Quantitative Fisheries Stock Assessment

Choice, Dynamics and Uncertainty

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Role of Stock Assessment in Fisheries Management

1.1. What is Stock Assessment?

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. Two key words are critical in this thumbnail definition: *quantitative* and *choices*. The basic concern of stock assessment is to go beyond the obvious qualitative predictions that any student of nature should be able to make about natural limits to production, risks of overfishing spawning populations, the need to allow fish to grow to a reasonable size before they are harvested, and so forth. Furthermore, it does not make sense to engage in the risky and often embarrassing business of quantitative prediction in settings where there are no management choices to be made in the first place, except perhaps as an aid to scientific thinking and hypothesis formulation.

It is widely accepted that the fundamental purpose of fisheries management is to ensure sustainable production over time from fish stocks, preferably through regulatory and enhancement actions that promote economic and social well-being of the fishermen and industries that use the production. To achieve this purpose, management authorities must design, justify (politically), and administer (enforce) a collection of restraints on fishing activity. In some systems, the management authority is also empowered to restrain various other economic actors who might impact the ecological basis for fish production (water polluters, etc.), and to engage in activities to "enhance" the basis for production (habitat improvement, hatcheries, etc.).

Practically all management activities, from fishing restraints to habitat improvement, are done as matters of degree rather than as yes or no decisions. Management authorities must make very difficult and quantitative choices about how much development of fishing to encourage or permit, what specific limits to place on catches (times of fishing, sizes of fish, total landings, locations of fishing), how much financial resource to spend on enforcement of regulations versus enhancement of production, and so forth.

The distinction between stock assessment and management

Too often the term stock assessment is synonymous with biological advice about harvest levels. In this view of the world, the biologists assess the status and potential production of the stock and make recommendations about catch levels, efforts, and so on. Any modification of regulations by politicians or fishermen is considered interference in the rightful mission of biologists to determine appropriate management actions.

Such a view fails to recognize the distinction between assessment of biological potential and the decision about how to manage the stock. Once the stock assessment is complete, choice remains. As we see in later chapters, the same biological yield is often possible over a very wide range of fishing efforts. Stock-assessment biologists are not the appropriate people to make such decisions. Similarly, fisheries management decisions often trade off between average yield and variability of yield. The stock assessment should provide estimates of the nature of the tradeoff, but the choice should be made on social and economic grounds. Some of the chapters of this book, particularly the third section, deal with the tools of stock assessment; the fourth section with the tools of decision making. Both are an integral part of fisheries management, but we should not fail to distinguish between them.

Alternative modes of stock assessment

A management authority can go about the difficult business of making choices among quantitative alternatives in three ways. First, it may simply mimic choices made under similar circumstances by other authorities under the assumption that previous decision making has already involved careful evaluation of alternatives. Second, it may make an initial choice that "looks reasonable" on intuitive grounds, then plan to systematically vary the choice while monitoring biological and economic responses, so as to eventually find the best choice by an empirical process of trial and error. Third, it may engage in formal stock assessment, the construction of quantitative models to make the best predictions possible about alternative choices based on whatever data are available to date, and then base its choices on the models while expecting to refine or modify the choices later as more data become available. A combination of the second and third approaches, using a mixture of quantitative modelling and empirical management experimentation, has come to be called "adaptive management" (Walters and Hilborn 1976, Walters 1986).

The simplest way to think about the role of formal stock assessment in fisheries management is as a means to move beyond mimetic or "seat of the pants" policy making, by providing at least some structured use of available data in comparing choices. This is not the same as making the ambitious

(and naive) claim that the role of stock assessment is to find the "best possible" or the "optimum" choice of such variables as catch quotas. The choice of policy options is normally, and rightfully, a political, social, and economic decision. The role of stock assessment is to provide the best possible technical support to these decisions. It is reasonable to expect that careful data analysis, using models whose assumptions are clearly specified, will in general result in technical support that is closer to the mark than subjective or intuitive guesses that may involve even worse hidden (subconscious) assumptions.

The choice in fisheries management is not really whether to do stock assessment, but whether to do it well. In the words of John Gulland (1983), perhaps the most broadly experienced stock assessment expert in the world,

> "All those concerned with making policy decisions about fisheries must take into account, to a greater or lesser extent, the condition of the fish stocks and the effect on these stocks of the actions being contemplated."

Any decision choice will somehow "take into account," or make some assumption about, the stock dynamics; thus, in a sense, any choice will necessarily be based on some predictive model, whether this model is explicitly stated or not. Another way to think about the role of stock assessment is as a means to force clear and explicit recognition of what model is being used as the basis for choice. Such clear recognition is a key step toward learning to do better over time.

