Marine Fisheries Ecology

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Preface

Fisheries play a key role in providing food, income and employment in many parts of the world. We might expect fishing to be a profitable and effective way of getting food, since fishers take harvests that they need not sow. Sadly, this is rarely true. Fisheries are often subsidized, wasteful, cause excessive environmental damage and ignite conflicts between otherwise friendly nations. Relatively few fisheries realise their potential benefits to fishers and society.

For many years, the main objective of fishery management was to maximize the yield taken from a fishery without compromising future catches. Intuitively, this seemed a simple and sensible objective, but in practice, there were good biological, sociological and economic reasons why it was rarely achieved. Not only were some fisheries so heavily fished that they collapsed, but they became economically inefficient and threatened species and habitats of conservation concern that were not their intended targets. Clearly, there is much scope to improve management of fisheries and the way we utilize the marine environment.

Fisheries science is now a more exciting and varied field of study than ever before. This is because contemporary management objectives are increasingly diverse, and our attempts to manage and conserve fisheries are based on a much broader scientific understanding of fishers and the fished ecosystem. Indeed, many fishery scientists are now asked to address biological, economic and social concerns. These range from dealing with uncertainty and reducing incidental catches of dolphins to ensuring that fished coral reefs remain attractive to tourists, that fisheries are profitable, and that conflicts between fishers are minimized.

Aims of this book

Effective fisheries management requires clear objectives and a decision-making process supported by the best scientific advice. The aim of this book is to give the reader a broad understanding of biological, economic and social aspects of fisheries science and the interplay between them. The overall emphasis, however, is deliberately ecological. By the time you have read this book we hope that you will appreciate:

- how physical and biological processes drive the production of fished species and why the abundance of these species changes in space and time;
- the scale, social and economic significance of global fisheries, the species that are caught and the gears used to catch them;
- the factors that motivate and limit human fishing activities and why fishers behave as they do;
- the economic, social and biological reasons why fished species tend to be overexploited and why governments and other authorities, including fishers, intervene to encourage sustainable fishing;
- how to make basic quantitative assessments of single and multispecies fisheries and to estimate the parameters needed for these assessments;
- the key strengths and failings of different fisheries assessment methods and the effects of uncertainty on the outputs;
- those aspects of the behaviour and life history of fished species, at individual and population levels, that make them vulnerable to fishing mortality;
- the impacts of fishing on marine ecosystems, birds, mammals, non-target species and habitats and what can be done to mitigate them;
- the objectives of fishery management and how fisheries can be regulated to achieve specific economic, social and biological objectives.

Why we wrote this book

Previous fisheries textbooks have concentrated almost exclusively on the mechanisms of stock assessment and management with little reference to the ecosystem in which the management practices are applied. However, students have often told us that they wanted to learn more about various fisheries-related issues that traditionally receive scant coverage in fisheries textbooks. These include trawling impacts, coral reef fisheries, discarding, seabirds, marine mammals, and poverty and conflict in fishing communities. They found it difficult to relate 'fisheries' courses that focused purely on quantitative assessment of population dynamics to many of the issues that confronted them in their own lives, the media and even in future employment. Thus, we wanted to write a book that reflected the global diversity of fished species, fisheries and fishing behaviour and showed how useful generalities could be drawn by working across conventional boundaries and treating fisheries as part of an ecosystem that includes the fishers. We also hope to convey our enthusiasm for fisheries ecology through our personal experiences and convince you that it is an exciting subject area that is helping to drive our understanding of marine ecosystems.

Plan of this book

We begin this book by introducing the world's fisheries, their diversity and history, suggesting why we need to conserve fisheries and the marine environment and discussing the main objectives of management. The remaining chapters can be divided into related groups that treat various aspects of fisheries ecology and their relevance to the assessment and management of fisheries. Chapters 2, 3 and 4 cover production processes, the species that are fished, the food chains that support them, and the factors that control the rates and variability of production. Chapters 5 and 6 consider the fishers: how and why people go fishing, the social importance of fisheries and the factors that affect the ways in which people fish. Chapters 7–11 deal with fishery assessment: how to assess the effects of fishing on target species, multispecies communities and ecosystems, bioeconomics, and how to get the data needed for assessments. Chapters 12–15 look at the wider effects of fishing, on community structure, diversity, population genetics, habitats, seabirds, marine mammals and species of conservation concern. In Chapter 16 we ask whether aquaculture can replace fishing as a source of protein, and in 17 we show how knowledge of production processes, fishers, assessment and fishing effects can be used to reach a range of management and conservation objectives.

We introduce most of the quantitative methods used for fisheries assessment but this is not a recipe book, and our emphasis is on why such models are needed, their assumptions and potential pitfalls. Many ideas are illustrated conceptually rather than mathematically, since several excellent texts already deal with quantitative stock assessment. For those who want to develop expertise in quantitative assessment we strongly recommend the excellent texts by Clark (1985), Hilborn and Walters (1992) and Quinn and Deriso (1999). These are packed with useful ideas and examples of their application. The history of fishery science and its contribution to wider ecological thinking are well described by Smith (1994).

Attention please!

Before you start reading we would like to draw your attention to the structure of this book. The chapters were written with the intention that they would be read in sequence, although each chapter has its own introduction and summary and can be read in isolation by the casual browser. We have referenced the text rather more extensively than many student textbooks. Our aim was to cite classic references from people who developed an idea coupled with contemporary sources that reveal the state of understanding that has now been achieved. These allow an easy lead-in to the research literature on a particular topic. For the reader who would like to know more, each chapter ends with a 'further reading' section. This lists 3–4 key books or reviews that develop ideas introduced in the chapter. Lecturers can download the figures that appear in this book from the Blackwell Science website (**www.blackwell-science.com/jennings**).

All places mentioned in the text are indexed on page 389 and their locations are shown on the accompanying map. Key terms are shown in bold at their first significant use and accompanied by a brief description. In the subject index, the pages on which these terms appear are shown in bold italic so the description can be found. The meanings of all symbols used in equations are given at their first usage and in the table on page 380. Note that biologists and economists often use the same symbols to denote different parameters. Common and species names are given in full at first usage and the taxonomic family to which they belong is shown in parentheses. This can be used to trace the taxonomic affiliation of the species in Tables 3.2 and 3.4. Common and scientific names of all species mentioned are indexed on page 393. The appendices also include a list of fisheries websites that provide a wealth of fisheries information and from which software, data and publications may be downloaded.

We hope you enjoy reading this book and find it useful.

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We hope to update and improve the book. Please send any comments, suggestions, gifts or abuse to us at 'Marine Fisheries Ecology' c/o Simon Jennings, CEFAS, Lowestoft Laboratory, NR33 0HT, United Kingdom, or e-mail mfe@cefas.co.uk.

