and crustaceans remained.

Klaer's analysis is unique both for the pristine nature of the ecosystem before documented trawling and because of the amount of data available throughout the fishery. By the time that conservation measures and restrictions on fishing effort were taken, the ecosystem had ceased to look anything like it had before, and a fishery management system that was informed only by recent data would have no knowledge of what had been lost, nor indeed of what might be if the system were allowed to rebuild by holding back on fishing effort. Until this study was made, no such information was available to managers.

1.3.6 Southwest Africa

Human activities were studied in the Benguela Current ecosystem (Griffiths *et al.* 2005). Like the southeast Australian fisheries, the main human impact occurred relatively recently, but is unfortunately less well documented. The aboriginal epoch until 1652 was characterized by low levels of mainly intertidal exploitation, whereas the pre-industrial epoch to about 1910 saw intense exploitation of few large, accessible species. The introduction of mechanized technology marked the beginning of the industrial epoch which had a huge increase in landings. Catches were stabilized in the post-industrial period after 1975, although there have been increasing impacts of non-fisheries on the system. Total extractions in the past 200 years were calculated at more than 50 million tonnes of biomass, with annual removals above one million tonnes in the 1960s. Subsequently landings have declined by over 50%. The short, sharp impact of fisheries in the twentieth century led to severe reduction of populations of whales, seals, and pelagic and demersal fish, which are now all showing signs of recovery thanks to declining fishing pressure and implementation of new management schemes. Inshore stocks, particularly abalone, rock lobster, and inshore linefish, remain severely depressed and are exposed to intense fishery and gathering for human subsistence.

1.3.7 Caribbean

Far from being a pristine ecosystem, the Caribbean was intensively fished already before the arrival of the Europeans, and subsequent removals happened on a massive scale through the seventeenth and eighteenth centuries. Twentieth-century fishing pressure has continued a trajectory of fishing down the food web.

The Caribbean HMAP team has continued Jeremy Jackson's pioneering work by documenting historical distributions of large marine vertebrates. In the absence of quantitative evidence for many species, the team analyzed a total of 271 descriptions from 1492 to the present, to demonstrate consistent patterns of decreased abundance and increased rarity through time. By assigning quantitative values to qualitative sightings of species, the team was able to build a comprehensive and statistically significant picture of decrease in abundance and increase in rarity in megafauna since the European settlement. The green turtle population, which had an abundance of 15.5 million to 116 million at the time of Columbus, is considered highly endangered today as only two nesting beaches with more than 100 nesting females now remain, whereas at least 23 nesting beaches have been eliminated. Similarly, 32 hawksbill turtle nesting beaches have been lost (McClenachan *et al.* 2006). The decline of the monk seal followed a clear path: exploitation first reduced the range of the population, which was estimated at 0.23–0.68 million around 1500. At the beginning of the twentieth century, monk seals occupied only 30% of their former range. Hunting in the two remaining breeding areas finally killed off the monk seal from Caribbean waters by 1952. The range of the American crocodile and the West Indian manatee was reduced in the eastern Caribbean before European settlement. Manatees were largely eliminated from the Lesser Antilles by 1700, and all but eliminated from all island sites by 1900. The decline of crocodiles was similar, except that they seem never to have been present in the Lesser Antilles. Estimates of abundance show probable declines of at least 90% for each species. The removal of large animals will have had significant consequences for food webs and the resilience of the marine system. Because hawksbill turtles consume primarily sponge matter, Bjorndal & Jackson (2003) suggest that large numbers of hawksbill turtles could have maintained high coral cover and sponge species diversity, with a concurrent increase in total benthic invertebrate diversity.

