Chapter 1
On the Future of Fisheries Science

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Abstract The invited papers in this book provide a range of opinions about the future of fisheries science in North America. The ideas of each author are carefully thought out speculations of what will change in their field and how the changes may be used to improve the stewardship of fisheries. The collection of thoughts does not cover all areas of fisheries science, but there is sufficient diversity to stimulate readers to contemplate what changes they anticipate. This introductory chapter is our perspective on the contents of the book and on the future of our science. We hope that this chapter and the chapters of our colleagues signal the urgent need for change and for strong leadership.

Keywords Fisheries Management · North America · ecosystem approach

1.1 Introduction

The future can evolve in many directions. Our theme is that while fisheries science is generally thought of in the context of an applied science, the quality of this applied science is limited by fundamental knowledge. In other words, significant investments need to be made in fundamental research in order to improve the quality of information available to improve the quality of fishery management. Our visions of the future are remarkably similar considering it is seen through different issues in different oceans. The fundamental understanding of the biology of key species must improve if we are to forecast the impacts of changing physical and biological environments on

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recruitment. For too long fisheries science has been used to manage fisheries without the necessary understanding of the processes that regulate the size of year classes.

1.2   Motivation

Fisheries science has focused on relatively simple goals. These goals are changing rapidly. A number of chapters set the stage for these changes that essentially specify or provide underpinning for the new requirements of fishery management. For example, Rice exposes us to the convention on biological diversity and a "new" requirement to include biodiversity in management. Benson discusses the conservation of biodiversity and its application to fishery management. O'Boyle describes the paradigm shift driven by the ecosystem approach to management, which has been anointed by the acronym EAM. Kaplan and Levin point out the challenges generated by EAM. Stringer et al. provide a perspective on the interaction between changing demands on the scientific community and the practice of scientific investigations in fisheries. Stokesbury et al. suggest application of the naturalist's approach, while Schnute and Richards recommend taking a perspective of high dimensionality that is thoughtful about the use of models. Timely and reliable assessments of multiple stocks require efficiencies beginning with the collection of data through to the presentation of results. Methot explores how this can be done by the development and acceptance of broadly applicable assessment methods. Not only will new concepts be required but, also, students will need to be trained to be responsive to the shifting focus. Peterman makes it abundantly clear that probabilistic approaches to fishery science will need shifts in training direction and also a capability to communicate and interact with wider audiences.

1.3   The Scope of Research

Ecosystem Approaches – Various workers are already considering responses to the new requirements. Some involve the application and evolution of existing approaches such as trophodynamics. Koen-Alonso considers how trophodynamic models can be applied to fisheries management. New approaches are also being developed. For example, Rochet and Trenkel give critical examination to the indicator concept. Norton et al. consider the cyclical interaction of California current ecosystem and the economics of the fishery. Saila reviews several ecosystem models and demonstrates how artificial life models can contribute to a fuller understanding of relevant ecosystem processes. Pepin makes the case that at the end of the day much will need to be done to develop a resolution of the recruitment problem. Watson-Wright identifies the commitment that is needed to take us back to an ecosystem approach to management.

Technology – Technology is our window to observing the ocean environment. It is our way of picturing the four-dimensional world that lies beneath the surface of the sea. There are at least two parts to technology. The first part is the sensors. The second

part is the platforms that carry or form a chassis for the sensors. Holliday surveys the field and makes the critical observation that sensor technology may be the weakest link in developing a materially improved approach to ecosystem management. Traditionally one of the most used technologies in fisheries research is acoustics. The state of the art in acoustics is described by Foote. There is increasing interest in optical approaches. An optical approach that has interesting specific uses is light detection and ranging technology (LIDAR). LIDAR is a focus of the chapter by Churnside et al. Clarke et al. describe one of the more innovative ideas in platforms, the autonomous underwater vehicle (AUV). Godø gives a perspective on the new technologies that will be required to undertake observations required by the ecosystem approach.

