CHAPTER 2. THE PURPOSE OF STOCK ASSESSMENT AND THE OBJECTIVES OF FISHERIES MANAGEMENT

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2.1 BASIC CONCEPTS AND THE IMPORTANCE OF MANAGEMENT AS THE ULTIMATE GOAL OF FISHERIES SCIENCE

The intention of this chapter is to briefly introduce some important concepts that will be needed throughout the rest of the manual and whose understanding is essential for the correct practice of fisheries work and the successful management of fisheries. The chapter also provides a general framework for the rest of the manual and gives context to the different and interlaced roles of stock assessment and management, which are sometimes mixed and confused. Given the importance and scarcity of good management in present-day fisheries, it is never redundant to clarify and emphasize these basic concepts and put the different components of fisheries work into perspective. The overall feeling and some of the sections of this chapter are inspired by the book of Hilborn and Walters (1992) and readers are encouraged to give a thorough read to this excellent source for more in-depth information.

Fisheries Science is the multidisciplinary study of fisheries. Which disciplines are part of Fisheries Science is to a point a matter of opinion, but a preliminary list would include fisheries biology, marine ecology, stock assessment, natural resource economics, social sciences, fishing technology, oceanography, statistics, and computer modeling.

A ***fishery*** is defined as the set composed of a particular stock (for a definition of stock see Chapters 4 and 5) plus the fishing activities related to its harvest, inclusive of fishermen, vessels, gears and even associated facilities. Often the word stock refers to a population or part of the population of a ***single species*** but in the frequent case of ***multispecific*** fisheries it includes a group of at least two similar or diverse species.

Stock assessment is the part of Fisheries Science that studies the status of a fish stock as well as the possible outcomes of different management alternatives. It tells us if the abundance of a stock is below or above a given target point and by doing so lets us know whether the stock is overexploited or not; it also tells us if a catch level will maintain or change the abundance of the stock. But stock assessment is not the goal of Fisheries Science.

The ultimate objective of Fisheries Science is to inform management. This statement embodies the real meaning of the work of fisheries scientists and technicians, whose fundamental objective is neither to learn how fish grow, where they go or how fast they reproduce, nor to investigate how much fishermen catch, how or where they catch it, or how much money they make. The real and ultimate goal of fisheries science is to provide the information needed for the adequate management of fisheries. Ultimately, if the collective work of all those working in Fisheries Science does not translate into management decisions and their implementation, then we are wasting time and money.

This does not mean that fish biology, stock assessment and other disciplines are not extremely important; in fact they are, but it is essential to keep in mind that they are a very important ***means to an end***. The relevance of all the knowledge we can obtain about the biology of the resources and the dynamics of capture fisheries is that this information is needed to underpin the proper management of the fishery, including target and non-target species, detrimental effects of fishing on ecosystems, and also the human communities depending on fishery resources. It follows from the above that it is worthwhile for governmental agencies charged with fisheries research and management to prioritize and invest resources in fisheries biology and stock assessment of resources for which this work is going to be actually used to do fisheries management. This is a very important fact often ignored in many parts of the world. On the other hand, basic monitoring of unexploited or less important resources can be invaluable several years down the line when fisheries exploitation expands or its associated effects are felt. In this case, it is usually academic and independent research institutions that can carry out the basic monitoring that might be unaffordable to government agencies. It is also often overlooked that a prerequisite to successful management is the existence of the proper institutional and legal structures. Without ***management institutions***, management ***plans*** with clearly stated ***objectives*** and management ***rules*** there can be no effective decision making and implementation for fisheries management.

2.2 THE PURPOSE OF STOCK ASSESSMENT IN FISHERIES SCIENCE

Stock assessment makes use of diverse types of information to give managers advice about the status of a fishery and the possible outcomes of management actions. This includes aspects not only related to the resource abundance such as whether the stock is depleted or close to its maximum biomass, but also in regards to other important aspects of fish population dynamics such as the current levels of mortality and expected levels of future recruitment, or even economically relevant features such as likely changes in catch per unit effort.