Where careful assessments are not made, due to distrust of models and available data or to lack of expertise in assessment techniques, management authorities often grasp at (or are forced to use through political pressures) estimates provided by advisors to industry interests. In other words, if you do not provide some answers for policy makers, someone else will. There are always "experts" available to provide whatever estimates will suit the purposes of people who want greater immediate access to fisheries. In the political arenas, where key regulatory decisions and limits are made, debate often focuses on simple summary statistics and simplistic (common sense) models of fish responses; in such arenas, it is common to use deliberate disinformation as a tactic to confuse debate and delay effective action. In the "good old days", before this tactic became widely known, there was a tendency to accept scientific assessment advice uncritically. Today a scientist who tries to wing it (by providing numbers that are not justified through clear, precise, and credible calculations) is liable to find himself either ignored or grossly embarrassed.

The breadth of stock assessment

Stock assessment is sometimes viewed as a rather narrow biological discipline that might be summarized as "the interpretation of commercial catch statistics to estimate potential yields." A well done stock assessment is much more than this. First and foremost, stock assessment involves understanding the *dynamics of fisheries*. This recognizes that fisheries are dynamic entities that will respond over time to management regulations, and to extrinsic factors. Modern stock assessment is not just the task of making static predictions about equilibrium sustainable yields. It should also involve making predictions about the time trends expected in response to policy change and about how policies should be structured in order to deal with the unpredictable changes that will inevitably occur.

Fisheries are also much more than fish catch. Fishermen are an important component of the dynamic system we call a fishery, and stock assessment must take into account how fishermen will respond, and also make predictions about things important to fishermen such as catch per unit effort. Fisheries are considered in crisis when income to fishermen drops below some acceptable level, and we believe that making predictions about how catch per unit effort (and therefore fishermen's income) will change is more important than predicting changes in total catch.

Processing and marketing are often very important components of the fishery system. Recognizing that fishermen are the political center of most fisheries and that returns to fishermen (in money) are the key measure of management success, one simply cannot ignore processing and marketing. For instance, for some biological models, one can show that the average biological yield will be maximized by holding the fish stock at a constant level. This will normally result in rather high year to year variability in catch, often with absolutely no catch in some years. Such variability is quite destructive of processing infrastructure and the maintenance of markets—yet many biologists have held that the "optimum" way to manage these fisheries is to maintain constant stock biomass.

1.2. The Changing Role of Assessment in Fisheries Development

Commercial fisheries are not static systems that can be manipulated and reshaped at will by management. They usually develop initially through a dynamic process that involves several distinct stages. One generalized diagram of these stages is shown in Figure 1.1. First, there is discovery and spread of information about the existence of a potentially valuable stock. This is labeled predevelopment. Second, there follows a period of rapid growth of effort attracted by the success of initial fishermen. Next the fishery reaches full development, where yields are near or perhaps a little above a long-term sustainable level. The rapid development results in declining rates of fishing success as the stock is reduced and more fishermen compete for the remaining fish until either some limit on fishing pressure is established

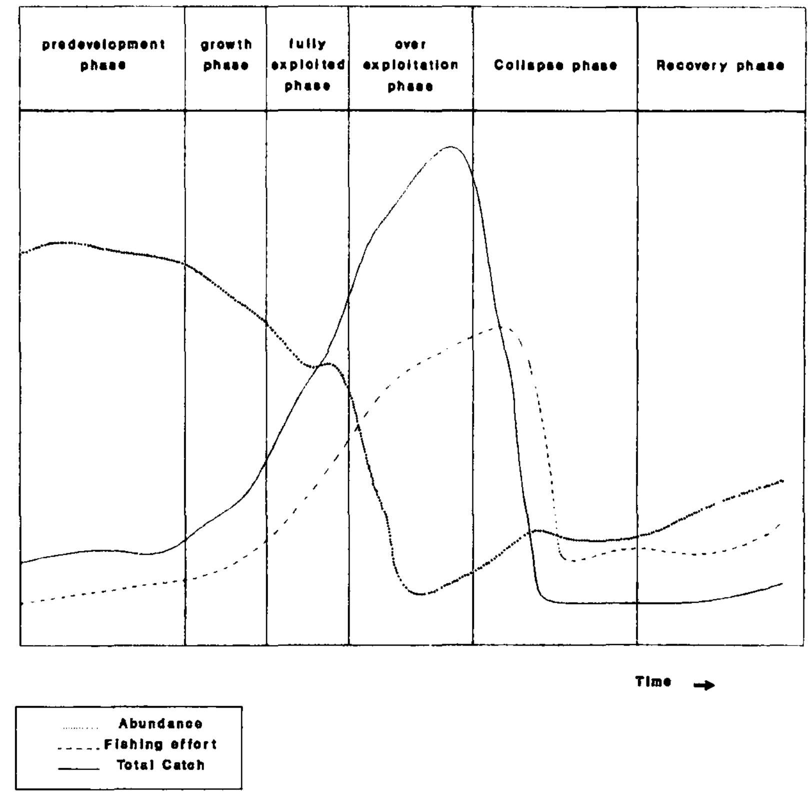

Figure 1.1. Phases of development of uncontrolled fisheries. Redrawn from Csirke and Sharp (1984).

through management or success rates become too low to attract more pressure. The fishery often then enters an overexploitation stage, which is followed by a collapse. If the collapse is not too catastrophic, there is often a period of declining fishing pressure as the less successful fishermen find it no longer worthwhile to pursue the stock. The stock may or may not recover somewhat on its own during this period. On a longer time scale, there may be an evolutionary rhythm in which occasional technological innovations result in increased fishing success and attraction of more fishing pressure and hence a repetition of stages three and four of the initial development, unless fishing effort is carefully managed through each technological transition.