Stock Structure and Genetics – One of the challenging problems in fisheries involves the fact that the same individual species may consist of groups of fish that do not mix freely. Sometimes these fish can be thought of as stocks, but sometimes they are genetically differentiated. How these stocks or genetically independent groups are differentiated and how the information on their structure applies to management is a continuing problem. To this end, Cadrin and Secor review the history and future of the incorporation of information on genetically or otherwise discrete stock of fish. The study of genetics is a rapidly growing field. Waples and Naish review the context of the genetic and evolutionary considerations in fishery management. Kochzius discusses recent developments in DNA-based species and stock identification.

Stock Assessment – The evolution of stock assessment concepts has been relatively slow. However, important new ideas are emerging. For example, the basic approach in stock assessment is to provide managers with an optimal magnitude of size- or age-specific fishing mortality. This seemingly simple problem becomes complex because several models can be used to estimate optimal mortality with different results. Which is best? Mohn considers the intercomparison of models – an issue that will be increasingly important as models begin to include assessment of several species simultaneously. A specific approach to interacting models is provided by Jiao, who considers Bayesian averaging. Observers of the process are framing new requirements for stock assessment. Methot develops the concept of operational stock assessment as an analogue to operational oceanography.

Application of Other Fields Such as Engineering – In a way, the science of fishery management relates almost to engineering and operations research techniques for managing inventories. Holt and de la Mare show how the theory of engineering control systems can be applied to the management of sockeye salmon. Recognizing that fisheries management is essentially a decision-making process, Goodman describes how applying decision theory, an important branch of applied mathematics, modifies the world view of traditional quantitative approaches.

Environment and Climate – The understanding of the relation of the environment to the variability in fish stocks is one of the biggest gaps. One practical example of the importance of the ocean environment relates to the idea that a depressed stock can generally be *rebuilt* evidently not recognizing that one interpretation of a decline in stock magnitude relates to its returning to normal abundance after a series of large year classes. Imagine taking an ecosystem approach to management without a better understanding of the ocean environment. The understanding of the environment is made complex in that the ocean environment is embedded in

a hierarchy of space and time scales. A critical research issue is the way that the smaller local time and space scales are embedded in the broader and longer basin and climate scales. But understanding and adapting to new knowledge on the ocean environment – the response to surprises – will provide new insights to add understanding as described by Beamish and Riddell. A clear result of learning from surprises is the transition from hindcasting to forecasting and the dynamical shifts in approach that are necessary to make this transition as discussed by Hollowed and Bailey. Schwing et al. discuss the steps that need to be undertaken to enhance this understanding of climate variability. Fisheries science is no longer just about fish. A focus on ecosystems and the environment requires an improved communication with the public. Squires shows how social science research in general and economics in particular can improve fisheries management. The focus of economic research will shift from overfishing to addressing the sustainability of ecosystems, the loss of biodiversity and the changes in the ocean.

1.4   Our Perspective

It is important to focus on what is meant by fisheries science so that the investments can be focused. The process of observing and reporting nature were the roots of fisheries science. Early fisheries science started out trying to understand the population ecology of fish, which included their associated species and their environment. It was the push to go fishing after the Second World War that changed the emphasis to assessing how many fish could be harvested. Fisheries management and the science that supported management became oriented toward providing managers with a magnitude of size-specific fishing mortalities for each stock. The basic idea was to use yield per recruit theory, production theory, or stock and recruitment theory to determine optimal levels of fishing mortality. Then, once these were determined, estimates of the age- or size-specific abundance of a stock could be employed to estimate fishing mortality. If fishing mortality was greater than the optimum, it was reduced, and vice versa.

In recent years new objectives for fishery management are beginning to emerge. Unfortunately, these make a problem that is already costly and difficult even more costly and difficult. Instead of "simply" determining optimum yield, estimating actual fishing mortality, and determining whether the actual mortality is greater or less than optimal, the "new requirements" of fishery management additionally include the mantras: (1) *managing ecosystems*, (2) *managing habitat*, (3) *ending overfishing*, (4) *using the precautionary approach*, and (5) *rebuilding stocks*.