Simon Jennings
Michel Kaiser
John Reynolds
July, 2000

1 Marine fisheries ecology: an introduction

1.1 Introduction

Humans have fished since prehistoric times, but in the last 50 years fisheries have expanded faster than ever before. Marine fisheries now yield around 90 million tonnes per year, more than 80% of global fish production. Catches have increased because a growing human population demands more food and because improved technology has simplified capture, processing, distribution and sale. Greater fishing power and increased competition between fishers, vessels or nations has led to the economic collapse of some fisheries that had flourished for centuries. The resultant reductions in fish production, income and employment are usually seen as undesirable by society. This is why governments intervene to regulate fisheries.

Effective fisheries management requires that managers work towards clearly specified objectives. These may be biological, economic and social. Thus, the fisheries scientist has to understand links between different disciplines and the ways in which science can usefully inform the manager. This chapter introduces the history and diversity of the world's fisheries, their current status and the main problems they face. This provides a basis for suggesting why we need to conserve fisheries and the marine environment and identifies the main objectives of fishery management.

1.2 Fisheries of the world

1.2.1 History of fisheries

Fisheries in ancient civilizations

Humans living in coastal areas have always eaten marine organisms. Initially, animals and plants were simply collected by hand from the shore, but more effective fishing methods were soon developed. Fish hooks fashioned from wood and bone have been found at sites dated 8000 BC, and there are references to fisheries in Greek, Egyptian and Roman texts. In Egypt, nets and spears were in use by 2000 BC. As the Pacific Islands were colonized, fish provided protein on islands with few other animal resources, and the successful migration of Melanesian and Polynesian people often depended on their ability to catch reef fish. Fishers were aware of cycles in the abundance of species they caught, and the Greeks used storage ponds and fish farms to ensure a continuity of supply. Latterly, fish could be preserved by salting and drying, allowing fishers to work further from their home ports and fish products to be traded and exported.

Pre-industrial fisheries

As nations developed their seafaring skills and began to explore the oceans, they discovered abundant fish resources. Explorers reported that huge numbers of cod *Gadus morhua* (Gadidae) could be found off Newfoundand, and by the early 1500s, French and Portuguese fishers were already crossing the north Atlantic Ocean to fish for them. The cod were caught with baited hooks, dried and shipped to the Mediterranean countries and the Antilles where they were known as ***bacalao*** and fetched high prices. Subsequently, English vessels joined the fishery. The countries that fished for cod were the major sea powers of the time and fought to control trade routes. They were often at war and many fishing vessels were lost. In the Anglo-Spanish war of 1656–1659, 1000 English vessels were sunk. Cod were such a valuable commodity that the vessels were also targeted by pirates. Moroccan pirates would rob vessels returning to Mediterranean ports, and the Sallee rovers, French, Spanish and English pirates under the Turkish flag, attacked fishing boats in so many areas that the fishers eventually sailed in convoy for protection. In later years, the cod fishery on Georges Bank and Grand Bank was increasingly fished by boats from New England ports. By the mid-nineteenth century, cod were caught with hook and line from fleets of eight or more small dories that transferred their daily catches to a larger schooner for storage in ice and salt. In 1880, some 200 American schooners with eight or more dories were operating (Cushing, 1988a; Kurlansky, 1997).

In Europe, pre-industrial fisheries flourished in France and in countries bordering the North Sea. Sardines *Sardina pilchardus* (Clupeidae) were caught with fine nets off the French Breton coast from the seventeenth century. Initially they were sold fresh but with the development of the oil press, sardine oil was distributed all over Europe. Canneries were opened from 1822. There were around 3000 boats in the fishery at the end of the nineteenth century. A tunny *Thunnus thunnus* (Scombridae) fishery developed in the same area. Five hundred boats would spend up to 2 weeks at sea and catch tunny with trolled lures. The tunny could also be canned successfully. Swedish (Scanian) fishers started to catch Atlantic herring *Clupea harengus* (Clupeidae) from the North Sea in the eleventh century, and by the late sixteenth century, large fleets from Sweden, Holland, England and Scotland all fished for herring. The fish were caught in drift nets and preserved in barrels with salt. The fishing industry would move from port to port as they followed the shoals of herring on their seasonal migrations (Cushing, 1988a).

Industrialization

The power and range of fishing vessels increased rapidly at the time of the Industrial Revolution, as did the demand for fish and fish products. In the 1860s paddle tugs powered by steam were first used instead of sailing boats to drag fishing nets in the North Sea. Calm weather no longer limited fishing activities, and catch rates were four times those of sailing vessels. At much the same time, steamers started to fish for Atlantic menhaden *Brevoortia tyrannus* (Clupeidae) off the east coast of the United States. From the 1840s, there was rapid development of industry and growth of the US economy. A modern farming industry was needed to feed the growing urban population, and fishmeal was a potentially cheap and accessible source of high-protein animal feed. The first **industrial fisheries** began to catch small and abundant shoaling fish that were ground and dried to make fishmeal. In 1840, Charles Mitchell of Halifax Nova Scotia started to preserve fish in hermetically sealed tins. Such canned products could be distributed and sold throughout the world. The markets for fish became more accessible as rail and road transport improved and consumers were increasingly concentrated in cities where they sought work in factories and service industries.

Similar patterns of development followed elsewhere as farmers demanded fishmeal, and urban populations demanded food. Fishery landings rose rapidly and continued to do so until the present time. Although we have seen that European vessels fished across the Atlantic for several centuries, steel fishing vessels with diesel engines and cold storage facilities made all the oceans accessible to fishers who could remain at sea for months at a time. These were the so-called '**distant water**' or '**high seas' fleets**. Japanese vessels fished the tropical and subtropical oceans for tuna, the former Union of Soviet Socialist Republics (USSR) fished for krill *Euphausia superba* (Euphausiidae) in the Antarctic, and Alaskan pollock *Theragra chalcogramma* (Gadidae) in the North Pacific. The greatest expansion in high-seas fisheries took place after World War II and the fleets, mostly from the former USSR, Japan, Spain, Korea and Poland, were catching between 7 and 8 million tonnes by the 1970s, over 10% of global landings at that time.

Control of the high seas

Traditionally, the oceans were regarded as common property and fishers were free to go where they liked. Although marine tenure systems were in place around many tropical islands, and fishers in temperate waters protected their local fisheries from outsiders, the 'ownership' of marine resources rarely extended more than a few miles from land. From the fifteenth century until the 1970s there was little restriction on where fishing took place in the world's oceans and what was done. It may seem strange that countries fished so freely in oceans many miles from their home ports when hunters could not take terrestrial mammals from countries without invading them and evading or repressing the local people, but the perception that land is owned and that the sea is open to all has persisted in many societies and for many centuries.

The existence of '**freedom of the seas**' had a powerful influence on the development of the world's fisheries. It was formalized in the sixteenth and seventeenth centuries when world powers decided to resolve ongoing and expensive conflicts over trade routes by allowing multinational access. In 1608, Hugo Grotius defended Holland's trading in the Indian Ocean in *Mare Lib-*

erum, and used fisheries to support his arguments for free access. He suggested that fish resources were so abundant that there would be no benefits from ownership and that large areas of national jurisdiction could never be defended. His argument prevailed and freedom of fishing became synonymous with freedom of the seas (FAO, 1993a; OECD, 1997).