Stock assessment has been defined in many ways, often in terms of its objectives. Sparre and Venema (1992) proposed that the basic purpose of stock assessment is “to provide advice on the optimum exploitation of aquatic living resources”. Probably the best modern definition comes from Hilborn and Walters (1992): “Stock assessment involves the use of various statistical and mathematical calculations to make quantitative predictions about the reactions of fish populations to alternative management choices.” The last definition is especially relevant because it explicitly says two important things, that ***quantitative predictions*** are needed in the process and that the objective is to provide ***advice*** to management ***about choices***.

2.2.1 Quantitative predictions, dynamics, and uncertainty

In order to be of practical use, modern fisheries stock assessment must be able to make quantitative predictions. To state that a fishery resource is “abundant” or “overfished” without further detail is of limited use for shaping management decisions if the level of abundance or depletion is not expressed as a quantity such as "the fishable stock is at 30% of its original virgin biomass". Equally important, stock assessment should be able to make ***quantitative predictions*** of the outcomes of different management regulations, such as how likely it is that an overexploited stock will recover to a target level in a specified time-frame under different catch or effort quotas. This is why modern stock assessment work is by necessity a ***quantitative*** discipline. While decades ago it was difficult to make these types of quantitative predictions, computers now allow us to do calculations we would hardly be capable of doing 20 years ago, and as time passes numerical methods are becoming more rigorous and powerful for stock assessment.

One of the most important roles of stock assessment is to understand the ***dynamics*** of fisheries. This follows because biological resources, fishermen and the environment are changing entities; they are dynamic not static. Furthermore, fisheries will necessarily respond dynamically over time to management actions as well as to external factors such as environmental forces. Understanding all of these dynamics in order to make good predictions is the ultimate role of stock assessment.

Uncertainty is an intrinsic characteristic of stock assessment. First, natural systems have a lot of random variability that translates into uncertainty and which can be due to variations in fish growth (Fargo and Kronlund, 2000) and reproductive output, as well as to environmental effects (abiotic and biotic) on biological and ecological processes (Parsons et al., 1998). Other sources of uncertainty are the variations in the behavior of fishing fleets and gear, the errors and biases in data collection, and the often incomplete or less than ideal quality of the data sets available for performing stock assessment. Uncertainty also arises from the choice of model used for stock assessment; some models are better suited to capture the underlying dynamics of a given resource than others but it is often impossible to determine which model is more correct for a particular stock. Considering all of the above, it is not surprising to find that the results of fisheries stock assessment are never precise estimates of biomass or mortality, but are in reality estimates that contain a certain degree of uncertainty and doubt. Dealing with uncertainty, acknowledging it and incorporating it into the decision-making process is something extremely important but that only recently has begun to be put into practice. Further reading on the need to embrace uncertainty and new methods to achieve this can be found in Punt and Hilborn (1997), Hilborn and Lierman (1998), McAllister et al. (1999), and Patterson et al. (2001).

2.2.2 The concept of MSY and its evolution from an objective to a reference point

The traditional concept of the dynamics of fishery resources is that there is an underlying model according to which as fishing effort increases, catch will increase up to a maximum, and if effort continues to grow then catches (also known as yield) will decrease. This leads directly to the concept of maximum sustainable yield (MSY) which has been the holy grail of fisheries (Larkin, 1977).

The specific shape of the yield curve shown in Figure 2.01 does not matter. The important principle always holds: zero effort means zero catch; too much effort leads to small or almost zero catch. Also, in theory there should be a point at which catch has a maximum—at least on average—and supposedly once the curve reaches the top, the MSY level has been found. For decades, finding MSY and keeping fisheries at this prescribed level of catch and effort became the sole objective and obsession of fisheries science, as eloquently put by Larkin (1977).