Other scientific achievements so far include an assessment of the degree of population change, ecological consequences of population change, and the historical distribution of large marine animals – including green turtles, hawksbill turtles, and monk seals – across the entire Caribbean basin and Gulf of Mexico (McClenachan *et al.* 2006). The team has documented and quantified changed Caribbean food webs as a whole (Bascompte *et al.* 2005). The Caribbean studies have brought out the potential effect of early non-mechanized fishing technologies on coral reef animals. Early declines in Jamaican coral reef fauna were a function of less than half a million people using simple gear. The research makes evident that sustainable levels of fishing in Jamaica are no more than 10–20% of current catch, or equivalent of a level of extractions already reached 100 years ago (Jackson 1997; Hardt 2008).

1.3.8 White and Barents Seas

The question of the impact of climate variability on fish populations is in the foreground of the work of the HMAP team working on the White and Barents Seas led by Julia Lajus. The climate effects are especially pronounced in high latitudes because many fish species occur there at the border of their distribution range. Moreover, during several centuries these effects were not masked by the human impact on ecosystems, which in the Russian north was minimal up to mid-twentieth century owing to very slow growth of the human population in the area and the late start of industrial development. Although fishing effort did increase steadily during this period, extractions were too low to influence fish populations significantly. Therefore historical data on fisheries provided a convenient research tool to trace the natural dynamics of populations, allowing reconstruction of effects of climate going back several centuries.

The team has analyzed landings records from monastic and governmental sources from the seventeenth to the twentieth centuries. The records of the Solovetsky Monastery, the largest monastery in the White and Barents Sea area, which controlled sea and river fisheries of the high north, proved to be especially rich. These records are possibly unique because in many cases they contain not only the number but also the weight of caught fish: Atlantic salmon, Atlantic cod, and halibut. Atlantic salmon was one of the most valuable products of the local economy. They were fished mostly in the lower parts of rivers, using weirs that were not changed technologically over the centuries (Fig. 1.6). This makes fishing effort commensurable over time and allows comparison of historical catch data of the seventeenth and eighteenth centuries (published in D. Lajus *et al.* 2007a) with official statistical data available since the last quarter of the nineteenth century.

Analysis of historical and statistical data from four different localities around the White and Barents Seas for the seventeenth and eighteenth centuries shows a positive correlation of catches with ambient temperature (D. Lajus *et al.* 2005). The conclusion was drawn that before the middle of the twentieth century the population dynamics of salmon was mostly driven by natural factors (D. Lajus *et al.* 2008a).

Signs of climate-related dynamics were observed also for other fish, such as cod, halibut, and herring, although correlation did not approach statistical significance (D. Lajus *et al.* 2005, 2007b). In particular, the White Sea herring fishery, of economic importance since the eighteenth century, showed considerable short-term fluctuations of catches both because of social and natural factors and their interaction, which may confound climate effects (D. Lajus *et al.* 2007b). Climate effects were also pronounced on Arctic marine mammals such as white whales, Greenlandic seals, narwhals, and others, which considerably changed their distribution patterns migrating to more southern