However, as human populations grew and fisheries became more intensive, there was increasing conflict over fisheries. Scotland claimed exclusive national rights to inshore waters in the fifteenth century, and other countries followed. However, there was no international agreement on the size of territorial waters. The 1930 Hague Conference on the Codification of International Law decided that the claims to territorial seas were acceptable but did not suggest how large these claims could be. In practice, most countries claimed no more than a few kilometres of inshore waters while the high seas could still be fished by any nation with a suitable vessel.

Following World War II and two United Nations (UN) Conferences on the Law of the Sea, coastal states had greater expectations about the limits of their authority over fisheries. Many states increased their fishery limits to 12 miles (19.3 km) and by 1972, 66 countries had 12-mile limits. Even this did not satisfy countries with important fishing interests who were concerned about the status of 'their' stocks, and countries such as Iceland, where cod were fished by British and German distant water fleets, went to international court in an attempt to impose extended unilateral limits. This claim for jurisdiction was opposed by foreign fleets and led to the 'cod wars' of the 1970s (Burke, 1983).

Most 12-mile claims had little impact on the activities of high-seas fleets, but nations were increasingly concerned that they were not in control of their most accessible fish resources. Further territorial claims were inevitable. As early as 1947, Chile and Peru had claimed 200-mile jurisdiction, and by 1972 another eight countries had joined them. At the 1973 UN Conference on the Law of the Sea, the right to 200-mile limits was formalized. By 1974, 33 countries claimed this **extended jurisdiction** and another 18 joined them in the next 3 years. Since 90% of global fisheries yield was taken within 200 miles of the coast, these changes brought 90% of fisheries under national control. The catches of the high-seas fleets fell and many small island states were suddenly in control of vast fishery resources (Burke, 1994). The tiny Seychelles Islands in the Indian Ocean, for example, with a land area of 455 km^2 and population of 75 000, were now responsible for fisheries in an Exclusive Economic Zone (EEZ) of 1 374 000 km^2. Kiribati in the South Pacific, with a land area of 690 km^2 and population of 72 000, took control of an EEZ of 3 550 000 km^2, which included rich tuna fishing grounds. In subsequent years, small island nations would receive license payments from larger and wealthier nations who wanted to keep fishing in their EEZs. However, extended jurisdiction did not bring an end to battles over fisheries, and they continue to ignite conflicts between otherwise friendly fishers and nations (Fig. 1.1).

Fig. 1.1 Fisheries continue to ignite conflict between individuals and nations.

Recent trends in fisheries

Marine capture fisheries now yield 86 million tonnes per year, more than four times that from freshwater fish production and aquaculture (FAO, 1999). The first sale value of fished marine species is around $US50 billion. Fished species include vertebrates, invertebrates and plants. Fish dominate landings and account for 80% by weight of the total (Box 1.1). Although there are around 17 000 species of marine fish, 50% of fish landings are composed of just 20 species. The other groups that dominate landings are molluscs and crustaceans that are commonly referred to as shellfish.

Few areas of the ocean remain unexploited and economic costs rather than technology now limit fishing power. Around 3.5 million fishing vessels are in use and most shelf seas to depths of 200 m or so are heavily fished. The main fish-producing nations are Peru, Japan, Chile, China and the United States. Target species are generally decreasing in abundance, but the high efficiency of modern fishing vessels makes catching them worthwhile. In the developed world, even the smallest inshore fishing vessels carry acoustic devices to provide images of the seabed and locate shoals of fish, accurate navigation systems to pinpoint fishing grounds and powered drums and blocks to haul fishing gear.

Small-scale and artisanal fishers working from the shore, canoes or small boats account for 25% of the global catch and more than 40% of the catch for human consumption. The highly mechanized fisheries of the developed world contrast dramatically with subsistence fisheries in poorer countries where fish are a vital source of dietary protein and fishing may provide the only source of income (Fig. 1.2). In highly populated coastal regions of South-East Asia, Africa and Central America, people turn to the sea as a last possible source of food and income when no alternatives are available. The fishers are usually very poor, have little equipment and are sufficiently desperate to support themselves and their families that they do anything to maintain daily catches. In practice this may mean fishing with dynamite or poisons that destroy the fished habitat.

Despite the collapse of individual fisheries and the demise of some high-seas fleets, new resources have been exploited and total landings have risen steadily since 1950 (Fig. 1.3). Landings have increased because fishing effort has increased in response to growing demands for fish. Global landings are dominated by low-value species, such as anchovies and pilchards, which are mostly converted to fishmeals and oils for

Box 1.1
Catches and landings.

The fish and invertebrates that fishers bring ashore are often called **'catches'** or **'landings'**. Strictly speaking, these terms are not synonymous, since much of the catch is discarded at sea and never landed (Chapter 13). Landings statistics compiled by the FAO and other organizations reflect the quantities of fished species brought ashore, and not necessarily the quantities caught.

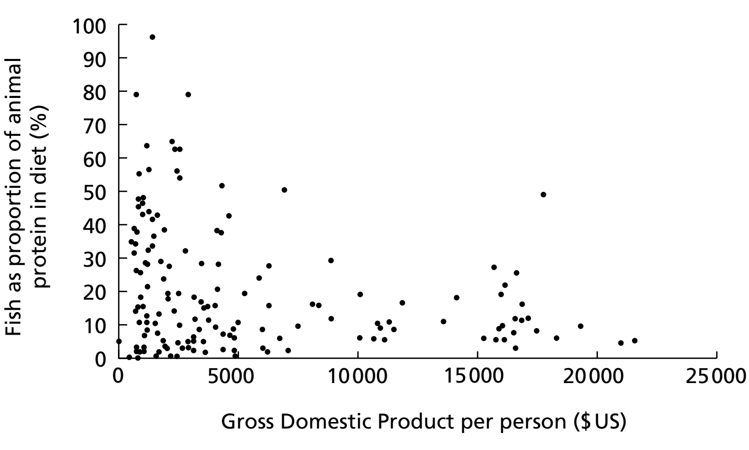

Fig. 1.2 Relationship between the proportion of fish protein in human diets and the relative wealth of nations where those people live. Wealth is measured as the total gross domestic product (GDP) divided by the population size. GDP is the total income of a country from all sources. After Kent (1998).

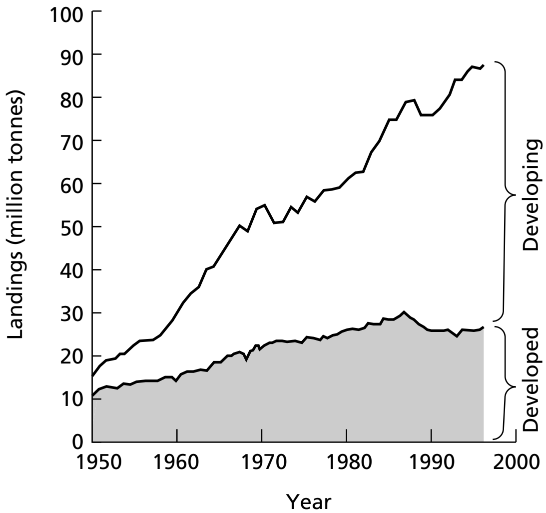

Fig. 1.3 Landings of marine fishes and invertebrates by economically developed countries (shaded) and developing countries (unshaded). Data from OECD (1997) and FAO (1999).

farming and food manufacture (Fig. 1.4). Despite the steady rise in overall landings, landings of individual species fluctuate widely. Catches by high-seas fleets rose and then fell with the imposition of extended jurisdiction (Fig. 1.5). At present, landings in less developed nations are rising faster than those in developed ones. This is partly because most resources in developed countries have already been located and fished as heavily as they can with the available technology. In developing countries, conversely, the availability of new technology and external funding has allowed access to new and lightly exploited resources. Developing countries took 27% of global landings in 1950 but now take over 60% (OECD, 1997).