The extent to which the collapse is severe, or the fishery does not collapse at all will depend on the price of the fish product, the delays in investment, the extent to which fishing success declines as abundance declines, and whether regulatory agencies act to reduce effort or catch before a collapse occurs. Figure 1.1 represents only one possible trajectory.

The role of stock assessment is different in each of the stages of fishery development. At first, assessment is critical in setting basic expectations and limits for development and in designing monitoring programs to provide estimates of key population parameters. Later, it can play an important role in "fine tuning" the fishing system for higher yields, in developing plans for stock rehabilitation in cases where the initial development results in overfishing, and in developing strategies for management during technological transitions to more efficient fishing methods.

Setting expectations early in development

Consider the situation management faces when a new fishery begins to develop. Someone (usually entrepreneurial fishermen) has discovered that there is a stock worth pursuing and is beginning to make a profit (or finding unusually good recreational action). Word is beginning to spread about the opportunity, attracting the interest of other fishermen and/or agencies concerned with the promotion of fishery development. It appears that fishing effort and related investment (for example, in processing plants, marketing arrangements, and tourist facilities) is likely to increase rapidly. There is no history of experience with the stock, so little is known about its distribution, total abundance, and productivity.

The most important management (and assessment) question at this point is obvious: what level of fishing pressure should be permitted (or encouraged, or subsidized) as an initial development target, recognizing the risk of eventual economic overcapitalization and/or biological overfishing? On a sustainable basis, is the stock eventually likely to support 10 fishermen, or 100, or 1,000? Notice that at this point in time, even an order-of-magnitude assessment will be of considerable value in development and regulatory planning; there will be time later to obtain more precise assessments, provided the initial development proceeds within reasonable bounds.

Beyond providing rough initial estimates of the stock distribution, stock size, and productivity, an important role of stock assessment early in fishery development is to help define key monitoring requirements that will permit more precise assessments later in the development. It is often not recognized by fishery biologists that even after many years of fishery data are available, some key assessment calculations will still depend heavily on data that can only be gathered early in the fishery's development. For example, estimation of potential yields, optimum sizes of fish to harvest, and most refined methods for stock size estimation all depend on having a reasonable estimate of the average natural mortality rate. Usually the only time this rate can be measured is early in fishery development, when it is possible to examine

the relative abundance of animals of different ages before the population age structure is much distorted by fishing. Later in development, the age structure carries information only about the combined effects of fishing and natural mortality. There is no reliable way to separate the combined effects (and hence measure the mortality rate due to fishing) unless the early data are available for comparison, the fishing mortality rate can be measured directly, or the fishing mortality changes greatly. Estimating fishing mortality directly is difficult because you would need to know the catch and total stock size directly or have an unusually good tagging program.

These considerations apply primarily to large single unit stocks. If the fish resource consists of many spatially isolated subunits, then one can (in theory) overexploit some, while underexploiting others. Unfortunately, the normal tendency of fishing fleets is to make fishing pressure uniform over all subunits.

Two biological characteristics of the fish species can provide very useful information very early in development. Knowledge about the longevity of the species can provide useful guidelines about the potential for large unsustainable yields. Fish that live a long time normally provide very large yields at the beginning of a fishery because of fishing down of the older age classes. Secondly, knowledge of the behavior of the species can provide useful information about the danger of severe stock collapse. Pelagic schooling fish are well known to collapse because they re-form in schools that provide easy targets for fishing nets. Species that do not form large aggregations are normally more resistant to dramatic collapse.

Improving information as development proceeds

Increasing catches during fishery development are generally accompanied by (1) a decrease in fish density in areas where fishing effort is initially concentrated, (2) movement of effort into less preferred fishing areas, and eventually (3) a decrease in indices of fishing success, such as catch per unit of fishing effort (CPUE). Changes in catch, CPUE, and other indices of fishing impact (e.g., age composition, average fish size) can be used to provide estimates of the stock size, and to measure rates of "surplus" production (excess of reproduction and growth over natural mortality) as related to the changing stock size. Pelagic schooling fish typically do not show declining catch rates as development proceeds, because the schooling assures that fish are found in high densities even when total abundance is greatly reduced. Such fisheries are very difficult to manage because the fishermen and managers get little sense that the stock is declining unless careful analysis of the spatial structure of the stock is made.

A key role of stock assessment during development is to provide regular updating and "feedback" of population parameters and estimated potentials into the management decision process. In particular, systematic and regular assessments may provide good early warnings of overfishing and help to prevent severe overcapitalization of the fishing industry.