So now the nature of the investments can be clarified. But before this can be accomplished, it is necessary to further shape the requirements of future fisheries management by considering what we have learned and failed to learn over the past 10 decades during which fisheries management has been practiced.

Leading questions have been: What causes large- and small-year classes? What is overfishing? What is the effect of the ocean environment on the abundance

of particular fish stocks? What is the effect of fishing intensity on recruitment, biomass, and production?

Additional questions may be needed for some species such as Pacific salmon (*Oncorhynchus* spp.). Hatchery production of Pacific salmon may now account for about one half of all Pacific salmon catches, which are currently at historic high levels. Current catches of pink (*O. gorbuscha*) and chum (*O. keta*) salmon represent about 88% of the total catch, and large numbers of these two species are produced in hatcheries. What are the impacts of these hatchery salmon on wild salmon? Because salmon are anadromous, what are the impacts of Pacific salmon produced in one country on the production from another country?

Over the past century parts of these questions have been answered. Turn-of-the-century curiosity on the causes of large- and small-year classes of cod and herring in Norway has still not been resolved. There is no unique definition of overfishing. The effect of the ocean environment on fish stocks is generally not understood. Interactions among species are not understood. While some advances have been made with regard to the effects of fishing intensity, we have learned to address the problem only partially.

These difficulties have arisen from a variety of circumstance that have related to the difficulty of the problem and the evolution of the body of knowledge. The problem of large- and small-year classes has evolved into the problem of understanding the intertwined influence of fishing intensity and the ocean environment on recruitment. This is a keystone problem in the sense that all of the problems previously cited would be solved if this problem was solved. To be specific, the term overfishing has been erroneously used to explain *any* decline in a fishery stock. Of course, stocks decline (or increase) because of a favorable or unfavorable ocean environment, or perhaps because of large increases in hatchery production. In fact, an unusual decline in a stock can be determined only after the fact, in the sense that our body of knowledge is not sufficient to determine whether the observation of a depressed year class is a chance event or whether it heralds a genuine long-term depression in the abundance of the stock.

So in shaping the problem we are quick to realize that these new objectives are in a sense a recasting of the old relatively simple approach into generally more complex, more difficult problems. This means that since in many instances the store of fundamental knowledge is exhausted, we need to think of new creative and innovative ways to shore up the fundamental knowledge base to support the applied research required by the new objectives.

1.5   Managing Ecosystems

The present state of the field is that each stock is managed independently of every other stock. While single species management is roundly criticized, techniques are generally not available to manage two interacting species, let alone an entire ecosystem. The difficulty lies at two levels. In the two-species case, there are the

interactions between juveniles and adults of a stock of interest with the juveniles and adults of another stock of interest. One form of interaction relates to the trophodynamic interrelationship between the two stocks. Stomach analyses are used to study this interaction, but the problem is exceedingly difficult because of the changing size relationships between the species, and the nonlinear aspects of prey–predator interaction, and the fact that the interactions between the two species of interest exist in a setting that generally involves other stocks of fish and invertebrates. The second level relates to the survival of the eggs and larvae of the two species of interest. On one hand, the survival of eggs and larvae may be independent of explicit interactions at the egg and larval stage. On the other hand, the dynamics of egg and larval survival to some extent depend on density dependent relationships at the egg and larval stage, and these in turn depend to some extent on the production of eggs and the quality of the eggs of the two species of interest. In the case of anadromous fish such as Pacific salmon and river herring (for example), there is the added complexity of an anadromous life-history strategy that involves feeding in a vast ocean and returning to spawn sometimes in the exact area in freshwater that the fish was hatched. There are even further complications given a sometimes complex freshwater life history.