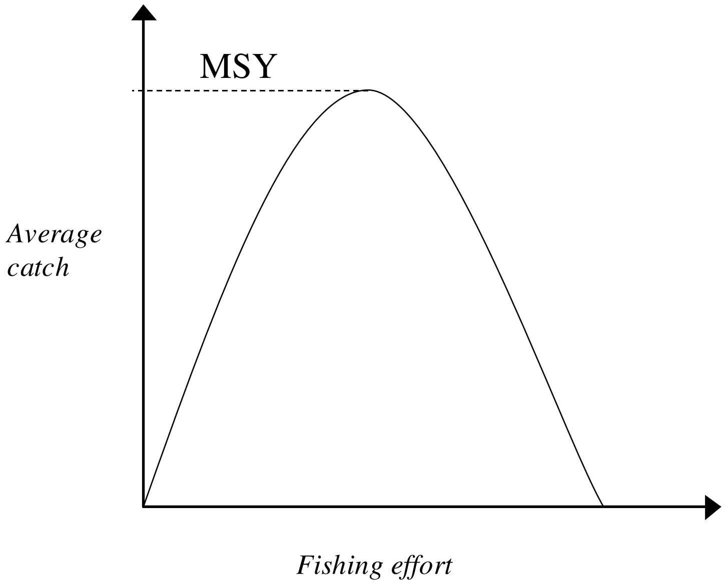

Figure 2.01 A graphical representation of the Maximum Sustainable Yield (MSY) concept.

There are several problems with this concept, the first practical problem being that natural systems have a lot of random variability. In practice, real data will always reflect this variability as “noise.” The great danger of focusing stock assessment work solely in finding MSY and its associated optimum effort (f_{opt} defined as the effort level that produces MSY) is that we can seldom be totally sure that we have witnessed the MSY level. Even if managers try to be very careful and cautious by developing a fishery at a very slow pace it will never be guaranteed that the stock will not be overexploited or that opportunities will not be wasted. An excellent example of the difficulties in finding MSY comes from work on Atlantic yellowfin tuna (*Thunnus albacares*) published by FAO and cited by Hilborn and Walters (1992). When scientists performed the first assessment of this resource in the mid-1970s, they thought they had already arrived at the MSY level and calculated this at about 50,000 t. However, due to lack of effective management the fishery continued to grow and a second analysis 10 years later suggested a different MSY level of more than 100,000 t, clearly indicating that the first assessment lead to a “false” MSY. The question remaining was if the second assessment was also an underestimate.

The real problem in the above example and most real fisheries is that in all cases and especially in situations of noisy data we would have to go beyond MSY to make sure that we have actually found it. In other words until yield does not substantially decrease for a good period of time at increased effort levels we cannot be sure that MSY has been observed. This effectively means that we can never prevent overexploitation, at least not a small amount of it in the best case. This is an important principle identified by Hilborn and Walters (1992): *"You cannot determine the potential yield from fish stocks without overexploiting them."* The secret is not to overexploit the stock beyond recovery in our effort to find MSY. An additional practical problem is that once fisheries have actually passed the MSY point and gone into the overexploitation phase, more problems arise. In such cases, the fishery is already in the overcapacity side of the curve. This leads to another sad but important principle stressed by Hilborn and Walters (1992): *"The hardest thing to do in fisheries management is to reduce fishing pressure."*

In an ideal situation a new fishery should start with all the mechanisms in place to assure, a) detection of MSY quickly after passing this point (i.e., a good monitoring and data acquisition system should be in place), and b) there should be mechanisms in place from the onset of exploitation , to reduce effort effectively without detrimental effects (high taxes that can be later used to buy back boats or compensate for the lost catches and revenue of each boat).

Nowadays, MSY is a theoretical concept that should hold on average, but it is mostly useful as a *general concept* that helps us to guide our work; it is *not the aim* of fisheries assessment. In present times the MSY concept is used to derive management targets and limits or biological reference points (BRPs). Biological reference points are levels of total biomass, spawning stock biomass, fishing mortality rate or other measurable characteristics of a fish population and a fishery, which are either the target of management or a limit beyond which the fishery will not be permitted to go. Two common BRPs are the biomass at which the population can produce the maximum sustainable yield (B_{MSY}) and the fishing mortality needed to achieve MSY (F_{MSY}). For additional reading about these and related concepts readers should refer to Clark (1991), Jacobsen (1992), Smith et al. (1993), Caddy and Mahon (1995), and Hayes (2000). A further important consideration is that MSY and the reference points based on it assume that environmental conditions are constant. However, human-induced (habitat destruction, species depletion) and environmentally driven phenomena (climatic "regime shifts"), can all produce changes in MSY. This issue has commonly been either ignored or mishandled in fisheries science.