It is important to understand that there is no substitute for the experience gained during development for estimating rates of surplus production and potential yields. The surplus of reproduction and growth over mortality that a given stock can produce is a result of the particular quantitative values that several key rates assume in the particular environment where the stock resides. These rates can differ drastically from stock to stock, even within a single species over a narrow geographic range. Rough bounds on productivity can be established from general biological information about the species (growth, longevity, etc.), but there are no precise quantitative "laws" or principles that might be used as predictive substitutes for the role of stock assessment in helping to "learn as you go."

One of the fundamental tenets of traditional fisheries theory is that there is a repeatable relationship between fishing effort and average catch as shown in Figure 1.2 (a similar figure is the first figure to appear in Gulland 1983 and in Clark 1988). Yield increases as fishing effort increases up to some point, at which point yield begins to decline with further increases in fishing effort. There may be year-to-year fluctuations about the average relationship, but the following must be true: (1) in the absence of fishing effort there will be no catch, (2) at very high levels of fishing effort the stock will be fished to such low numbers that the remaining fish will not be able to produce a large surplus, and (3) the maximum average yield is therefore somewhere in between no effort and very high effort. If the fishing gear is inefficient it may not be possible to fish the stock very hard, but in general we accept the above three propositions as a starting point in the analysis of most populations.

Unfortunately, the apparently obvious nature of Figure 1.2 has pointed stock assessment in the wrong direction. Once we accept Figure 1.2, it is easy to believe that the purpose of stock assessment is to estimate the level of fishing effort that will generate the maximum average yield and to estimate what that average yield will be. Indeed, a discouragingly large proportion of fisheries stock assessments concentrate on precisely and only these two questions: what is the optimum effort and what is the maximum sustainable yield (MSY)? *These are the wrong questions.*

A simple minded view of stock assessment as development proceeds is that the thing to do is to monitor fishing effort as it increases slowly and gradually, while monitoring yields so as to eventually be able to plot a relationship like Figure 1.2. According to this view, once the fishery has reached the top of the curve (and yield begins to drop), you know you have found MSY. What could be simpler! Unfortunately, quite a few things are simpler. You cannot find the top of a curve as in Figure 1.2 without going beyond

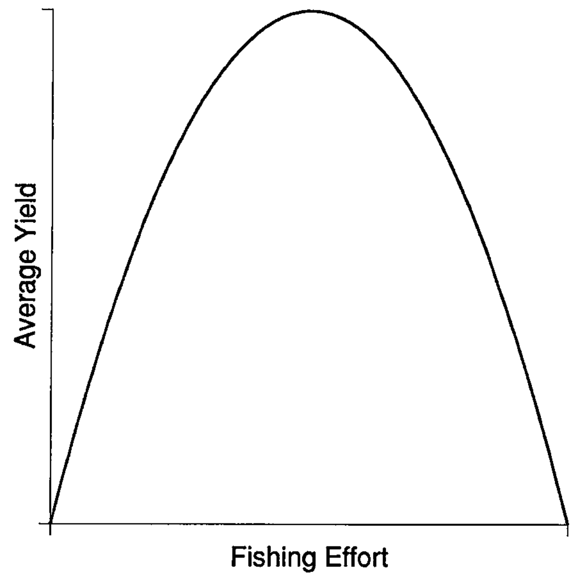

Figure 1.2. The assumed relationship between fishing effort and average catch. Perhaps the most commonly printed illustration in fisheries textbooks, and the most dangerous.

the top. The noisier the data are, the farther beyond the top you have to go before you are sure that you have actually found it.

Figure 1.3 shows the yield-effort relationship for yellowfin tuna (*Thunnus albacares*) in the eastern Atlantic Ocean, from Hunter et al. (1986). In 1975, the International Commission for the Conservation of Atlantic Tunas (ICCAT) analyzed the data from 1964 to 1973 estimated the sustainable yield as approximately 50,000 tons, and estimated the optimum effort as approximately 60,000 fishing days. They believed they had reached the top of the yield-effort curve.

However, ICCAT was politically unable to constrain effort at the "optimum," the fishing effort continued to increase, and by 1983 the yield was over 100,000 tons. It was clear that the 1975 estimate of 50,000 tons was a "false summit," and that the real top was at higher efforts and higher yields. The second curve fit in Figure 1.3 gives the 1985 estimate of the optimum effort and maximum sustainable yield. The key question is "Did they find the top in 1985?"

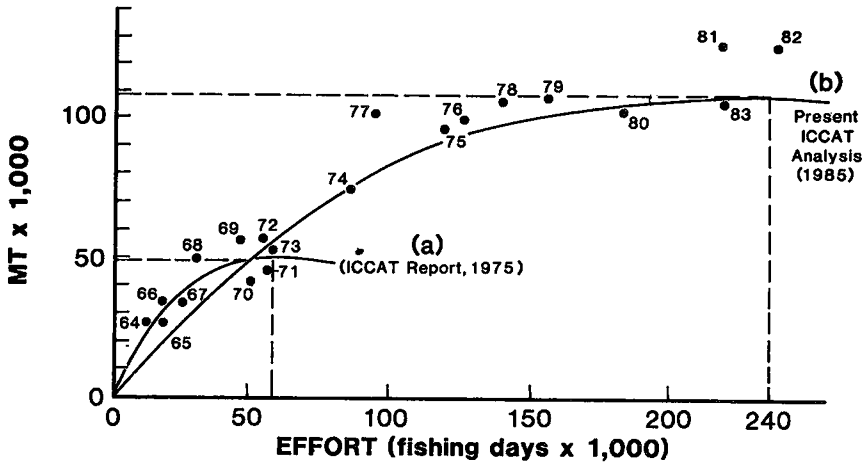

Figure 1.3. Yield-effort relationship for eastern Atlantic yellowfin tuna. From Hunter et al. 1986. Reproduced by permission of the Food and Agriculture Organization of the United Nations.