Since 1950, the effort (e.g. time at sea or fuel consumed) needed to catch a given weight of fish has increased. Technological development and increases in fleet size meant that total yield rose, but for many vessels fishing was no longer cost effective and government subsidies kept vessels at sea and fishers in jobs. Of course, their continued activities further depleted stocks and made fishing even less profitable. In 1989, the former USSR fleet was estimated to have operating costs of $US10–13 billion and yet their landings of around 10 million tonnes of low-value species were worth $US5 billion. This left a deficit of $US5–8 billion, to be met by subsidy (FAO, 1994).

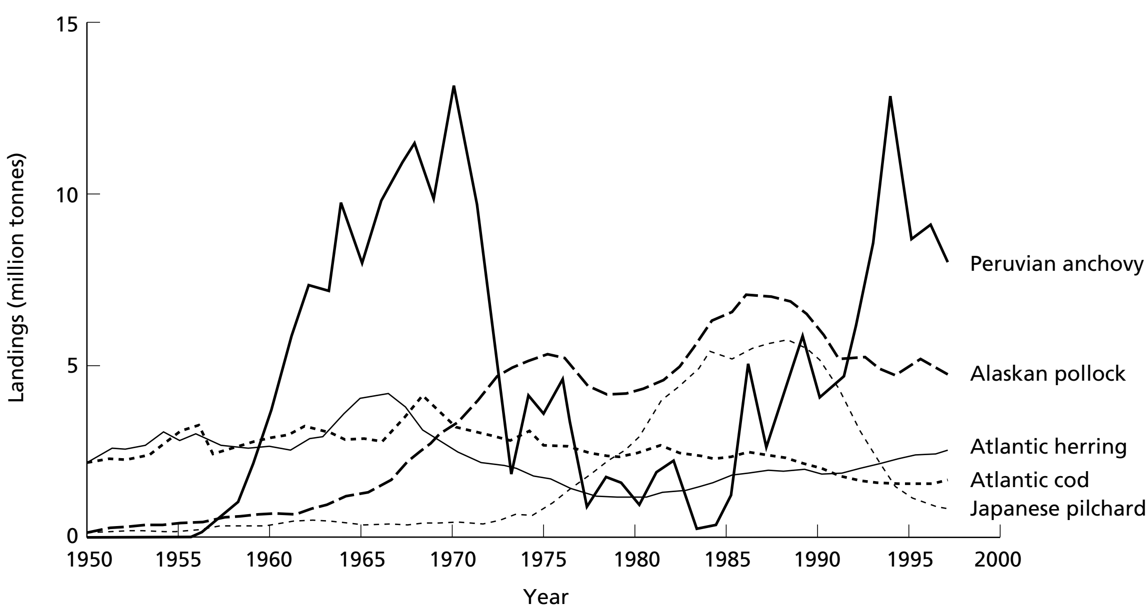

Fig. 1.4 Landings of the five marine species that have dominated global landings since 1950. These species are: Peruvian anchovy, *Engraulis ringens* (Engraulidae); Alaskan pollock, *Theragra chalcogramma* (Gadidae); Atlantic herring, *Clupea harengus* (Clupeidae); Atlantic cod, *Gadus morhua* (Gadidae); and Japanese pilchard, *Sardinops melanostictus* (Clupeidae). Data from FAO (1995a, 1999).

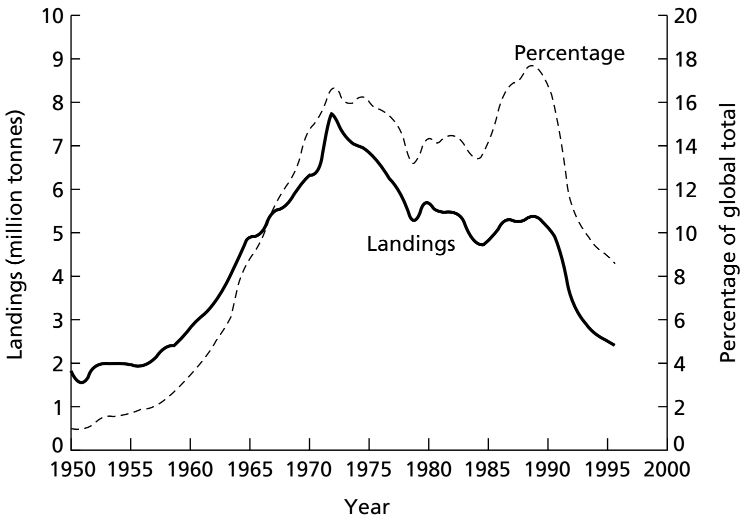

Fig. 1.5 Landings by distant water fishing nations (high-seas fleets) since 1950 and their landings as a proportion of the global total. After FAO (1999).

1.2.2 Fishery science

Fishery science has been recognized as a scientific discipline since the late 1850s, when the Norwegian government hired scientists to find out why catches of Atlantic cod fluctuated from year to year (Smith, 1994). Cod had been caught off the Lofoten Islands in northern Norway for several centuries and the local people relied on them for food and income. As in the Newfoundland fishery, cod were caught with lines and preserved by drying. The money made from exporting dried cod was used to import other foods and to pay traders and bank loans in southern Norway. If the cod fishery failed, then the people of northern Norway would default on their bank loans. For the Norwegian government, fluctuations in the cod fishery caused economic and political strain.

Soon, fishery scientists were also working in Germany, Sweden and Russia, and within 20 years fisheries research was in progress in the United States, Denmark, the Netherlands and the United Kingdom. Scientists were increasingly concerned that fluctuations in abundance could be driven by fishing. At the Great International Fishery Exhibition, held in England during 1883, Thomas Huxley, then president of the Royal Society, declared that 'the cod fishery, the herring fishery and probably all the great sea fisheries are inexhaustible; that is to say, that nothing we do seriously affects the numbers of fish'. Although his statement is often used to suggest that people were generally unaware of the finite limits to natural resources at that time, Huxley himself had qualified many of these remarks, and many fishers in Europe had reported declining catch rates. Moreover, tens of generations of people who depended on the reef fish resources of tropical islands were well aware they could not sustain intensive harvesting and were forced to move to new islands as they depleted fish stocks. There was a growing scientific consensus that research was needed to identify the effects of fishing, and new laboratories were established in Europe and North America (Cushing, 1988a; Smith, 1994).