2.2.3 Model complexity and the importance of cross-comparison in stock assessment

Predictions are always based on the use of a model, whether the model is explicit or implicit. Even the simplest prediction about what will happen to a stock if effort is increased implies a set of assumptions or conceptual model. Formally, a model is just a representation or abstraction of a given system or process, which in the case of quantitative disciplines such as fisheries stock assessment takes the form of equations or sets of equations. The type and complexity of models depends on the field of research and the particular problem to be analyzed. In terms of Holling's (1978) classification, problems in population modeling generally lie in the area of low quality/quantity of relevant data. However, it is important to emphasize that the complexity of a model (understood as the number of variables included) is not always directly related to its performance and usefulness.

Models available for stock assessment (see Chapters 9 and 10 for more details) range from the simple holistic models that intend to capture all biological processes in a simple equation such as surplus production models, to the detailed and elaborate age-structured, spatially-structured, multi-stock or even multi-species models that include several sets of equations and which intend to give a more realistic representation of fish population dynamics. But while intuition tells us that complicated and detailed models should be better than simple ones because they more accurately represent "reality," research has shown that simple models can often perform better because they require fewer parameters to be estimated, and very frequently the uncertainty surrounding the estimation of some of these parameters only reduces the ability of models to produce useful information (Ludwig and Walters, 1985; 1989; Ludwig et al., 1988). Readers are encouraged to investigate this topic in more detail by referring to chapter 3 of Hilborn and Walters (1992) for an excellent discussion and further references on this topic. Starfield and Bleloch (1986) give an excellent accessible introduction to model building.

Perhaps the most important message that readers should take home is that while analyzing a fishery, it is imperative to avoid using a single "best" method; the idea that any given model is the best and only model to be used for fisheries stock assessment is dangerously wrong. Instead, it is best to employ a carefully chosen suite of methods—considering the available data—and if possible including both simple and complex models. This will allow the cross-comparison of alternative results that helps detect coincidences and patterns as well as inconsistencies, often highlighting errors in data or guiding the acquisition of additional key information through additional research. In a similar fashion, conflicting results using the same model with different data sets should be carefully analyzed for possible biases in the data. Stock-assessment scientists should ask themselves why there might be differences in predictions about the status of the stock or about the outcomes of different management alternatives across models. An objective picture of the situation can only be obtained when we question the conclusions from one analysis with those of a different one and critically use the different results to gauge our conclusions and to identify which pieces of the puzzle are missing. Only this complete process will allow us to improve the data and methods, and therefore increase the capacity to perform better assessments in the future. The same principle applies also to different data sets that could be available to perform a particular stock assessment. Sound stock assessment is achieved only through healthy cross-comparison and exhaustive questioning of the results of alternative models and data sets.

Finally, it should be mentioned that the complex and often politically charged topic of model choice in stock assessment can nowadays be dealt with through the use of Bayesian approaches (Hammond and O'Brien, 2001) and decision analysis techniques (Punt and Hilborn, 1997; McAllister and Kirkwood, 1998). These methods offer quantitative ways to choose between different models and management options taking into account the uncertainty involved, and are the best way to make management decisions based both on the outcomes of the stock assessment and the probabilities of success of the proposed management options.

2.3 THE DIFFERENT OBJECTIVES OF FISHERIES MANAGEMENT AND THEIR INTERPLAY

What is the purpose of fisheries management? While early fisheries management had implicitly or explicitly MSY as it most important objective (Gulland, 1968) presently MSY is considered only a biological concept and benchmark to guide management. Although MSY still plays an important role as a guiding light for fisheries management, often specific and multiple objectives of fisheries management may be more important than obtaining maximum yield in the long term (Alverson and Paulik, 1973). According to Hilborn and Walters (1992), the most widely accepted fundamental purpose of fisheries management is "to ensure the sustainable production over time from fish stocks, preferably through regulatory and enhancement options that promote economic and social well-being of the fishermen and industries that use the production".

