Banishing Ignorance: Underpinning Fisheries with Basic Biology

PAUL J.B. HART AND JOHN D. REYNOLDS

1.1 INTRODUCTION

Tourists mingle with local people among the stalls set out by Zachariasbryggen, Bergen, Norway. Young men and women in bright orange oilskin overalls, fluent in several languages, sell fresh crabs (*Cancer pagurus*), lobsters (*Homarus gammarus*), mackerel (*Scomber scombrus*), cod (*Gadus morhua*) and farmed salmon (*Salmo salar*) to Japanese, German, British, American and Dutch tourists. People from Bergen buy their supper as they pass by during their lunch break. Unseen by the mill of tourists and locals are thefishers who started from port at four in the morning to set their nets, go trawling or lift their crab pots. If you travel about a kilometre along the western shore of Vågen, the bay surrounded by the centre of Bergen, you come to Nordnes, the location of the Institute for Marine Research, the public aquarium and the offices of the Norwegian Fisheries Ministry. The tall building is full of biologists working on fish stock assessments and on research into the marine environment. At the Fisheries Ministry the coastguard and fisheries officers plan and execute monitoring programmes and quota allocations. On the other side of Vågen can be found the Bergen Fisheries Museum as well as the warehouses and factories of fish processing and distribution firms. On the southern edge of the city centre, scientists in the Department of Fisheries and Marine Biology of the University of Bergen are researching the ecology of marine organisms, work that underpins the conservation of biodiversity. This area of Bergen, covering perhaps 2 km², contains all the elements of the community that the two volumes of this book are designed to serve. In other parts of the world the various institutions of fisheries are not as close to each other as they are in Bergen but the elements will be some local version of what exists around Vågen. The heart of the system is the fisher and the market at which the produce is landed and sold.

1.2 GLOBAL FISHERIES

According to the United Nations Food and Agricultural Organization (FAO), there was a steady increase of fish catches until the middle of the 1990s when the catch began to level off (Fig. 1.1). Recent work by Watson and Pauly [2001] has shown that in reality the total marine catch of fish has been declining by some 10% a year since 1988. The apparent continued increase until the mid-1990s was due to inflated catch statistics reported by China, the world’s biggest fishing nation. This was thought to be due to local managers being under pressure to show increased production to meet the goals of a centralized communist economy. FAO estimates that 47–50% of the world’s fish stocks are fully exploited, 15–18% overexploited and 9–10% depleted (FAO 2000). A drop in fisheries production in 1998 was primarily due to the El Niño event that took place in 1997–8. This influenced most directly the Southeast Pacific region, one of the regions that contributes
most to the catch of marine fish, mainly anchovy
(Engraulis encrasicolus) and Chilcan jack mackerel
(Trachurus murphyi) (Fig. 1.2).

As shown in Table 1.1, the catch of fish taken by
capture fisheries in inland waters continued to
million fishes landed 92 million tonnes of fish and
shellfish. A further 9 million people were busy produc-
ing 32 million tonnes of farmed fish. International
trade in fisheries commodities was worth
some US$53.4 billion in 1999. The marine fishing
fleet consisted of around 23014 vessels over 100
tonnes. In reality there are probably at least as
many vessels again under this quite large lower
weight limit. The fish caught by all these vessels
and people were processed and sold in a variety of
ways. In 1998, the latest year for which data are
available, 79.6% of fish landed was used for direct
human consumption while the remainder went
into non-food production. Of the proportion being
used directly as human food, 45.3% was sold fresh,
28.8% was frozen, 13.9% was canned and 12%
was cured. Fifty years ago the proportion that was
frozen would have been much smaller and the part
cured or canned much higher.

Fish form an important part in the diet of many
people. Average consumption per head has grown
considerably over the past 40 years, increasing
from 9 kg per person per year in the early 1960s to

![Fig. 1.1] Global landings of marine and inland capture fisheries and aquaculture. Data from 1970 corrected for misreporting of marine landings [Watson and Pauly, 2001; R. Watson, personal communication]. [Source: from FAO 2000.]