Understanding how marine ecosystems support fish and associated species is not easy. It is even more difficult now because we are changing the climate at a rate that is much greater than the rates of change that created the life-history strategies of the organisms in these ecosystems. It is not too much of an exaggeration to see the future as a crisis within fisheries science. In an oversimplified way, fisheries science finds itself trying to understand how the factors that created a particular life-history strategy will change the strategy as the factors change. Adding to this complexity, in many cases, are the changes in biology that may have occurred from fishing. Thus the complexity of the tasks of ecosystem management should be apparent to just about anyone who has thought about the situation. If progress is to be made, it is clear that a much improved understanding of these fundamental population dynamic issues needs to be acquired not only in the context of population dynamics per se, but also for population dynamics as forced by the ever-changing, multiscale physical environment.

1.6 Managing Habitat

It is generally recognized that habitat, or more precisely the quality of habitat, constrains the abundance of the harvested stocks. The habitat problem has many facets. The importance of freshwater habitat for Pacific and Atlantic salmon is well known. The impact of dams, logging, and the general destruction of spawning and rearing habitats has been extensively studied. Less well known are the impacts of changing flow and temperature patterns that are forecasted to occur in the future (see Chapter by Beechie et al.). For marine habitats, the estuarine/riverine aspect is perhaps the easiest to define. The degradation of estuaries is well-known. These degradations range from loss of productive areas, pollution, toxics, etc. These are

well known, and it is up to the political system to resolve the issues, some of which might include the recognition of introduction of classes of substances not previously recognized, such as hormone inhibitors.

Moving to the open ocean, the habitat problem becomes more complex. There are two classes of problems: the benthic problem and the water-column problem.

As far as the benthic problem is concerned, most discussion relates to the effect of bottom-tending gear. There are views that bottom-tending gear should not be allowed to destroy structure. Beyond this belief is an important scientific issue, which is, how does bottom-tending gear modify the biological productivity of the bottom boundary layer? In some settings it is conceivable that bottom-tending gear decreases productivity; in other circumstances it is conceivable that it increases productivity. In other settings it is easy to imagine how continual application of bottom-tending gear could change the equilibrium species composition. The problem rapidly becomes complex because bottom-tending gear not only changes the productivity of the benthos per se through physical interaction with the bottom but also by changing the equilibrium abundance of the species of fish that feed on the benthos.

There is not much that can be said about water-column habitat except that it is obviously critical to the majority of species of concern. The scientific problems basically relate to the ecosystem, which is covered under ecosystem management. The two serious scientific issues relate to the greenhouse-gas-induced warming and acidification of open ocean habitats. The realization that the deep ocean is warming, as well as the surface waters, is a reminder that the biology of species known to be important forage for commercially important species is so poorly known that it may not be possible to forecast the impacts of a changing climate on these forage species. In the North Pacific the intensity of the winter Aleutian Low strongly affects the recruitment of many species. It is still not known if the long-term impact of greenhouse gas increases will weaken or strengthen the Aleutian Low. Natural cycles are important, as the California sardine (*Sardinops sagax*) literature shows. Thus, sorting out the impacts of natural climate trends and impacts resulting from greenhouse-gas-induced climate change is a major challenge.

1.7 Ending Overfishing

Ending overfishing is an admirable goal. However, the concept of overfishing has drifted in and out of a scientific definition. The term first arose in England in the eighteenth century. The concept was that increased fishing was correlated with the decline of the stock. As fishery science advanced, it became difficult to develop an operational definition of overfishing. As a consequence, in the early 1900s ICES (International Council for the Exploration of the Sea) formed an overfishing committee – Committee B – to study overfishing. Resulting reports did not yield a clear definition.

The subject was more or less fallow until the post-World War II era when Beverton and Holt, Ricker, and Schaefer developed various theories that linked stock size or fishing mortality and indices of stock production. These theories yield various

optima or asymptotic relationships that gave the maximum production for some level of fishing mortality. Any magnitude of fishing mortality greater than the optimum could be described as overfishing. Unfortunately, there were three types of problems with these definitions. First, optima were not generally obtainable, data did not fit the theory and finally data were often not available for the most sensitive parts of the curves. Furthermore, the term stock overfishing was utilized with yield per recruit theory, and yield per recruit theory has no intrinsic optimality consequences. So it all boils down to understanding the productivity of the stock.