By the end of the nineteenth century, scientists had developed techniques for ageing fish and tagging them to follow their migrations, but had not shown why catches varied. Work focused on whether killing small fish, before they were able to spawn, would cause catches to fall, whether fishing affected the size and abundance of fish, and what could be learnt from the collection and analysis of catch and effort data from the fishery. The major breakthrough came early in the twentieth century, when a Norwegian scientist, Johan Hjort, showed that the abundance of a year class of fish was established within the first few months of life and that renewal of fish stocks did not take place by a constant annual production of young but by highly irregular annual production with a few fish surviving in most years and many fish surviving in a very few years.

Changes in the rate of survival would cause fluctuations in catches. Soon, fisheries scientists would predict catch rates in some of the larger fisheries by measuring the abundance of young fish in the years before they grew large enough to be caught by fishers.

The number and efficiency of vessels fishing increased rapidly in the years before World War I and the fish caught were getting smaller and less abundant. During World War I, military activity led to a drop in fishing effort, and when the war ended in 1918 fishers caught larger fish and enjoyed higher catch rates. It was clear that the reduction in fishing effort during the war allowed fish populations to recover from the effects of fishing, and fishery science increasingly focused on understanding these effects. By the 1950s, 100 years after fisheries science had begun, models that described the dynamics of fish populations and their responses to fishing were developed by scientists working in the United States, England and Canada. These predicted the yields from fisheries when fish were killed at different rates and provide the background to much of the science we describe in this book. In subsequent years, fishery science would play a leading role in the field of ecology as a whole, describing why populations fluctuate and how population structure changes in space, time and in response to increased rates of death imposed by humans.

Many countries had interests in the same fisheries and there was strong international cooperation between fishery scientists. In 1902, the International Council for the Exploration of the Sea (ICES) was established in Europe and set up a number of international programmes to examine the effects of fishing. Despite the cooperation between scientists, only two fisheries were managed internationally before World War II, the Pacific halibut *Hippoglossus stenolepis* (Pleuronectidae) and Baltic plaice *Pleuronectes platessa* (Pleuronectidae). After the war, many new scientific and regulatory bodies were established. The International Commission for North-west Atlantic Fisheries (ICNAF) and the Inter-American Tropical Tuna Commission (IATTC) formed in 1949, to be followed by a series of Food and Agriculture Organization (UN) commissions.

In the late twentieth century, concerns about fish stock collapse, the uncertainty that underlies fisheries assessment and the recognition that management objectives do not relate solely to the fished stock, has led to a diversification of fisheries science. There is increasing input from sociologists and economists who consider how different management strategies will affect the lives and incomes of fishers and associated communities. There is also greater emphasis on the effects of fishing on the marine environment and the impacts on species or habitats of conservation concern. Fisheries laboratories are found in many countries around the world, many fisheries are assessed by more than one country and international fisheries statistics are collected by the Food and Agriculture Organization of the United Nations (FAO) (Box 1.2).

1.2.3 Diversity of fisheries

The sheer diversity of fisheries makes fisheries science a fascinating field. Fishers are found on almost any coastline and working in any ocean. At one end of the spectrum a woman will fish daily with hook and line from a coral reef flat in Kiribati to supply food for her family. She winds the line on a simple spool and holds the bait and catch in a bag of woven palm leaves. She collects small crabs from the shore to use as bait and may glean shellfish for food at the same time. Most of her fishing is done within a few hundred metres of her village and total investment in fishing equipment is

Box 1.2
International assessment and management of fisheries.

For the purposes of collecting fisheries data, the FAO divides the world's oceans into Statistical areas shown in Fig. B1.2.1 and listed in Table B1.2.1. International fishery management areas are not necessarily the same as the FAO statistical areas. There are many international fisheries organizations that try to develop rational management policies for fish that migrate across national boundaries. Some examples are given in Table B1.2.2.

References: FAO (1994, 1999) OECD (1997).

Continued p. 8

Box 1.2 (*Continued*)

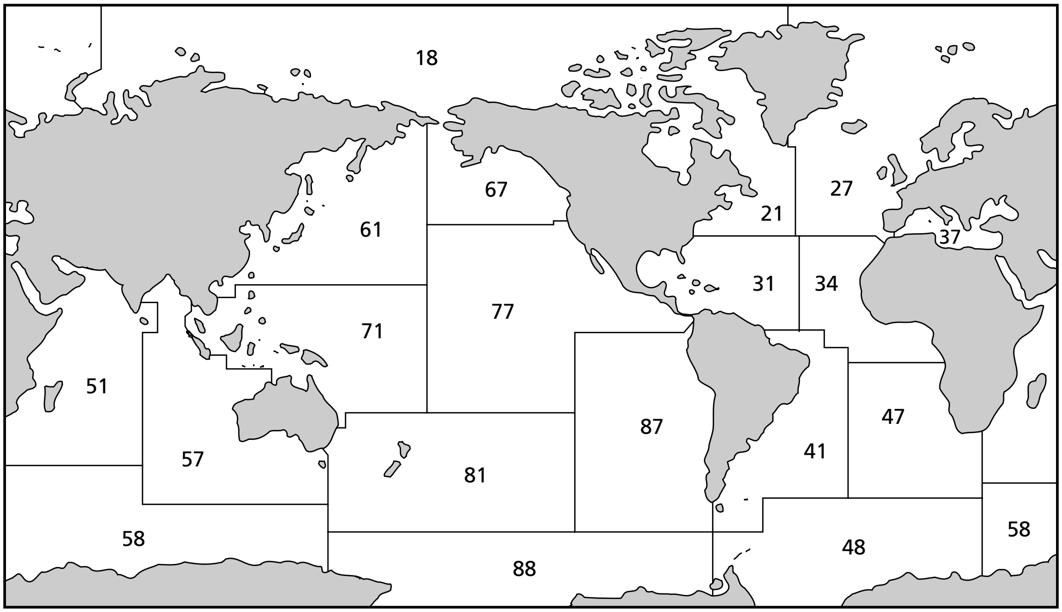

Fig. B1.2.1 Boundaries of FAO statistical areas.

Table B1.2.1 FAO statistical areas.

Area code	Statistical area	Area (million km^2)
Atlantic Ocean and adjacent seas		
18	Arctic Sea	7.3
21	North-west Atlantic	5.2
27	North-east Atlantic	16.9
31	Western Central Atlantic	14.7
34	Eastern Central Atlantic	14.0
37	Mediterranean and Black Sea	3.0
41	South-west Atlantic	17.6
47	South-east Atlantic	18.6
48	Atlantic Ocean–Antarctic	12.3
Indian Ocean and adjacent seas		
51	Western Indian Ocean	30.2
57	Eastern Indian Ocean	29.8
58	Indian Ocean–Antarctic	12.6
Pacific Ocean and adjacent seas		
61	North-west Pacific	20.5
67	North-east Pacific	7.5
71	Western Central Pacific	33.2
77	Eastern Central Pacific	48.9
81	South-west Pacific	28.4
87	South-east Pacific	30.0
88	Pacific Ocean–Antarctic	10.4

Continued

Box 1.2 (*Continued*)

Table B1.2.2 Examples of International fisheries organizations.