In the modern world of fisheries, management tries to balance multiple objectives that span beyond biological concerns. Oftentimes these multiple objectives are in opposition to each other, such that it is not possible to achieve all of them simultaneously. Managers have to make quantitative decisions about how many fish can be caught, what is the number of boats that will be allowed to enter a fishery, or what is the minimum size of a fish or a gillnet mesh that should be allowed. They also have to make decisions about how much should be spent on research, enforcement of regulations, administration, etc. Within this context, fisheries assessment is about giving advice on the status of the resource and the likely results of alternative measures. Once this is done, the choice of which action to take remains (usually a given amount of fish or quota that can be caught by many different combinations of effort and number and size of boats), and this is where choices have to be made by managers, usually on economic and social grounds. More precisely, fisheries management objectives can be broken down into at least the four categories presented below.

2.3.1 Biological and conservation objectives

By default the biological objective of fisheries management is obtaining MSY, or in other words achieving biological yield maximization. This concept has already been explained above. The standard indicator of biological yield is the annual weight or number of fish caught.

Resource conservation, as well as biological and genetic diversity, are also important biological objectives with an increasingly important role in fisheries management. Explicit directives to avoid putting stocks of target ***and*** non-target species at risk of extinction, and to develop plans for their recovery in case they are already endangered, play a very important role in fisheries legislation in many parts of the world. This is exemplified in the 1996 Magnuson-Stevens Fishery Conservation and Management Act of the USA. Even more recently, ecosystem-health objectives are beginning to take a very important role in fisheries management (Sainsbury et al. 2000; Stevens et al. 2000). Several fishery management plans already incorporate ecosystem objectives and it is just a matter of time until ecosystem-based objectives replace some of the more traditional biological objectives such as obtaining single-species MSY levels. However, that topic is beyond the scope of the present manual.

2.3.2 Economic objectives

In economic terms, to obtain the maximum amount of fish (MSY) is not the main objective. Fisheries are an economic activity and thus should aim for economic rent and more specifically for ***profit maximization***; that is the maximization of total revenue minus the total costs. Thus, the concept of maximum economic rent (MER) is an economic analogue to MSY. The MER level is defined as the point on the revenue curve (simply the yield curve times the unit value of fish landed) where the difference between the total costs of fishing (typically a straight inclined line) and revenues is greatest. However, as shown in figure 2.02 the point of the curve where we find MER will be by definition always at an effort level that is lower than MSY. It is clear from this that it is impossible to attain MSY and MER at the same time and this is a typical example of a likely conflict between multiple objectives in fisheries management (Figure 2.02). Further reading on economics and fisheries management can start with Crutchfield (1965) and MacKenzie (1992).

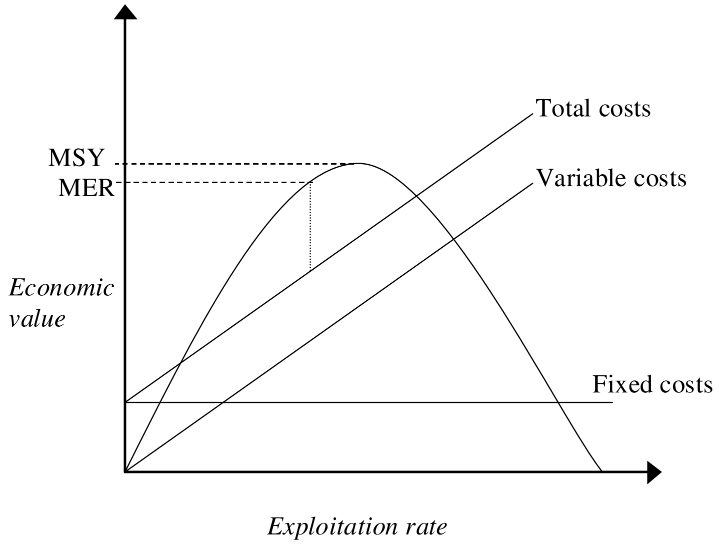

Figure 2.02 A graphical representation of the Maximum Economic Rent (MER) concept and a comparison with MSY.