Principle: You cannot determine the potential yield from a fish stock without overexploiting it.

The yellowfin example illustrates the problem of finding the top: you simply cannot do it without going past it, and perhaps quite a bit past it. In subsequent chapters we discuss some of the biological and economic reasons why you must exceed the maximum considerably. For our current purposes it is sufficient to accept that one must go well past the top to find the best effort and MSY. This means that once the MSY and optimum effort have been found, the next step is to reduce the fishing effort down to the optimum.

Principle: The hardest thing to do in fisheries management is reduce fishing pressure.

Reducing fishing effort is the hardest thing to do in fisheries! It involves either driving fishermen from the fishery or reducing everyone's catch. Neither of these is politically practical or socially acceptable. By the time the optimum has been found, the catch per unit effort is quite a bit lower than it was when the fishery started. Note that the 1975 ICCAT optimum catch was roughly 1 ton per day; at the 1985 "optimum" the catch per day was less than 0.5 ton. This illustrates the point that by the time you know fishing pressure should be reduced, the fishermen's returns per day are low. In fact, by then fishermen are normally just breaking even. Remember that we still

do not know if the ICCAT 1985 level is the true optimum, and we need to increase effort another 20% to 30% to make sure!

If we follow the simple stock assessment prescription of gradually increasing effort until we detect we have passed the top of the yield-effort curve, we must then somehow reduce fishing pressure by 20% to 30% at a time when fishermen are in tight financial conditions. *This is a prescription for disaster.*

Thus, we argue that you cannot predict the MSY at early stages of development and that, once you have found it, it may be too late to do much good. It would be very nice if we could predict MSY and optimum effort prior to reaching the top, but this is an unobtainable dream. Rather, we must concentrate stock assessment efforts during the development phase on assuring that we (1) detect the top as rapidly as possible and (2) build mechanisms into the fishery so that it will be possible to reduce effort when the time is necessary. These mechanisms can include biological tactics, such as setting aside spatial refuges that are unfished during development, as well as economic tactics such as imposing high taxation rates that can be reduced later to compensate for lowered catches.

Again, these difficulties are much less severe if the fish resource consists of discrete subunits and there is contrasting fishing effort in the subunits. As a general rule, the more independent spatial units are available, the easier is the assessment.

Fine tuning and rehabilitation planning in "fully developed" fisheries

The world fisheries catch went through a period of remarkable (6% per annum) growth during the 1950s and 1960s. With the collapse of the Peruvian anchoveta (*Engraulis ringens*) fishery in the early 1970s the growth flattened out, but by the 1980s it had begun to rise again (Figure 1.4). Some major fisheries that sustained the growth spurt in the 1950s and 1960s, such as Peru's anchoveta fishery, have subsequently collapsed. Although there is some potential to develop new fisheries in offshore locations (krill in the Antarctic, deep water pelagic fishes), the main opportunities now for increasing fishery yields around the world are through "fine tuning" regulations on stocks that are fully exploited, and through rehabilitation (rebuilding) programs for stocks that have been overexploited. Stock assessment will play a key role in defining these opportunities and in planning how to make use of them.

The alternative to better management of stocks is the high technology world of aquaculture and genetic engineering. Aquaculture is undoubtedly going to continue to grow; however, it should not be viewed as a substitute for good management of natural resources.

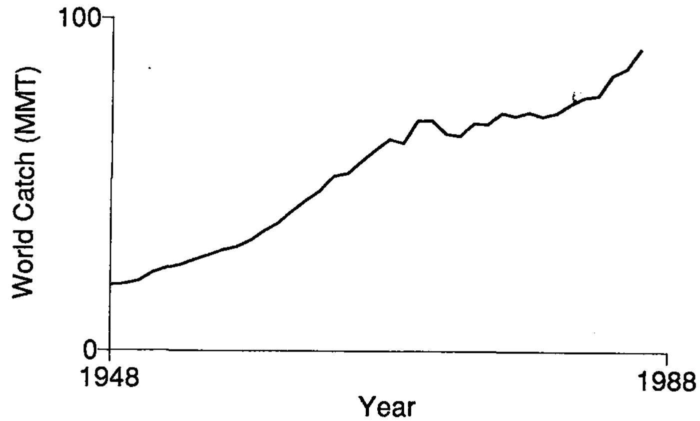

Figure 1.4. History of world fisheries catches. Data from Fisheries and Agricultural Organization of the United Nations FAO *Yearbook of Fishery Statistics* (1980–1985).