Organization	Founded	Countries	Fisheries
International Pacific Halibut Commission (IPHC)	1923	United States, Canada	Pacific halibut
North-west Atlantic Fisheries Organization (NAFO)	1979	European countries, United States, Canada	Pelagic and demersal stocks
North-east Atlantic Fisheries Commission (NEAFC)	1963	European countries, Former USSR, Eastern Europe, Iceland, Norway	Pelagic and demersal stocks
Inter-American Tropical Tuna Commission (IATTC)	1949	North, Central and South American countries, France, Japan, Vanuatu	Tuna
Convention for the Conservation of Southern Bluefin Tuna (CCSBT)	1994	Australia, Japan, New Zealand	Bluefin tuna
Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR)	1982	Most economically developed countries	Various

probably less than $US1. At the other extreme, a purse seining vessel pursues schools of tuna over the entire Pacific Ocean using satellite navigation devices. The vessel carries a helicopter to search for fish, a crew of 35 and costs $US40 million. One catch may weigh 30 tonnes and can be frozen to –20°C in a few hours. After several weeks at sea the frozen fish are delivered to a processing plant where they are thawed, cooked and canned for distribution to all the continents of the world. Between these extremes, fishing ranges from trawling for prawns in the muddy waters off Louisiana in the United States to hand-netting fish for the aquarium trade in Sri Lanka.

We will introduce many fishing methods in subsequent chapters, but hope that Figs 1.6 and 1.7 capture some of their variety. It is vital to appreciate this variety because fisheries provide different things for different people and thus the objectives of management differ too. Thus, the provision of a constant food supply may be essential for the small fishing villages in Kiribati while maximum profitability may be essential for a multinational company that catches tuna for canning. Despite the diversity of fisheries, many common principles describe the way in which fished species respond to fishing and the effects of fishing on the environment. Fisheries scientists realize that research in tropical waters can usefully inform scientists working in temperate waters and vice versa. We have attempted as far as possible to use examples that reflect the global diversity of fisheries.

1.3 Patterns of exploitation

1.3.1 Boom and bust

Fisheries are not static, as any study of the history of exploitation will show. Fisheries develop, some fish stocks collapse, some fishers get rich, other fishers go bankrupt and move elsewhere and into other jobs. An examination of numerous fisheries around the world shows that when a potentially fishable resource is discovered, new fishers start to explore its potential and begin exploitation as soon as possible. Indeed, on an individual basis, the faster they can exploit the new fishery the more income they will receive. Other fishers who find out about the new fishery and think it has more potential than their own will join the race to fish there. Eventually, there will be too many fishers chasing too few fish, the stock will be depleted and catch rates and profits will fall. Once fishing is no longer profitable,

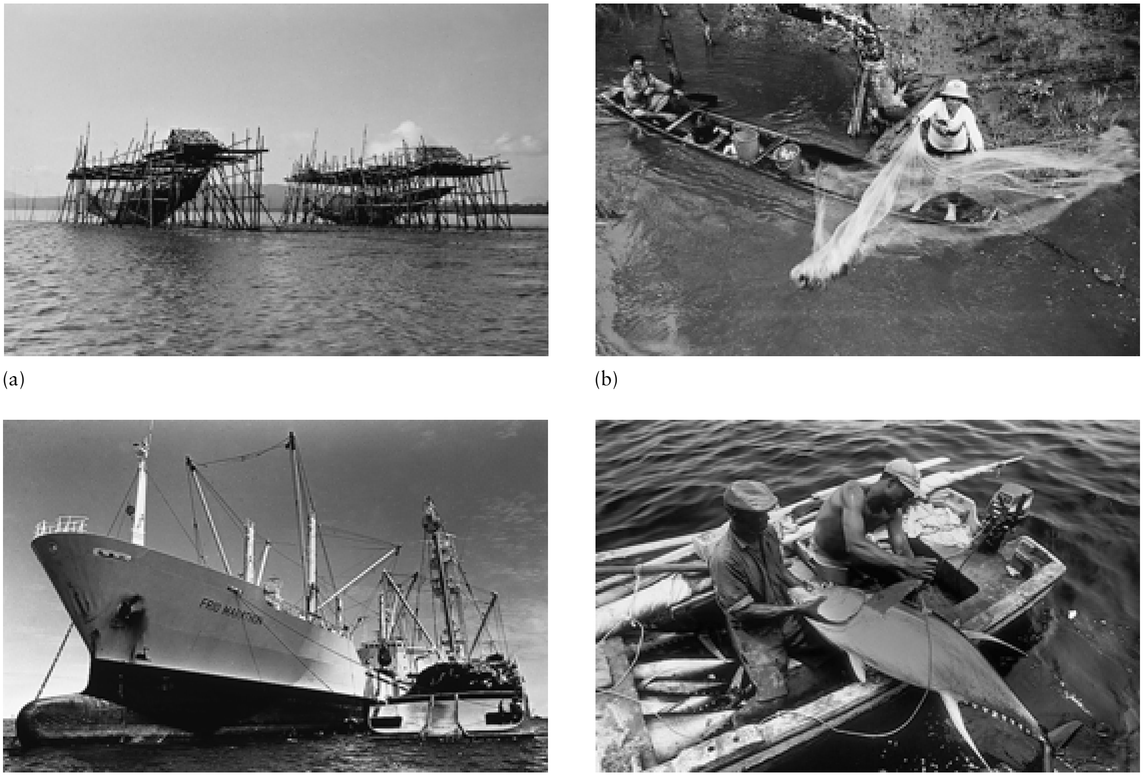

Fig. 1.6 The diversity of fisheries. (a) Fish traps set in the Lupar Estuary in Sarawak to catch prawns and small fish (see Blaber, 1997), (b) cast-netting for prawns in a small estuary near Mukah, Sarawak, (c) a tuna purse seiner trans-shipping catches to a freezer vessel in the Seychelles, and (d) tuna fishing from a small boat off Cape Verde Islands (d). Photographs copyright S. Blaber (a, b), S. Jennings (c), M. Marzot (FAO photo, d).

the fishers who can will redirect their energies, but those who cannot may continue to fish the depleted stock. To avoid the unemployment and social costs from fishers becoming bankrupt, governments may subsidize fishers to continue exploiting the depleted stock. By this stage, production of the stock is minimal and it will either recover because fishers shift their attentions elsewhere, or collapse, because fishers have no choice but to keep fishing.

Fishers can exploit fisheries at rates exceeding their capacity for replenishment. As this occurs, so the fishery passes through a series of phases (Fig. 1.8). These can be described as fishery development, full exploitation, over-exploitation, collapse and recovery (Hilborn & Walters, 1992). During each of these phases, there are clear trends in the abundance of fished species, fleet size (or fisher number), catch and profit. While the trends rarely follow the smooth and necessarily stylized curves shown in Fig. 1.8, the general patterns are consistent.