2.3.3 Social objectives

Social objectives are concerned with employment and equity. Fisheries are not only about landing fish and making money out of it, but also about employing people and making sure that those involved in the fishery make a living that is adequate and sustainable. In many coastal communities of the world it is common that fishing is the most important source of employment. In such situations, having a large number of not-so rich fishermen might be more desirable than having a few very rich ones. Also, it is often important to preserve community structure and traditional lifestyles. Communities that have been fishing for a few hundred years and hold traditional fishing rights, such as the case with many indigenous groups, must be taken into consideration as part of management. From the social point of view, the total number of jobs related to the fishing activity is often the standard indicator, as well as the distribution of income among fishers and the maintenance of traditional lifestyles. Excellent further reading in topics related to economic and social issues in modern fisheries can be found in Fairlie (1995).

2.3.4 Recreational objectives

In some parts of the world, fish stocks have to be shared between commercial fisheries and recreational fisheries. Although both sectors are pursuing fish, their objectives are often very different. For recreational purposes, both the catch and the effort (number of successful fishing trips) might be important objectives. The total number of fish available to be fished is usually more important to a sport fishery than the total biomass of fish available, and in the specific case of trophy fish (such as marlins, swordfish or tunas), the size of the fish will be of outmost importance. In such a case it might be an objective for the fishery to have a few large fish rather than many small ones. The standard indicators for recreational fisheries include the estimated total value of recreational effort (dollars per day times days fished), and the number and size of the recreational catch.

2.3.5 Fisheries management as a balancing act and the importance of explicit objectives

Fisheries management is about making difficult decisions among multiple choices. The decisions go beyond choosing between multiple stock assessment model/data results with different degrees of uncertainty, but also include choosing or balancing between conflicting objectives. While the obvious dilemma between whether to aim for MSY or MER has already been mentioned above, perhaps the major and most difficult dilemma faced today by fishery managers throughout the world is the conflict between economic performance and social issues. Fisheries throughout the world are grossly overcapitalized; massive subsidies are responsible for the persistence of a situation in which too many vessels and too many fishermen chase fish stocks that could be fished by fewer vessels and crews in a much more economic efficient way (Greboval and Munro, 1999). However, should hundreds of thousands or perhaps even millions of jobs across the coastal areas of the world be lost in the name of economic efficiency? And where are resources going to come from to give alternative jobs or pensions to those displaced? Balancing these opposing objectives is a major challenge for fishery managers. It is precisely for this reason that the explicit statement of the objectives for fisheries management is an extremely important step, but one that is unfortunately often overlooked in fisheries science. The major risk of not having explicit objectives is that management then faces getting lost in a sea of political waves driven by which interest group flexes more power at any point in time. This will probably lead only to disaster in the long term. On the other hand, Hilborn and Walters (1992) have pointed out correctly that it might not be desirable to set very rigid and detailed objectives that might be impossible to reach, thereby leaving management at an impasse when legislation does not allow for frequent and efficient review of management objectives. Given the likelihood that objectives will eventually collide with each other even if the have not been explicitly stated, it is more important that a healthy and open discussion of the overall general objectives of management for each fishery is held as early as possible. However, it is important to clarify at this point that it is not the job of biologists and sometimes not even managers to define what the objectives of fisheries management will be. This should ideally be a collective decision by a management advisory body that includes all stakeholders and interested groups, from fishers and local communities, to government agencies and non-governmental organizations.

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2.5 REFERENCES

ALVERSON, D. L., AND G. J. PAULIK. 1973. Objectives and problems of managing aquatic living resources. J. Fish. Res. Board Can. 30:1936-1947.

CADDY, J. F., AND R. MAHON. 1995. Reference points for fisheries management. FAO Fish . Tech. Pap. 347, FAO, Rome.

CLARK, W. G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 8:734–750

CRUTCHFIELD, J.A. (ed.). 1965. The fisheries problems in resource management. University of Washington Press. Seattle.

FAIRLIE, S. (ed.). 1995. Overfishing: its causes and consequences. Ecologist. 25(2/3).