Many fisheries around the world have been stabilized or limited by regulatory policies that were developed piecemeal and without good data as the fisheries grew. In many cases the current, relatively stable regime is likely to be sustainable, but is far from optimum in terms of regulations on where, when, and how the fish are taken. In particular, many fisheries focus on fish that would produce higher yields if they were allowed to grow more (and often, move offshore). Other fisheries use gear that is wasteful of the target species (kills adults or juveniles without capturing all of the kill) or of other species that are taken as "by-catch" or "discards." The role of stock assessment in such cases is to provide a coherent framework of calculations for putting together data on fish growth, movement, mortality, and vulnerability to fishing. This framework of calculations (the assessment model) can then be used to systematically search for better policy options.

Perhaps 60% of the world's major fish stocks are now overexploited, in the sense that stock sizes have been driven to lower levels than would produce the largest annual biological surplus or net economic value. The 60% is a very rough guess. Reviews we have seen of the status of stocks in Canada, the U.S., Australia and New Zealand indicate few if any underexploited stocks and a large proportion of stocks thought to be overexploited. Rebuilding these stocks to more productive levels will involve difficult choices to reduce catches in the short term, so as to produce more in the long term. A key role of stock assessment is to quantify the choices as precisely as possible: how long will rebuilding take if only a small catch reduction is acceptable, and how much can this painful time for fishermen be shortened if a larger reduction is accepted? Stock rebuilding programs

will only be politically "saleable" if these questions can be answered with calculations that are credible to all parties involved in decision making.

Some fisheries agencies are attempting to buy their way out of overfishing situations without reducing harvest rates, by instead trying to artificially enhance the productivity of stocks through technologies such as fish hatcheries and provision of artificial habitats. A key role of stock assessment in these situations is to help measure whether the production enhancement is in fact working as planned and whether it is having any deleterious side effects on those parts of the stock (and other stocks) that are not directly enhanced. The assessment work may well discover for example that the enhancement activities are successful enough to stimulate increased fishing pressure, which then compounds the overfishing problem on unenhanced portions of the stock so as to cause a further loss in natural production. That further loss in natural production may more than make up for any gains from enhanced parts of the stock. An example of this happening is the fishery for large and highly prized chinook salmon *(Oncorhynchus tshawytscha)* in the North Pacific Ocean (Figure 1.5). American and Canadian fisheries agencies tried to keep up with growing demand for chinooks by releasing more fish from hatcheries, and at first they were very successful. But the natural stocks kept declining, even faster in some areas, and in recent years the catch has declined dramatically. There is now a major United States/Canada treaty initiative to rebuild the chinook stocks, and fisheries have been cut back in many areas of the Pacific coast.

1.3. Stock Assessment and Cooperative Management

A traditional view of stock assessment is as a collection of analyses aimed at estimating stock size and productivity from statistics gathered from the commercial (or sport) fishing process. In this view, the fishery is seen as the primary and most economic sampling device for getting information about the stock. Typically total catch statistics are gathered, along with measures of fishing effort (the area or volume of water searched by fishermen in their "sampling"); the catch per effort is then often assumed to be proportional to the actual stock size. In some fisheries, catch and effort statistics are recorded in detailed logbooks to permit spatial mapping of relative fish abundance, at least over whatever area is fished enough to give reasonable sample sizes. The catch is usually sampled for other characteristics of the fish, such as size and age composition.

Unfortunately, the pursuit of fish for sport or economic gain usually results in a highly unrandom and nonrepresentative sampling pattern in time, space, and characteristics of fish sampled. For instance, fishermen can often concentrate their effort on areas of relatively high fish density, so that catch per effort can remain high over time, even while the total stock size is re-

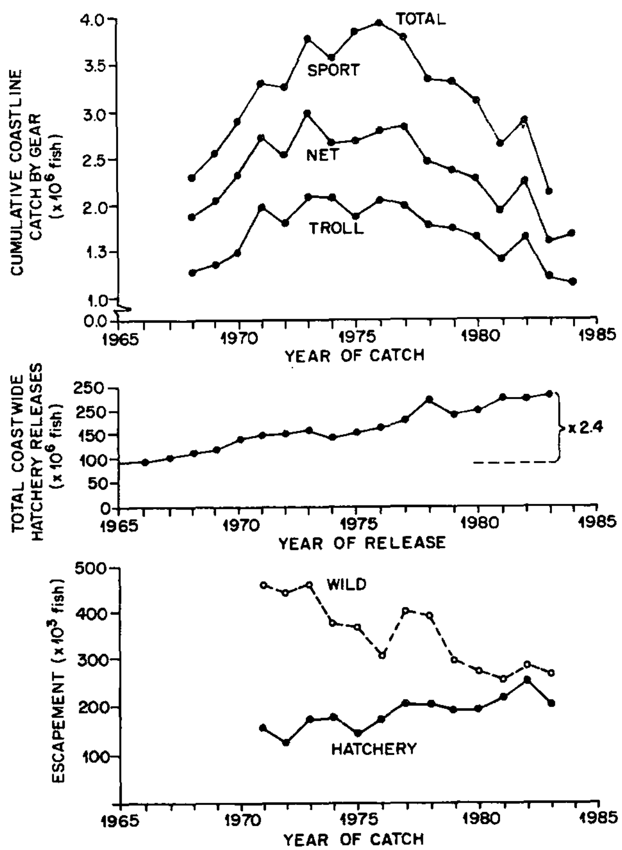

Figure 1.5. Chinook salmon catches, hatchery releases, and relative abundance of hatchery and natural spawners in the Northeastern Pacific. Is hatchery production helping to sustain the fishery? From Walters and Riddell (1986).