![Fig. 1.2] Capture fisheries production by major fishing regions in 1996 and 1998. [Source: from FAO 2000.]
Table 1.1  Recent trends in world fisheries production and utilization. The data in this table are given without correction for the inflated catches documented by Watson and Pauly [2001]. [Source: from FAO 2000.]

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<td>Inland</td>
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<td>Utilization</td>
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<td>Human consumption (million tonnes)</td>
<td>79.8</td>
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<td>93.9</td>
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<td>92.6</td>
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<td>23.9</td>
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<td>5.8</td>
<td>5.9</td>
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<td>Per-capita food fish supply (kg)</td>
<td>14.3</td>
<td>15.3</td>
<td>15.8</td>
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1.6 kg per person per year in 1997 (FAO 2000; Table 1.1). In developed countries consumption per head over the same period has risen from 19.7 to 27.7 kg per year. Countries at the other end of the wealth scale have much less fish available, although they too have experienced a rise in supply from 4.9 to 7.8 kg per person per year. In poor countries fish can form 20% of a person’s protein intake. African countries have access to much less fish than do countries in Southeast Asia (excluding China).

1.3 THE QUEST FOR KNOWLEDGE

When T.H. Huxley made his infamous remarks in 1883 about fish being too fecund for their numbers ever to be influenced by fishing, he was showing supreme confidence in his knowledge of fish and their biology. This confidence meant that others had to work hard to collect information before he could be proven wrong (see Smith, Chapter 4, Volume 2). We now realize that uncertainty about fish biology and fishing systems is inherent and has to be taken into account at all times. Uncertainty comes in different forms and has been categorized by Charles (1998) into three types: (i) random fluctuations, (ii) uncertainty in parameters and states of nature and (iii) structural uncertainty. The latter can be put more bluntly as ignorance; we just do not know how the system works. Ecology is a difficult subject, especially when the species under study is not easy to see and its population dynamics display unpredictable fluctuations, a phenomenon widespread in the natural world. Uncertainty in parameters and in the state of nature can now be embraced by various estimation procedures, ranging from simulation methods to Bayesian statistics to fuzzy logic (Wade 2001). When all else fails, we may have to tackle structural uncertainty by learning more about the system.

The first volume of this book reviews the extent of our knowledge about many aspects of fish biology, while the second volume integrates this knowledge with descriptions of a wide range of topics in fisheries biology and management, from how fish are caught to methods for assessing their populations and predicting impacts of exploitation.
on the targeted species and their ecosystems. In effect, the first volume tries to show what we know and to demarcate the limits of structural uncertainty about basic biology. Along the way the authors also show the degree to which our knowledge is plagued by the other two sources of uncertainty. Some of the chapters inevitably overlap and the different viewpoints on the same part of nature are reminiscent of a passage from John Steinbeck’s (1952) foreword to *Between Pacific Tides* by his friend Ed Ricketts. He wrote: ‘There are good things to see in the tidepools and there are exciting and interesting thoughts to be generated from the seeing. Every new eye applied to the peep hole which looks at the world may fish in some new beauty and some new pattern, and the world of the human mind must be enriched by such fishing.’ We think that these different viewpoints are important as they illustrate how there is often not enough known of an ecosystem or species to allow a definitive account to be given.

Structural uncertainty is meat and drink to the scientist. Problems are rarely solved entirely, because we are always uncovering new layers of complexity. The view is often expressed that we really need to do more research on this or that problem so that we can better understand what is going on and therefore be in a better position to manage it. To a point this is true, but as Ludwig et al. (1993) wrote:

Recently some of the world’s leading ecologists have claimed that the key to a sustainable biosphere is research on a long list of standard research topics in ecology. Such a claim that basic research will (in an unspecified way) lead to sustainable use of resources in the face of a growing human population may lead to a false complacency: instead of addressing the problems of population growth and excessive use of resources, we may avoid such difficult issues by spending money on basic ecological research.