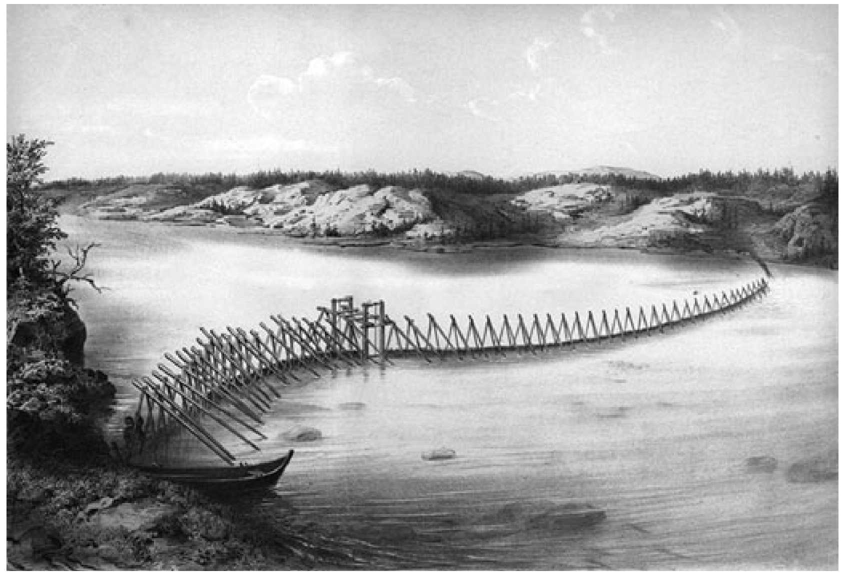

Fig. 1.6
Weir for catching Atlantic salmon at Kitsa River (tributary of Varzuga River). From the album "Risunki k issledovaniiu rybnykh i zverinykh promyslov na Belom i Ledovitom moriakh", St. Petersburg, 1863.

regions than usual in cold periods 1800–1809 and 1877–1903, and again in 1970–80 (D. Lajus *et al.* 2008b).

For marine mammals, anthropogenic pressure became a significant factor earlier than for fish. Hunting impacted the general dynamics of the population of the eastern walrus from at least the seventeenth century and may explain changes in its distribution range over several centuries. However, the walrus population was able to sustain itself as long as remote islands such as Franz Josef Land were not discovered by humans. Improvements of navigation and hunting techniques in the late nineteenth century resulted in a considerable decrease in the walrus population by the middle of the twentieth century. For fish, particularly Atlantic salmon, clear stress signals related to human activities such as overfishing and development of forestry with timber-rafting became apparent only by the end of the nineteenth century (Alekseeva & Lajus 2009).

Conducting fishing operations in such remote areas with severe climate conditions was especially difficult for humans in the pre-industrial age, causing clear interaction between natural and human factors. Fisheries productivity varied because of climate conditions, and, in particular, the price of salmon was negatively correlated with the level of catches and population abundance (J. A. Lajus *et al.* 2001). For herring, the long-term trend was a positive relation between catch size and human population in the area, likely reflecting an increase of fishing effort, emphasizing the importance of detailed historical analysis when reconstructing long-term trends of population abundance (D. Lajus *et al*. 2007b).

1.3.9 World whaling

Whaling was one of the most profitable extractive industries ever undertaken, and it was likely the one activity that impacted life in the oceans more than any other single pre-industrial activity. Relative to the fisheries it is extremely well documented and well researched (Fig. 1.7). Yet we still do not know how many whales there used to be in the ocean and where. Whereas historical fisheries research has really only developed in the past decade, the ecological history of whaling has been pursued for management purposes for many years. Since its origin in 1946 the International Whaling Commission has had a keen interest in estimating historical population sizes based on catch records in order to identify a conservation target for the rebuilding of whale populations. The approach taken by the HMAP team is to estimate historical abundance using population models based on the evidence of historical logbooks and catch records, and using present-day abundance estimates.

A global overview of the history of whaling identified 120 whaling operations grouped into 14 methodology-defined eras (Reeves & Smith 2006). Maps of the spatial and temporal extent of whaling in the nineteenth century allow resource managers to identify areas where populations have and have not recovered to their pre-whaling distribution, and to identify formerly occupied areas where whales are now essentially absent. Where recovery has been less than complete, human activities may need to be better managed to allow further recovery. Spatial distribution should become a more important element in assessing population recovery, in addition to the more usual measure based on current population size as a fraction of historical, or pre-whaling, population size.

The catch history of North Atlantic humpback (*Megaptera novaeangliae*) whaling was estimated by the HMAP team (Smith & Reeves 2006), and used in a stock assessment sponsored by the International Whaling Commission to estimate that current abundance is 37% to 70% of the historical abundance, which itself was 22,000–26,000. A previously unknown humpback whale feeding ground was

Fig. 1.7
Logbook for the ship *Abigail* of New Bedford, Benjamin Clark, master. The logbook was kept by Holder Wilcox during the November 19, 1831–June 12, 1835 whaling voyage to the North and South Atlantic and South Pacific Oceans. The logbook begins five days after the start of the voyage. Courtesy of New Bedford Whaling Museum.