duced substantially (e.g., as fewer areas of high density are left). Alternatively, catch per effort can decline rapidly as a few local concentrations of fish are depleted, but with little change in the total stock size if only a small percentage of the fish are in the local concentrations. The net effect of ignoring such distortions in stock assessment calculations can be absolutely disastrous: gross overestimates of stock size and potential yield, missed opportunities for fishery expansion, and wasteful regulations on the sizes of fish to be harvested and the times and places of harvest.

An important role of stock assessment is to help identify whether catch and effort statistics are likely to give a misleading picture of stock trends

and health, and hence whether some more systematic and expensive sampling program may be worthwhile. The design of better sampling programs involves challenges that go beyond where to locate sampling stations and what to measure; a key issue becomes who should gather the samples and under what economic incentive system.

Recognition of dangers in using commercial and sport sampling data alone has led many agencies to invest in research sampling programs involving agency-owned or chartered fishing vessels. These programs are generally very expensive to develop and maintain, and a single research vessel can collect only a tiny number of samples compared to a whole commercial fishing fleet.

An alternative to agency research vessels or direct charters is to provide incentives for fishermen to work cooperatively with the management agency by spending part of their time "fishing for information," using standardized fishing procedures and gear on informative sampling locations (transects, grids, preset stations). Such methods have been used in Australia. An obvious incentive for such cooperation is to allow increased catches by cooperating fishermen; stock assessment techniques can help decide how large a catch increase would be "safe" or worth accepting in terms of the value of improved information. Stock assessment may also help to define other incentives for cooperation, such as preferential access to particularly lucrative times and places of fishing.

For many fisheries, it will probably never be worthwhile to engage in refined data collection, stock assessment, and regulation unless some type of cooperative data-gathering system can be established with the fishermen. In such cases, stock assessment will either continue to operate in a twilight of potentially misleading data from normal fishing activity or else take a leading role in defining imaginative schemes to make cooperation worthwhile for both fishermen and the management agency.

Even where very accurate sampling and survey programs have provided a good picture of past changes and the current status of a stock, it is often not possible to predict how that stock will respond to new management initiatives (or further development of fishing pressure) whose effects have never been seen before. A classic role of stock assessment has been to provide some reasonable extrapolation (or best prediction based on available information) about such circumstances. In providing such extrapolations, it is easy to overlook the fact that even perfect data on how a complex system has behaved over a limited range of historical circumstances can be misleading about how it will behave outside that limited range, even when a very reasonable biological model is available. A wiser role for stock assessment when faced with policy questions that involve gross extrapolations would be to provide assistance in the design of management experiments to test the extrapolations in a relatively safe and economically productive man-

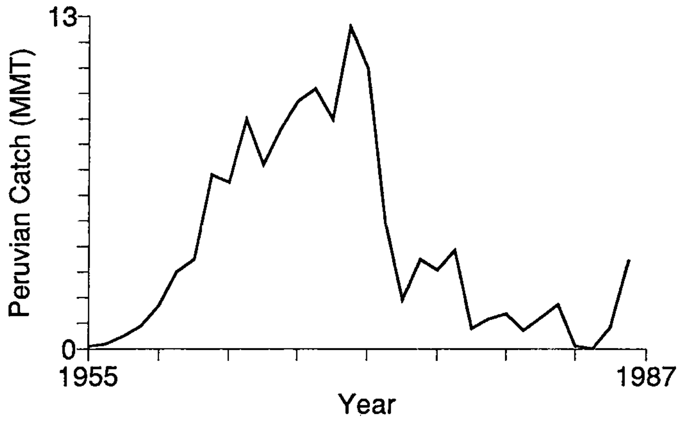

Figure 1.6. Catch history of Peru's anchoveta fishery. Data from FAO Yearbook of Fisheries Statistics (1980–1985).

ner. Such experiments would be especially powerful tools for improving management if used in conjunction with cooperative data-gathering programs involving fishermen (for an example of that approach, see Walters and Collie 1989).

1.4. Two Great Failures in Fisheries Management

To illustrate some of the points made earlier in this chapter, let us briefly examine the history of two of the most infamous fisheries, the Peruvian anchoveta fishery and the North Sea herring fishery.