There is a danger that those interested in fisheries management and conservation will not know when to stop in the quest for more knowledge. These two volumes show that we do know a great deal about fish biology and ecology, yet the world’s fish stocks are still being reduced mercilessly. The problem is that knowing about the resource is not enough. As Walters (1986) has said, fisheries management is more about managing people than ecosystems, a point that we return to in our introduction to the second volume.

With two volumes composed of 34 chapters written by 54 people, we hope we have provided a holistic view of fisheries science. In this chapter we want to draw attention to our reasons for including the chapters we have in the first volume. In addition we also try to show how the study of commercial fish populations has led to new insights in many basic areas of biology and ecology. The early years of fisheries science created a discipline that was considered very separate from the rest of biology (Graham 1956). The need to tackle practical problems often made it hard for fisheries scientists to contribute to the literature on basic ecology. Despite this, scientists such as Hjort, Hardy, Beverton and Holt [see Smith, Chapter 4, Volume 2] left a lasting legacy in ecology as well as in the specialist field of fisheries.

1.4 PART 1: BIODIVERSITY

This volume starts with two accounts that tell us what fish there are, how we determine which taxa are related to one another, and where they can be found (Gill and Mooi, Chapter 2; Mooi and Gill, Chapter 3). These are fascinating studies in their own right, and the information also underpins several aspects of fisheries science. For example, recent work that attempts to predict which species are likely to be vulnerable to exploitation has used phylogenetic information to guide comparisons of responses to fishing. Common responses could be due to close taxonomic relatedness and this component needs to be accounted for explicitly (see Reynolds et al., Chapter 15, Volume 2). Without this systematic knowledge, it would not be possible to make the comparisons necessary to derive rules of thumb telling us which species are likely to be vulnerable to exploitation and
which will be robust. Similarly, Hutchings (Chapter 7, this volume) makes comparisons of life-history variation in well-defined taxonomic groups. Furthermore, Rickman et al. (2000) showed that variation in recruitment depends in part on fecundity, but this relationship only becomes apparent when comparisons are made between populations of the same species. Good systematics is also necessary for the analysis of substocks within species as described by Ward (Chapter 9, this volume). Finally, data collection, as described by Evans and Grainger (Chapter 5, Volume 2), and stock assessment (Sparre and Hart, Chapter 13, Volume 2) are only possible if species can be identified. Many tropical fisheries suffer from poor knowledge of the systematics of the exploited fish. For example, the trawl fishery on Lake Malawi catches 177 different taxa, most of which are unnamed (Turner 1995). We can say without a doubt that all the methods described in Volume 2 require good systematics at the species or stock level.

Knowledge of biogeography not only allows us to know where important species are found but also shows up hotspots of diversity where conservation measures may be particularly needed. Biogeographical knowledge also defines the type of fish fauna expected from different habitats. Polanin and Pinnegar (Chapter 14, this volume), Persson (Chapter 15, this volume) and Jones et al. (Chapter 16, this volume) deal with the dynamics of communities in different biogeographical zones.

Knowledge of contemporary distributions will be increasingly useful as fisheries biologists are required to pay more attention to the influence of climate change. This process will influence the distribution of fish, and knowledge of present biogeographical limits makes it possible to identify sensitive species. An example is the North Sea stock of cod (Gadus morhua), which is at the southern limit of the species’ distribution (O’Brien et al. 2000). Recruitment is poor in warm years. Should the North Sea continue to get warmer it will become harder for the cod to maintain its current distribution and the limited area closures employed in the spring of 2001 to protect the fish from exploitation during spawning may not be enough.