identified based on nineteenth century whaling logbooks (Reeves *et al.* 2004), and the logbook data were used to help direct the Census Patterns and Processes of the Ecosystems of the Northern Mid-Atlantic (MAR-ECO) project (see Chapter 6). In the mid-nineteenth century some humpback whales migrating from breeding to feeding areas remained at mid-summer in oceanic habitats near the mid-Atlantic Ridge. Today humpbacks have only been known in summer months on coastal feeding grounds around the North Atlantic. Similarly, textbook assumptions on the distribution and abundance of North Pacific right whales (*Eubalaena japonica*) have been corrected (Josephson *et al.* 2008). The causes of failure of the North Pacific right whale to recover both numerically and spatially after the severe depletion of the 1840s continue to be a mystery.

Working as part of the HMAP New Zealand project, the team described the historical distribution and landings of southern right whales (*Eubalaena australis*) through analysis of over 150 whaling logbooks and other landings records. With 95% statistical confidence, population modeling shows that southern right whales numbered between 22,000 and 32,000 in the early 1800s, declining rapidly once whaling began. By 1925, perhaps as few as 25 reproductive females survived. Today the population has recovered to some 1,000 animals around sub-Antarctic islands south of New Zealand (Jackson *et al.* 2009).

Because of the strong need to establish past population sizes to inform conservation policy, the HMAP team is working closely with scientists who have proposed another possible modeling approach to working on historical landings data. This is the Whales Before Whaling project headed by Steven Palumbi at Stanford University. Palumbi's project aims to measure the amount of genetic diversity of current populations and use knowledge of DNA mutation rates to estimate how many individuals a population must sustain over time to accumulate the measured diversity. Based on this method, Palumbi estimates that the pre-contact population size of the eastern Pacific gray whales (*Eschrichtius robustus*) was three to five times larger than the population size calculated by historical data. The HMAP team has therefore scrutinized the available landings and total removals and, in cooperation with the US National Marine Fisheries Service and the International Whaling Commission's Scientific Committee, is working to address this apparent inconsistency between historical whale removals, apparent population increases measured over the latter half of the twentieth century, and the genetic variability model (T. Smith, personal communication).

We now know more about the human drivers behind the whaling operations. In particular the project focused on how the enormously profitable so-called Yankee whaling changed from 1780 to 1924. The team has documented the nature of the changes in vessels, rigging, destinations, and catches over the lifespan of this fishery. They suggest that questions of the effect of whaling on the whale populations must be asked at regional rather than global levels, and that indeed regional depletion, even extirpation, was a frequent occurrence (see, for example, Josephson *et al.* 2008; Jackson *et al.* 2009). For example, contrary to Whitehead (2002), they show strong depletion of sperm whale abundance in the Pacific and raise the question why such depletion apparently did not occur in the Atlantic (Smith *et al.* in press). They also suggest that global economic analyses that do not account for these regional changes (see, for example, Davis *et al.* 1997) greatly oversimplify the dynamics of this fishery and are misleading about the causes of its decline.

1.3.10 Megamollusks

Shellfish have been heavily collected and used for meat and ornaments through history. Although some shells will be traded, most will be discarded. Shell middens have been known since the nineteenth century as excellent archaeological sources of information on coastal-dwelling peoples. Through the nineteenth and twentieth centuries, the oyster reefs of the US Atlantic and Pacific coasts were severely impacted by fishing (Kirby 2004) as were North European oyster banks (Holm 2005).