As a new fishery develops so more fishers or boats enter the fishery because it is profitable for them to do so. The fishers who start fishing first, or catch most with least effort, will make the greatest profit. During **fishery development**, the effects of fishing are seen as a slight reduction in catch rates and the size of individuals in the catch. Total catch will rise as fishing effort increases. Prior to industrialization and the human population boom on many tropical coasts, fisheries often stayed in the 'development' phase and replenishment was easily fast enough to counter the effects of fishing. As more fishers enter the fishery, it passes through the fully exploited phase. Here, abundance falls and total catch increases. During the **fully exploited** phase replenishment is sufficient to maintain fish production and hence

(a)

(b)

(c)

(d)

Fig. 1.7 More diversity of fisheries. (a) Unloading sardines from a coastal purse-seiner in the Portuguese port of Aveiro, (b) a Japanese squid jigger sailing to fishing grounds off Hokkaido, (c) fishing with dynamite on a reef in the Philippines, and (d) a large catch of demersal (bottom dwelling) fish on a Russian stern trawler. Photographs copyright *Fishing News International* (a, b, d) and T. Heeger (c).

catches. If yet more fishers enter the fishery, their catching capacity will exceed the rate of replenishment (**over exploitation**). This usually leads to a fall in profits because more fishers are competing for a dwindling resource. As profits tend to zero, so fishers stop entering the fishery. Total catch will peak close to the time when the number of fishers reaches a maximum, and subsequently fall as abundance and the capacity for replenishment is reduced. If fishing effort is not reduced then the fishery will ultimately **collapse**, with marked falls in abundance and catch. Following collapse, the fishery will no longer be profitable. If fishers can afford to leave the fishery they usually will, and **recovery**, the rebuiding of stock biomass, may begin. In other cases, the fishers' only option will be to stay because they have to keep fishing to pay loans on boats and equipment.

We will now look at four examples of the many fisheries that have followed this common pattern. They are for different species, in different countries and have been overexploited on different time scales.

The Chilean loco

The loco *Concholepas concholepas* is a muricid gastropod (family Muricidae, subclass Prosobranchia). It is collected from the seabed by divers and is the most economically important shellfish in Chile. Loco are widely eaten in Chile and provide a very valuable export to Asian markets. From 1960 to 1975, 2000–6000 tonnes of loco per year were collected and sold for domestic consumption. The fishery appeared to be sustainable, and divers could make a good living from the fishery. However, in 1976, divers began to collect loco for sale and export. The fishery developed rapidly as more fishers became loco divers and by 1981 annual export revenue

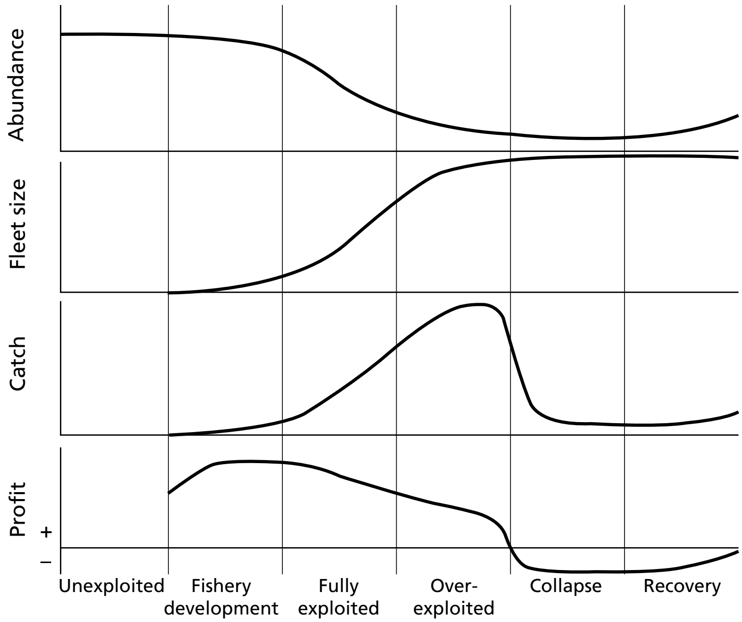

Fig. 1.8 Trends in the abundance of fished species, fleet size or fisher number, catch and profit as a fishery is developed and exploited through to collapse and recovery. Based on Hilborn and Walters (1992).

had exceeded $US20 million. Landings peaked at 25 000 tonnes in 1980, but the abundance of loco and the catch rates of many divers were falling fast. In the mid-1980s the fishery collapsed, with divers losing their incomes or jobs and coastal communities suffering from reduced economic activity and trade. The Chilean government intervened and closed the fishery completely in 1989. When it was reopened, strict catch limits were imposed. The fishery is now recovering slowly (Bustamante & Castilla, 1987; Castilla & Fernandez, 1998).

The Californian soupfin shark

Before 1937, the soupfin shark *Galeorhinus galeus* (order Carcharhinformes) was caught in small numbers off the Californian coast. The flesh was sold as shark fillet and the fins were dried for export to Asian markets where they were used in shark fin soup. In 1937, nutritionists discovered that the livers of soupfin shark were the richest known source of vitamin A. Vitamin A was in great demand as wealthier Americans began to worry about what they were eating and considered the health benefits of vitamins and minerals. Fishers knew that soupfin shark were abundant, but demand for the livers was so high that the price of sharks rose from $US50 to $US1000 within a few years. The fishery developed rapidly, and many boats switched from other activities to catch sharks. Hook and line was the favoured fishing method in early years, but latterly nets were used as these increased the catch rates. Landings peaked in 1939 at over 10 times the levels prior to 1937, and 600 boats were operating in the fishery. These catch rates were not sustainable and the fishers found it increasingly hard to catch sharks as abundance fell. By 1944, the fishery had effectively collapsed. Many fishers became bankrupt and others reverted to their former fishing habits (Ellis Ripley, 1946).

The Galápagos sea cucumber

Sea cucumbers (Holothurians) have been exploited throughout the Pacific for several centuries, and provide many examples of boom and bust fisheries. Sea cucumbers, often traded as *bêche-de-mer*, are cooked and dried after they have been collected from the seabed by divers and can be stored dry for many months. They are mostly exported to markets in Asia and the Pacific rim countries, where they are used to thicken and flavour soups and other dishes. Until the 1990s, the Galápagos Islands was one area where the fishers had not been. However, the waters around Galápagos had been increasingly fished by Korean tuna vessels and fishers learnt that the sea cucumber *Isostichopus fuscus* (class Holothurioidea) was abundant. Exporters soon established a market, and in 1992 there was a sudden and massive expansion of the sea-cucumber fishery. Fishers could make more money from a day of sea-cucumber diving than from a month spent catching fin fish for local markets. Local people switched from other types of fishing to dive for sea cucumbers and when people in mainland Ecuador saw how much money could be made they flocked to the islands with their families. The fishers, known locally as pepineros, set up camps for cooking and drying the sea cucumbers on protected islands in the National Park. The camps caused great concern for conservationists who wanted to prevent the introduction of new species and saw pepineros arriving with rats, cats and dogs. The influx of money to the Galápagos changed the lives of many Ecuadorians, and traders became very rich. At one stage a local prostitute was demanding payment in sea cucumbers. The Ecuadorian government attempted to ban the fishery, but the momentum was too strong. Faced with violent protest that threatened the island's stability and the valuable tourist industry, and with the deliberate slaughter of rare tortoises in the National Park, the government revoked the controls and the fishery continued unabated.