1.8 Precautionary Approach

A precautionary approach sounds like a good idea. In a decision-making setting, such as fishery management, a precautionary approach would suggest that we err on the side of caution. For example, if a normative fishing mortality is estimated to be F = 0.5, let's be cautious and set fishing mortality at F = 0.4.

The problem is that while it is easy to estimate F = 0.5, it is not easy to develop rules that set the degree of caution. For example, person A might be more cautious then person B, and so person A would set F = 0.2, and so on. In other words, different individuals have different degrees of risk proneness or risk aversion. An illustrative parable relates to three starving individuals waiting to cross an avenue streaming with high velocity traffic to reach a restaurant on the other side. The risk-prone individual doesn't look either way and crosses the street. He is hit by a car and killed. The risk neutral person looks both ways, carefully assesses the flow of traffic and navigates safely to the restaurant. The risk-adverse person is afraid to cross the street and as a consequence starves to death.

The subject of risk has been studied in detail in disciplines aligned with decision theory, utility theory, and risk analysis. An examination of these fields will reveal that they require higher quality and more informative data and understanding than presently available. Some of the ingredients require a definition of "risk." Risk of what? Risk of a stock becoming extinct? Recruitment failure for 1, 2, 3,… N years into the future? The stock falling below a particular level? In addition to defining the terms of risk, these techniques require probabilistic calculations of the effect of any management action or of the environment on the stock becoming extinct, etc. And finally there needs to be an assessment of the utility associated with the outcomes. As specified above, this problem becomes complex in risk-averse or risk-prone settings. Basically the state of knowledge is not well-tuned to dealing with these problems in a probabilistic setting.

1.9 Rebuilding Stocks

A common assumption in contemporary fisheries management is that all stock declines are caused by fishing and that if fishing mortality is reduced, then stock abundance would increase. There are many examples that show this assumption is not

necessarily true. So how do we know when fishing mortality is coupled or uncoupled with changes in stock size?

It is important to recognize that there are major world fisheries that are healthy and at high levels of abundance. As previously mentioned, Pacific salmon catches are at historic high levels and have been at these levels since the mid-1990s, even though some stocks have declined substantially. Pacific halibut (*Hippoglossus stenolepis*) is a major fishery off the Pacific coast of North America, and by all accounts, it is in good shape. The United States fishery for walleye pollock (*Theragra chalcogramma*) in the Bering Sea remains as one of the largest fisheries in the world. A focus on rebuilding stocks is a major task for fisheries science, but it is also important that fisheries science recognizes and reports the reasons that some major North American fisheries are in very good shape.

Aquaculture is outside of the scope of this book, but aquaculture is an important component of efforts to rebuild and sustain stocks. Many people in North America have eaten *Tilapia*, farmed catfish, farmed salmon, farmed shrimp, or farmed shellfish. It is apparent that an increasing amount of "seafood" is no longer "wild" and that some aspects of fishing are turning into farming. The impact of the developing fish farming industry on the traditional fisheries remains to be determined, but there is an impact.

1.10 A Common Theme

In a way the new-found goals or mantras of fishery management exemplified by these goals have common threads. The common thread that relates to all of the problems is a basic understanding of single-species population dynamics in a multiple species setting involving physical forcing. The main issue in dealing with this problem is to define it in a manageable way, and to somehow simplify its very high dimensionality and multiscale nature. This is a major innovation that certainly includes the 5-decade-old theories of yield per recruit, production, and stock and recruitment, but at the same time recognizes that they explain only a small part of the variability in the data. Advance estimation techniques, including Bayesian analysis, refine inference. However, these advanced techniques, however useful, are still constrained by a lack of data and a 5-decade-old view of the problem (basically the effect of stock size or fishing mortality on the productivity of the stock independent of causal connections with other populations and forcing by the physical environment). With these constraints it is not surprising that existing techniques, while becoming more and more refined, do not yield basic insights into the new requirements of fishery management.