Thanks to the initiative of Andrzej Antczak of Venezuela, we now have a global series of studies of human–megamollusk interactions. Generally, mollusk populations are quite exposed to human impact as they may be collected close to the shoreline. The southwest African HMAP project showed that human gathering of inshore shellfish may reach a level where it threatens certain inshore species. In Papua New Guinea the exploitation of the giant clam (family Tridacnidae), which seems to have been at sustainable levels through a long period of history, has in recent decades necessitated a ban on collecting for export (Kinch 2008). Similarly, although ecological impacts such as declining size may be detected for the pre-Hispanic exploitation of queen conch (*Strombus gigas*) beds off Venezuela (Fig. 1.8), the exploitation was much less harmful to the mollusk population than the short-term modern fishery between 1950 and the 1980s (Antczak *et al.* 2008). However, few human populations have been so dependent on mollusks for food to cause local or species extinctions (Bailey & Milner 2008).

The study of megamollusks is particularly rewarding for our understanding of human values and trade. The queen conch was heavily targeted between about 1100 and 1500 at the offshore islands of Los Roques, Venezuela, and both the meat and shells were brought to the mainland for consumption and redistribution. Ceremonial activity on the islands and the use of the queen conch as a symbol on the mainland indicate that the mollusk had achieved a central importance to north-central pre-Hispanic peoples in Amerindian Venezuela (Antczak and Antczak 2008).

1.3.11 Emerging projects

Two HMAP projects have not yet arrived at publication stage because they were only begun fairly recently: the New Zealand and the Southeast Asia projects. The Maori were experienced sailors and hunters, and on their arrival to New Zealand the Europeans encountered nothing like a pristine ecosystem. The Taking Stock project is therefore confronted with understanding fully the impact of pre-European, pre-industrial technologies on what was, until the arrival of the Maoris around 1300, a pristine marine and terrestrial ecosystem. The project will conclude by the end of 2010, but it is clear that the distributions and population sizes of seabirds, fur seals, and sea-lions were considerably impacted relative to pre-Maori conditions already by 1800. Fur seals, for instance, had been extirpated from North Island and only colonies at the southern tip of South Island awaited the arrival of European hunters to be ren-

Fig. 1.8
Pre-Hispanic mega-middens of queen conch (*Strombus gigas*) on La Pelona Island, Los Roques Archipelago, Venezuela, A.D. 1200–1500. Copyright Magdalena and Andrzej Antczak.

dered extinct. The Southeast Asia project covers a vast area and focuses on indigenous and American historical whaling in the Philippines, Taiwanese offshore tuna fishery, and shark fishing in Indonesia. All HMAP Asia research projects are now at an advanced stage, and a monograph (representing the main output of the project) is being prepared for publication by the end of 2010.

1.4 Conclusions

What is the big picture emerging from these regional and species projects? What is the scale of change between now at the completion of the Census and, say, 100 years, or between now and the origin of large-scale pre-industrial fisheries? When were the decisive moments? What were the main drivers? These are questions that we are grappling with now as the Census is coming to an end. Already we know some of the answers but many more will emerge as we have an overview of the vast amount of information that has been uncovered.