The Galápagos fishery grew so fast that the whole cycle of fishery development through to collapse was complete in only 5 years. Sea cucumbers are now so scarce that fishing them is not worthwhile, and the pepineros who moved to the islands have to make money in other ways. This has led to increased fishing pressure on other resources which were formerly seen as sustainable.

The Canadian cod

Our final example shows the cycle from development to collapse over a much longer time scale. In section 1.2.1 we saw that cod, *Gadus morhua*, were caught off Newfoundland in the early 1500s, but in 1992, after almost five centuries of fishing, these were fished to commercial extinction. Cod were largely caught with hook and line until the early 1900s, and although the fishery supported many fishers and provided good economic returns, the replenishment of the stock was fast enough to sustain the fishery. In later years, more effective fishing techniques such as bottom trawling, traps and gill nets were used. Landings of the so-called northern cod increased from 100 000 to 150 000 tonnes per year from 1805 to 1850 and reached 200 000 tonnes at the end of the nineteenth century. Factory freezer trawlers from Europe started fishing northern cod in the 1950s and landings rapidly increased from 360 000 tonnes in 1959 to a peak of 810 000 tonnes in 1968. In 1977 Canada extended jurisdiction to 200 miles and took over management of the stock. The stock was already overexploited and landings were now 20% of 1968 level. Under Canadian management the stock continued to be fished at low but increasing levels and in 1992 the stock finally collapsed and the Canadian government closed the fishery. The size of the spawning stock had fallen from an estimated 1.6 million tonnes in 1962 to 22 000 tonnes in 1992. The collapse was a disaster for a Canadian fishing industry that had few other resources to turn to, and the government had to support many fishers with welfare payments (Hutchings & Myers, 1994).

Other fishery collapses

Our examples are not unique. Similar stories of development and collapse apply to whales, fur seals, sea-lions, turtles and other species of fish. Marine mammal and turtle populations were hunted to such low levels that they contributed a fraction of 1% to global fisheries yield in the 1990s, and many species are protected by conservation legislation. The indirect impacts of fishing on these species are now the main concern, and we deal with these, rather than the few remaining fisheries directed toward them, in this book. However, the history of whale fishing can provide some important lessons for the fisheries scientist. Sperm and right whales, which were the most accessible to fishers with simple harpoons and rowing boats, were hunted from the twelfth century. As their populations declined, and new technologies such as powered vessels and explosive harpoons were developed, so the whalers could target larger and faster species such as blue, fin and sei whales. These populations were also hunted much faster than they could reproduce and became increasingly scarce. Thus, the whalers would reduce one species as far as possible with the available technology and then move on to another. This is shown very dramatically in Fig. 1.9, which illustrates catches of five species in the Antarctic Ocean (Allen, 1980). These landings data show fisheries for the blue whale developing and collapsing, to be followed by similar development and collapse for fin, sei and minke whales. Later in this book we will see that fishers often maintain yields by

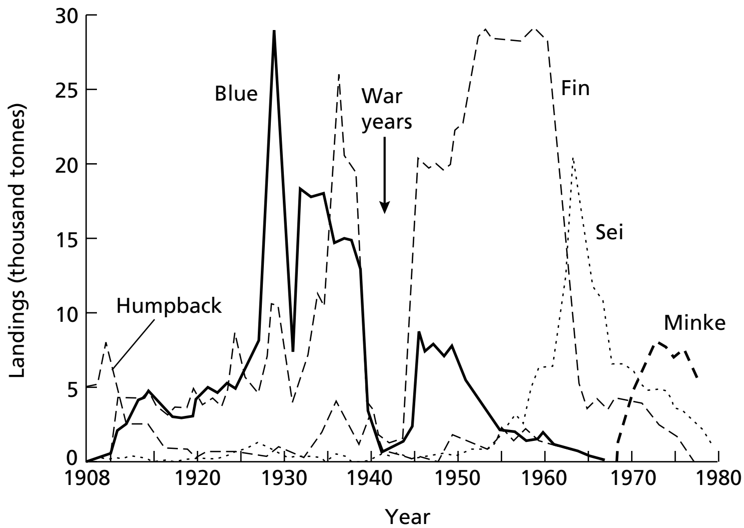

Fig. 1.9 Landings of whales in the Antarctic Ocean. Catches of all species dropped during World War II. After Allen (1980).

shifting from species to species as the most desirable ones are depleted.

1.3.2 Conservation and ecosystem concerns

For many years, fisheries scientists tried to provide advice that could be used to prevent the overexploitation or collapse of fished stocks. However, the increasing intensity of fishing throughout the world has had impacts on the marine ecosystem other than those on target species and these impacts are now the focus of many research and management programmes.

In many fisheries, species of fish, seabirds and marine mammals are caught on lines or in nets when the fishers are pursuing other species. Skippers of tuna fishing boats in the eastern Pacific Ocean would set their nets around dolphins because these often swam above tuna and marked their position. However, when the nets were hauled, many dolphins would be trapped and killed. As a result, populations of spinner *Stenella attenuata* and spotted *Stenella longirostris* dolphins fell to around 20% and 45% of pre-exploitation levels between 1960 and 1975 (Allen, 1985). Baited hooks on long-lines set in the Southern Ocean to catch bluefin tuna *Thunnus maccoyii* (Scombridae) and Patagonian toothfish *Dissostichus eleginoides* (Nototheniidae) would be taken by seabirds such as wandering albatross *Diomedea exulans* before they sank. These long-lived birds cannot reproduce as fast as they are being killed and are now threatened with extinction. In the Irish Sea, the large common skate *Dipturus batis* (Rajiidae) is caught in towed nets that are used to catch other bottom-living species. Because the target species are usually much smaller than the common skate, the nets have relatively small mesh and any common skate that passes into the net will be caught. The common skate only reaches maturity after 12 years and has a very low reproductive rate. The abundance of these fish has been so reduced by fishing that they are rarely recorded in catches (Brander, 1981). Similar reductions have recently been recorded for other skate species in the same area (Dulvy *et al.*, 2000).

Other concerns about the ecosystem effects of fishing focus on the impacts of towed gears on benthic fauna and habitat, the impact of fishers who use dynamite and poisons on coral reefs, and the effects of fishery waste on populations of scavenging birds and fish. Fishing can also affect food webs by removing predators, such as fish that eat other fish, or prey, such as small shoaling fish that are eaten by seabirds and marine mammals. We consider these effects, what is known about them and what can be done to mitigate them.

1.4 Why manage fisheries?

Fisheries are managed because the consequences of uncontrolled fishing are seen as undesirable. These consequences could include fishery collapse, economic