1.5 PART 2: PRODUCTION AND POPULATION STRUCTURE

Sustainable fishing is maintained by the growth and reproductive output of individual fish. Growth is governed by physiological ability to cope with environmental challenges. Some of the physiological mechanisms that fish have for living in water are described by Brix (Chapter 4, this volume). Fish stocks are often divided into local subunits, with their own adaptations to local conditions. A good example of this is provided by the different haemoglobin genotypes possessed by cod that live close to the Norwegian coast. Brix describes how these genotypes are linked to temperature-sensitive oxygen-binding properties of the haemoglobin molecule, which adapt fish to the conditions in which they live. The haemoglobin genotypes also have an influence on competitive behaviour (Salvanes and Hart 2000). The temperature sensitivity of the haemoglobin genotypes links back to the comments made earlier about cod being at their southern limit in the North Sea. Fish are fine-tuned to the particular conditions they face and knowledge of physiology will make it possible to predict which fish will suffer or benefit from a warming of the seas. Similarly, the physiological and behavioural attributes of fishes will determine how they can respond to pollution in estuaries and the nearshore environment (Jones and Reynolds 1997).

In the next chapter, Jolling (Chapter 5, this volume) discusses the processing of energy and its consequences for growth. Jolling also describes the way in which a fish develops and the models that can be used to predict growth. The model of growth that is used most often is the von Bertalanffy equation, which pops up in many analyses of stock production. One interesting development is by Schmutz and Richards (Chapter 6, Volume 2), who show how a generalized version of
this model can also be used to describe population growth.

From individual productivity we move on to population productivity. Myers (Chapter 6, this volume) describes the pattern of recruitment in a range of species and discusses what is known about the causes of variation. This is a key question in fisheries science (Cushing 1996). Myers’ chapter underpins Chapters 6–13 in Volume 2, which deal with aspects of stock assessment and modelling. A key issue for the conservation of stocks and for rebuilding those that have been overexploited is whether stocks at low abundance have the ability to produce enough offspring to regenerate the stock (compensatory reserve). An analysis of 246 fish populations has shown that the maximum annual reproductive rate, determined at the origin of the stock–recruit curve, is between 1 and 7. This assumes that the stock–recruit curve goes through the origin and implies that there are no disruptions to the reproductive process as the spawning stock becomes very small (the Allee effect). Frank and Brickman (2000) showed that this Allee effect can exist at the subpopulation level and this may be obscured if data are aggregated from several subgroups.

The study of life histories (Hutchings, Chapter 7, this volume) follows naturally from studies of recruitment. For example, an important link between fishing and recruitment is the size and age at which fish become sexually mature. These depend on growth rates and other components of life histories that schedule reproduction in relation to the lifespan. A major determinant of this schedule is the stage at which the animal experiences the most severe mortality. Law (1979) showed theoretically how increasing the mortality at some particular age would lead to the evolution of increased reproductive output in the years before that mortality occurred. This may lead to a reduced age at maturity. A recent review by Reynolds et al. (2001) has shown that large late-maturing fish are the most vulnerable to exploitation. Thus, it is not surprising that other studies discussed by Hutchings have shown that the principal life-history changes due to fishing are reduced size and age at maturity. These may be plastic responses of the growth process or evolutionary responses mediated by gene frequency changes.

One aspect of life histories reviewed by Hutchings (Chapter 7, this volume) concerns relationships between characteristics such as body size, body growth rate, natural mortality rate and length of first reproduction. These relationships were first studied by Beverton and Holt (1959) and have since been formalized and extended to other taxa by Charnov (1993). These life-history invariants have proved useful for predicting the vulnerability of populations to fishing (Pope et al. 2000). Likewise, Roff (1981, 1984) did pioneering work on the lifetime allocation of energy to growth and reproduction and concluded in the earlier paper for the Pleuronectidae that reproductive lifespan within the group was not a response to variations in reproductive success but to variations in the age at maturity. Researchers such as Charnov (1993) and Charlesworth (1994) have since developed these early studies of aspects of life histories into modern life-history theory, which is applicable to a wide range of sexually reproducing species.

Life histories and recruitment feed into migration, reviewed by Metcalfe et al. (Chapter 8, this volume). Indeed, this chapter shows that migration is a fundamental facet of the life histories of many commercially important fish species. In diadromous species, the life history has become split between two habitats, one of which is better for feeding and the other for reproduction. Salmon species provide classic cases of this lifestyle. Migration also makes them particularly vulnerable to fishing, because they must pass through a narrow bottleneck on their way to spawn, and to environmental degradation through silting of spawning grounds and general deterioration in water quality (see Reynolds et al., Chapter 15, Volume 2).