- The HMAP project has resolved the problem of the baseline. We now know that everywhere we look there is potential to know much more about the past and that we need to inform ourselves of the past both to enrich our understanding of the present and to inform our future preferences and decisions. The HMAP project is the beginning of the historical discovery of ocean and human interaction. Even after 10 years we have far from exhausted the archives and archaeology of the sea. We have made significant discoveries both of the importance of the sea to human life and of the impact of humans on the sea. Historical baselines should be an important element of future conservation plans. In some ecosystems, stocks will rebuild if given a chance. In other systems, regime shifts may have forever changed the food web so that past abundances of top predators will have a slim chance of rebuilding. Yet, environmental history has a very real role to play for future ocean policy by preserving the memory of what once lived in our seas. New management policies can be developed to promote recovery and prevent further declines of species and ecosystems.
- The distribution and abundance of marine animal populations change dramatically over time. The effects of climate variability during the Little Ice Age on marine mammals as well as fish stocks are clearly documented by the White and Barents Seas project and the Baltic Sea project, whereas the North Sea documents the effects of the past 20 years of warmer surface water for the introduction of southern species. Historical data will inform us of past patterns of distribution of species such as demonstrated for North Atlantic humpback whales and North Pacific right whales, and indeed for the southern North Sea haddock.
- We now know that major extractions occurred more than 2,000 years ago in the Mediterranean and Black Seas, we know the basic outline of the origins of commercial fisheries in Northern Europe, and we have a good sense of developments in many regions around the globe during the past 500 years ranging from the Caribbean to the White Sea, from southeast Australia to South Africa. Pre-industrial technologies were sufficient to put marine animal populations under severe stress, and indeed by the late nineteenth century extractions in Europe, North America, and the Caribbean had reached levels that would be equivalent to today's Total Allowable Catches. The effects of large-scale removals in the seventeenth century North Sea herring fishery and the eighteenth century Grand Banks cod fishery may have been significant.
- Regime shifts may have occurred as a result of some pre-industrial fisheries such as the Caribbean, whereas the effects of industrial gear were striking in the southeast Australian case when a pristine ecosystem changed dramatically after 30 years of trawling. Collapses of stocks and serial depletion are widespread phenomena, even before the industrial era, but in most cases populations have been able to rebuild.
- Overall it seems that the removals of large marine animals have reduced abundance by an order of magnitude; a recent review concluded that 256 exploited populations declined 89% from historical abundance levels on average (range: 11–100%) (Lotze & Worm 2009). The detailed historical evidence for cod, ling, and bluefin tuna corroborate this general picture. Smaller animals have been less impacted and indeed may have replenished as larger predators have been removed.
- Human impacts on coastal environments have been similar across the globe, even in quite different ecosystems (Lotze *et al.* 2006). Although few exploitable marine species have gone extinct, there is concern that entire marine ecosystems have been depleted beyond recovery. Major impact on sensitive ecosystems such as the Wadden Sea may have happened before 1900, and there is therefore a need for deep historical assessment of ecosystem change.

We know now that we can push back the chronological limits of our knowledge.

More importantly perhaps, we now have the basis from which to start raising new questions: what more can we know about the drivers of change from the human perspective, can we extrapolate from the local or regional to the global, what about the continents or large countries that did not have an HMAP team such as much of South America and Africa, what about India and China? Can we unlock the sources to some of the large industrial fisheries in the deep seas that have become such important fisheries areas in recent decades for already endangered species such as orange roughy and Patagonian toothfish?

All these are challenging but certainly not impossible questions. They are questions that will not only be raised but answered in coming years as research continues beyond the HMAP project. Data rescue and digitization will provide vastly increased libraries of the kind we already know and that have served us well. We are beginning to understand the main drivers of change from the human perspective such as changing patterns of consumption, technology, price differentials, politics, and cultural preferences. We now know enough to begin to understand the importance of marine products for human consumption, and we have a much better basis from which to assess the main drivers of human marine exploitation. In the academic realm the historical turn of marine ecology is now a given, and the ecological challenge to traditional historical models cannot be neglected. In the future, new techniques and methodologies may be used to move what may now seem the unknowable into the realm of the knowable. If knowing the basics of marine ecological history seemed impossible some 10–15 years ago, we stand a good chance that in the next 10–15 years there will be several major breakthroughs. Scientific advances in fields such as genetics and stable isotope analysis have already impacted what we know and much more is to come. Advanced computer animations and geographic information systems (GIS) will be fully used to show changes in abundances, distributions over time, and how they could look in the future (under recovery situations), and we shall see new quantitative approaches for modeling changes in biodiversity, species' abundance, and distribution.

Perhaps new methodologies will enable us to lift the veil on what the pristine sea looked like before human contact. So far nearly all the information accessible to us relates to early human records of contact. Certainly we shall know much more about the implications of the ice ages for "trapped" species. Advances of molecular biology and ocean biogeography will tell us of the separation of species and subsequent development. Sediment cores will be unlocked as a library of past DNA of what used to be swimming in the water column above. All of this will underline what was one of the first steps of the HMAP project, the need to train the next generation of researchers in interdisciplinary skills.

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