What is needed is a new theory and new observations to support the theory. It is not exactly a new idea to enhance the existing theories with environmental data. To be successful though, the enhancement needs to be more than correlational. It can readily be seen that the acquisition of new or enhanced biological theories and new data will be a complex task that cannot be accomplished with less than a critical mass of resources or within the confines of applied research. In other words, it is time to resort to the traditional scientific approach of developing new and enhanced

theories, develop data sets that enable testing and amplifying the theories and then recreating this cycle.

Reliable scientific information comes slowly and is costly. We think that wise managers at all levels in our political systems now know this. Fisheries science will eventually produce reliable stock assessments that will clearly identify risk, but it is not clear when this will happen. The development of farmed and certifiably safe-cultured seafood may ease the pressure on fisheries managers and fish populations, but it is also not clear when we will get to this stage in fisheries management or how the nutritional requirements of aquacultured fish are coupled with wild fisheries. The immediate problem is that there will be dramatic changes among species in regional ecosystems around North America as climate and ecosystems change. Fisheries scientists will need to focus on understanding the dynamics of regional ecosystems. Fisheries managers will remain as a major user of science, but it will be the general public that needs to become more aware of the importance of understanding their own impacts on marine ecosystems. Thus, ecosystem management needs to include ecosystem understanding by the public because marine ecosystem health will become an index of human impacts on the planet. Our way of doing fisheries science needs to change, and change will only happen with strong teams and effective leadership. We recognize strong teams and leaders in competitive sports, but the team approach has not been popular in fisheries science. We have experimented with team approaches in the past such as GLOBEC, FOCI, and CalCOFI, and we need to use this experience to rethink how we carry out fisheries science.

We see the future of fisheries science in North America as centred on regional ecosystem-based stewardship. The best advice will come from the best teams that have the best leaders. There will be a need for more field observations and more and cheaper monitoring. A team approach effectively solves the age-old problem of data ownership. All of the skills needed to know what to measure, to make accurate measurements, to analyze the data correctly and to interpret the results would be by a team. Teams need to use the new electronic reporting technologies to provide information quickly to colleagues around the world. Thus fisheries science around North America needs to move away from the individual investigator approach and become an "ecosystem" of interdisciplinary marine stewards. Fisheries science entered a new regime when it became obvious that the changes in our climate were having dramatic impacts on the population ecology of the species in our fisheries. Fisheries science needs to move in a new direction, and the direction is beyond alarming the public. The tough task is advising what to do now. If we do not maintain fisheries, there is not much use in paying for a large number of fisheries scientists beyond the need for educators and the curious. What does a manager do tomorrow? Do banks continue to lend money to fishermen? What will happen to coastal communities that depend on fishing? It is important to fund a project that will tell us that the food base is changing, but it is equally important to recognize that the future of our fisheries may be in unchartered waters, and our clients cannot wait for years while we charter their future.

It is important that organizations such as the American Institute of Fishery Research Biologists continue to bring thoughtful people together to talk about changes,

as Jones describes in her paper in this book. However, there is no organization in North America that currently represents our vision of fisheries science. There are a number of societies and organizations that offer annual opportunities for scientific exchange, but there is no focus for the regional marine fisheries science issues around North America. We believe that it is time to think about the equivalent of a North American ICES. We think that fisheries science needs a clearly thought out strategy that articulates large scales and regional priorities. The old saying that if you do not know where you are going, any road will get you there, probably applies to our current way of doing fisheries science. We need to excite fisheries science with a new spirit. For example, in the Pacific and the Atlantic we could have an "International Year of the Salmon." Fisheries scientists are drawn to the profession because of a passion for discovery and the satisfaction of working with other living things. The potential members of the potential scientific teams still have this passion. We now need the individuals to step up and lead the teams.