Information on migration is essential for the management of many stocks. The movements of the fish will determine where the fishing boats will be. The way in which fishing effort is applied to the stock will be determined by this spatial correlation and should be incorporated into models (see Sparre and Hart, Chapter 13, Volume 2). An understanding of animal movements is also fundamental to the success or failure of marine pro-
protected areas (see Polunin, Chapter 14, Volume 2). For example, the closure of 40% of the North Sea to cod fishing in the spring of 2001 is a sign that very large areas have to be enclosed if a marine protected area is designed to conserve a species that migrates over large distances. Indeed, many biologists are sceptical about whether even this area of closure was sufficient to have had appreciable conservation impacts on the stock.

From migration we move on to a review of population genetic structure of fish stocks (Ward, Chapter 9, this volume). Stocks used to be identified by morphological characters such as the number of vertebrae or the number of fin rays in dorsal or other fins, in conjunction with tagging studies. Ward reviews the modern molecular methods that are now used, often in conjunction with advanced technology to track fish migrations (see Metcalfe et al., Chapter 8, this volume). The increasing evidence of the importance of substock structure in fish populations provides a growing market for this information. Molecular methods are also helping to determine relationships among taxa that can then be compared to understand population characteristics while taking into account phylogenetic relationships (Reynolds et al. 2001). Ward also describes uses for new molecular techniques, such as identifying fishes or fish parts in markets, and identifying endangered species offered for sale in disguised form. A recent guide to Australian seafood contains a cellulose acetate-based fingerprint for each of 380 species.

The final chapter in Part 2 rounds out the reviews of various aspects of production and population structure with a review of reproduction [Forsgren et al., Chapter 10, this volume]. Traditionally, models in fisheries science have assumed that behavioural aspects of reproduction are not important. Cushing [1968] in his book on fisheries biology devotes just one sentence to the spawning behaviour of the Norwegian cod in Vest Fjord, in the Lofoten Islands: ‘The male fish arrive in the Vest Fjord first, and spawning takes place in the midwater layer where the fish are caught by drift nets, long lines and purse seine...’. Subsequent work has led Nordeide and Folstad (2000) to argue that cod may have a lekking system, which implies considerable behavioural complexity. Details such as this can be important in understanding spatial vulnerability of individuals, as well as reproductive success. For example, Chapter 10 [this volume] shows how fertilization mode, aggregation behaviour, sex changes and sperm limitation all determine vulnerability to Allee effects (depensation). In the many reef species that undergo sex change, impacts of fishing on the populations depend on the cues that determine sex change. Fisheries typically remove the largest individuals, and in many wrasses and groupers these are males that had been females when they were younger. If sex change is flexible according to the females’ perceptions of presence or absence of males, the loss of males to the fishery may be replaceable. But if sex change occurs at a fixed size, males may not be replaced fast enough, and sperm depletion is possible.

1.6 PART 3: FISH AS PREDATORS AND PREY

Three chapters on feeding ecology illustrate the truth of Steinbeck’s observation about how different people see the world in different ways depending upon which ‘peep hole’ they use. Mittelbach’s view in Chapter 11 [this volume] of predator-prey relationships is very much influenced by the theoretical structure that he employs to understand trophic ecology and habitat use. He is interested in explaining the ways that interactions between fish species in freshwater lakes can be predicted from a knowledge of the costs and benefits of different prey types. The view of Juanes et al. in Chapter 12 [this volume] focuses more clearly on the perspective of fish as predators, with most attention paid to the way in which feeding habits shape the life histories, body form and ecology of predators. Krause et al. in Chapter 13 [this volume] take the prey’s point of view, emphasizing how their ecology and behaviour are moulded by predation pressure.