FARGO, J., AND A.R. KRONLUND. 2000. Variation in growth for Hecate Strait English sole (*Parophrys vetulus*) with implications for stock assessment. J. Sea Res. 44 (1-2): 3-15.

GREBOVAL, D., AND G. MUNRO. 1999. Overcapitalization and excess capacity in world fisheries: Underlying economics and methods of control, p. 1-48 *In*: Managing fishing capacity. Selected papers on underlying concepts and issues. FAO Fish. Tech. Pap. no. 386. FAO, Rome (Italy).

GULLAND, J. A. 1968. The concept of maximum sustainable yield and fishery management. FAO Fish. Tech. Pap. 70. FAO, Rome.

HAMMOND, T. R., AND O'BRIEN, C. M. 2001. An application of the Bayesian approach to stock assessment model uncertainty. ICES J. Mar. Sci. 58:648–656.

HAYES, D. B. 2000. A biological reference point based on the Leslie matrix. Fish. Bull. 98:75–85.

HILBORN, R., AND C. J. WALTERS. 1992. Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. Chapman and Hall.

__________, AND M. LIERMANN. 1998. Standing on the shoulders of giants: learning from experience in fisheries. Rev. Fish Biol. Fish. 8:273-283.

HOLLING, C. S. (ed.). 1978. Adaptive environmental assessment and management. Wiley, Chichester.

JAKOBSEN, T. 1992. Biological reference points for North-East Arctic cod and haddock. ICES J. Mar. Sci. 49(2):155-166.

LARKIN, P. A. 1977. An epitaph to the concept of maximum sustainable yield. Trans. Am. Fish. Soc. 106:1-11.

LUDWIG, D., AND C. J. WALTERS. 1989. A robust method for parameter estimation from catch and effort data. Can. J. Fish. Aquat. Sci. 46:137-144.

____________, AND __________. 1985. Are age-structured models appropriate for catch-effort data? Can. J. Fish. Aquat. Sci. 42:1066-1072.

____________, C. J. WALTERS, AND J. COOKE. 1988. Comparison of two models and two estimation methods for catch and effort data. Natural Resource Modeling 2(3):457-498

MCALLISTER, M. K., AND G. P. KIRKWOOD. 1999. Applying multivariate conjugate priors in fishery-management system evaluation: how much quicker is it and does it bias the ranking of management options? ICES J. Mar. Sci. 56:884–899.

__________, P. J. STARR, V. R. RESTREPO, AND G. P. KIRKWOOD. 1999. Formulating quantitative methods to valuate fishery-management systems: what fishery processes should be modelled and what trade-offs should be made? ICES J. Mar. Sci. 56:900–916.

MACKENZIE, W. C. 1992. An introduction to the economics of fisheries management. FAO Fisheries Technical Paper 226. FAO, Rome.

PARSONS, L.S., H. POWLES, AND M.J. COMFORT. 1998. Science in support of fishery management: New approaches for sustainable fisheries. Ocean Coast. Manage. 39 (1-2):151-166.

PATTERSON, K., R., COOK, C. DARBY, S. GAVARIS, L. KELL, P. LEWY, B. MESNIL, A. PUNT, V. RESTREPO, D. W. SKAGEN, AND G. STEFÁNSSON. 2001. Estimating uncertainty in fish stock assessment and forecasting. Fish Fish. 2: 125–157.

PUNT, A., AND R. HILBORN. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Rev. Fish Biol. Fish. 7:35–63.

SAINSBURY, K. J., PUNT, A. E., AND A.D.M. SMITH. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES J. Mar. Sci. 57:731–741.

SMITH, S. J., J. J. HUNT, AND D. RIVARD (eds.). 1993. Risk Evaluation and Biological Reference Points for Fisheries Management. Can. Spec. Publ. Fish. Aquat. Sci., no. 120.

SPARRE, P., AND S. VENEMA. 1992. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish. Tech. Paper 306/1 rev 1. FAO, Rome.

STARFIELD, A. M., AND A. L. BLELOCH. 1986. Building models for conservation and wildlife management. Macmillan Publishing Company, New York.

STEVENS, J. D., R. BONFIL, N. K. DULVY, AND P. A. WALKER. 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Sci. 57:476–494.