All three foraging chapters take advantage of huge advances in our understanding of foraging
theory through the application of optimization methods (Stephens and Krebs 1986; Giraldeau and Caraco 2000). They feed directly into the trophic models of fisheries, reviewed in the second volume by Pauly and Christensen (Chapter 10, Volume 2), as well as multispecies virtual population analysis reviewed by Shepherd and Pope (Chapter 7, Volume 2). For example, details of predatory behaviour determine the shape of the ‘functional response’ of diet choice in relation to availability of alternative prey types (see Juanes et al., Chapter 12, this volume). The shape of this relationship is important in multispecies models of fisheries.

The basic research into prey choice and habitat choice reviewed by our triumvirate of chapters also feeds into our understanding of the role of piscivores in trophic webs (Chapters 14–16, this volume). For example, in freshwater systems, predation on planktivorous fish species can lead to trophic cascades. This information has been used to improve water quality in many freshwater ecosystems through biomanipulation. Although it is unlikely that marine systems could be managed in the same way because of differences in scale, fishers have changed the structure of marine food webs by reducing the abundance of large organisms in much the same way as piscivores reduce the abundance of planktivores (see Pauly and Christensen, Chapter 10 and Kaiser and Jennings, Chapter 16, Volume 2). Another market for the information on foraging behaviour (Chapters 11 and 12, this volume) is in stocking programmes designed to boost freshwater sport fisheries (see Cowx, Chapter 17, Volume 2). We need to be able to predict the likely benefits for anglers and the environmental damage that may be caused by stocking programmes (see Reynolds et al., Chapter 15, Volume 2). The chapter by Krause et al. (Chapter 13, this volume) looks specifically at the antipredator adaptations of fish that can lead to a species being very vulnerable to fishing. For example, schooling behaviour, which is so effective against the attacks of individual fish predators, is a disadvantage in the face of fishing. Schooling makes it relatively easy for purse seiners (Misund et al., Chapter 2, Volume 2) to find fish using long-range sonar and to catch species such as mackerel (Scomber scombrus) and herring (Clupea harengus). Schooling behaviour also makes catch per unit effort (CPUE) useless for estimating the abundance of the stock as high CPUE is observed until the stock is virtually extinct. The catch rate of large aggregations of cod off Newfoundland remained constant at 1.5% of all cod catches right up until 1992 when the stock collapsed (Hutchings 1996).

1.7 PART 4: FISH IN ECOSYSTEMS

The final four chapters of this volume take the details of behavioural interactions involving fish as predators and prey [Part 3] and scale them up to understand community ecology. Polunin and Pinnegar (Chapter 14) focus on marine food webs, Persson (Chapter 15) examines freshwater communities and Jones et al. (Chapter 16) make explicit comparisons between these habitats. An important theme that emerges is that as fish grow their niche changes so much that the young and adults inhabit different worlds. Thus, in Swedish lakes the interactions between European perch (Perca fluviatilis) and roach (Rutilus rutilus) are a mixture of competition and predation that depend on the age and size of the interacting fish. A similar relationship holds for cod and gobies (Gobiusculus flavescens) in Norwegian fjords. When cod are small they compete for food with gobies but gobies are eaten by larger cod (A.G.V. Salvanes, personal communication). The same is true of the large-mouth bass (Micropterus salmoides) and bluegill sunfish (Lepomis macrochirus) in North American lakes. This information is critical for the implementation of multispecies models (see Shepherd and Pope, Chapters 7 and 8, Volume 2) and ecosystem models (see Pauly and Christensen, Chapter 10, Volume 2).

The final chapter of the first volume presents a detailed examination of fish parasites [Barber and Poulin, Chapter 17]. The mixture of pure and applied research reviewed here includes evidence that parasites can change behaviour and drive population events. For example, threespine stick-
lebacks infected with *Schistocephalus solidus* are more likely to take risks when feeding near predators than are uninfected individuals [Milinski 1984]. Likewise Milinski [1982] found that competitive interactions between sticklebacks were altered by parasite load. That parasites seem able to drive population cycles was shown by Kennedy et al. [1994] for *Ligula intestinalis* infecting roach in a lake in Devon, UK. For marine populations, there is little evidence for this type of population effect, although Holst et al. [1997] have shown that there is a possible link between abundance of Norwegian spring-spawning herring (*Clupea harengus*) and infections of the fungal parasite *Ichthyophonus* sp.

Parasites in fish can endanger human health. Herring often contain the nematode worm *Anisakis simplex*. The preparation of pickled herring, particularly popular in Scandinavia and the Netherlands, does not always kill the parasite in the fish flesh and the worm can be passed on to the human consumer, sometimes finding its way to the brain. Such infections can seriously undermine marketing efforts to persuade people to eat more fish [see Young and Muir, Chapter 3, Volume 2].

One of the biggest problems on salmon farms in Norway and Scotland has been the sea louse (*Lepeophtheirus salmonis*). Estimated costs to the industry vary widely but are likely to exceed £20 million a year in both Scotland and Norway. Low fish growth, stock losses and a reduced price at harvest cause these costs. In addition the farmer has to pay for monitoring and treatment, which can cause severe environmental impacts. At present, efforts are being made to use wrasse (*Labridae*) to act as cleaners so reducing the need to use chemical treatments. The study of parasites is one area in fisheries science where there is little argument over the need for basic biological information.

### 1.8 Ignorance Banished?

As this chapter has outlined, the principal purpose of Volume 1 of the *Handbook* is to provide the biological basis for the tools of management and conservation described in Volume 2. Along the way, we have allowed ourselves (and our authors) the luxury of following paths that have led through a considerable amount of additional background information that may never find its way directly into fisheries management, but which enriches our overall understanding of fish biology. We will never reach the limits of our ignorance about the way the fish world works but in the context of management we do not need to know everything.

How much do we need to know? Ludwig et al. [1993] present the case that it is silly to always argue that we cannot act to manage stocks sustainably until we have more information. However, we cannot divorce the management of fishers from the biology of their prey. As fish stocks have collapsed, the search for solutions has led to new questions. As Hutchings [2000] has noted, many of these concern ecology and evolution, subjects that are reviewed in this first volume. Hutchings draws examples of questions from the collapse and slow recovery of Atlantic cod along the eastern Canadian coast, to which we can add a few of our own. Could the slow rate of recovery be due to changes in mating behaviour and Allee effects [depensation] at small population sizes? What new predator–prey relationships might he in place now that the fish occur at less than 5% of their population biomass of 30 years ago? Have ecosystem shifts occurred that hinder recruitment? What is the role of habitat disturbance? Are temperature changes important? Have there been evolutionary impacts on the populations? How many populations are there, and what kind of source–sink dynamics might be involved in population recovery?

Few of these questions were being asked in any fishery 10 or 15 years ago. They are common now, and we do need the answers for effective management of many fish populations and ecosystems. How large should a marine reserve be and how close should it be to other reserves [see Polunin, Chapter 14 and Reynolds et al., Chapter 15, Volume 2]? How will our management of one species affect populations and yields of others [see Pauly
and Christensen, Chapter 10 and Kaiser and Jennings, Chapter 16, Volume 2! How can we estimate natural mortality rates of target species, in order to make accurate forecasts from models [see Shepherd and Pope, Chapter 7, Volume 2]! How do life histories, behaviour and economic value affect vulnerability to extinction [see Reynolds et al., Chapter 15, Volume 2]!

Many of the contributors to these two volumes have never worked alongside one another before. We hope that these two volumes will help to bridge the gap between pure and applied research, leading to a productive dialogue between those who study fish biology for different reasons but whose interests may have more in common than they realize.

1.9 CONCLUSIONS

We have tried in this chapter to illustrate how the material in the 17 chapters of Volume 1 of this Handbook can be used for an intelligent application of the methods covered in Volume 2. Fisheries scientists are often accused of being so preoccupied with the details of stock assessment that they forget about individual interactions by fish within stocks as well as connectivity between stocks and the rest of the ecosystem. We hope that the information in this volume will be of interest for its own sake, and for helping to put ecology and evolution back into fishery science and management.

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REFERENCES