The Peruvian anchoveta fishery

Figure 1.6 shows the catch history of Peru's fishery for anchoveta. The fishery became a major producer of fish meal in the early 1950s, stimulated somewhat by the collapse of the California sardine (*Sardinops sagax*) fishery and the movement of processing and harvesting equipment from California to Peru. By the mid 1960s, the anchoveta fishery was the largest fishery in the world. However, in the mid 1960s there was a dip in catch associated with an *El Niño* event, and a few biologists began to issue warnings about the future of the fishery. By the late 1960s, there was more widespread concern about the potential for overfishing, and numerous overseas experts were called in to assess the stock. As usual, the experts could not agree, and produced numerous estimates of sustainable yield ranging from 7 million to over 10 million tons per year. A consensus of sorts was established at a level of 9.5 million tons. However, the economic pressures for growth

were very strong, and the fishery continued to catch more than what all but the most optimistic of biologists felt was sustainable.

These arguments became somewhat academic in 1972–1973, when a second *El Niño* oceanic condition (warm surface water, reduced upwelling) apparently had two effects: it initially concentrated the fish close inshore where they were highly vulnerable to the fishing boats, and then it caused poor juvenile survival for the offspring of the remaining spawners. The net result was a general recruitment failure. All the biologists agreed that a major if not total reduction in fishing was necessary to let the stock rebuild. The Peruvian government was unable or unwilling to reduce fishing pressure, and high exploitation rates continued for several years until the stock was reduced to such low levels that it became economically unimportant. The stock apparently started to recover in the late 1970s, but was hit again by a strong *El Niño* event in 1982–1983. There remains no general agreement about the relative importance of the *El Niño* events and continued exploitation as causes of collapse in this fishery, but almost everyone agrees that both are to some extent responsible.

For the purposes of this book, we want to ask "What can we learn about the role of stock assessment from this example?" First and foremost, the stock assessment work prior to the 1972–1983 *El Niño* concentrated almost exclusively on trying to predict the MSY; the government of Peru wanted to know what level of harvest was sustainable, and the stock assessment experts tried to provide a number. This is probably the greatest failing of fisheries scientists. When decision makers ask the wrong question, try to convince them to ask a better question instead of providing them a silly answer that will eventually lead them even further astray. In the 1960s, it was widely recognized that species such as the Peruvian anchoveta are prone to major fluctuations; after all, the California sardine had recently collapsed. At the time, it was felt that if we just kept the catches low enough it might be possible to avoid such collapses.

The stock assessment biologists should have emphasized more forcefully that they could not predict the sustainable yield with any reliability (perhaps plus or minus 50%). They should have told the Peruvian government that the time would come when the stock would decline, they should have insisted on helping to work out a management plan for that contingency.

It is easy to make these pronouncements in retrospect; in the late 1960s, fisheries scientists did not have as much appreciation of the natural variability of fish stocks as we do today, nor had they seen enough cases of collapse to issue any warning with great confidence. However, we no longer have those excuses today. The role of stock assessment is not to make best guesses at MSY, but rather to help design a fishery management system that can respond to the types of variability we see in nature.

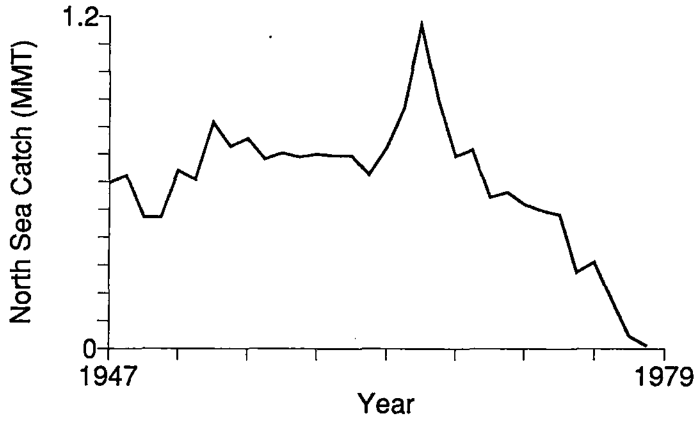

Figure 1.7. Catch history of North Sea herring. Data from Saville and Bailey (1980).

North Sea herring

Another great disaster in fishery management involved the stocks of herring in the North Sea (*Clupea harengus*). Figure 1.7 shows the catches from 1947 to 1978. The fishery had maintained yields of between 300,000 and 1,000,000 tons between 1903 and 1965, but beginning in the late 1960s the fishery began a serious decline.

As the stocks declined, biologists started to recognize that overfishing was occurring, but this recognition was slow in coming. After all, the stocks had a history of substantial natural variation; who would want to raise an outcry when a natural recovery might be just around the corner? Saville and Bailey (1980) said, "the advice given to the regulatory bodies on management . . . has tended to be much too optimistic in respect of total allowable catches." In the herring case, the overoptimism was due at least in part to the use of virtual population analysis (VPA), which depends upon estimates of current fishing mortality rates to provide a "reconstruction" of historical stock trends. As it turned out, estimates of fishing mortality for North Sea herring were consistently too low, leading to overestimates of stock biomass and therefore overoptimism about the current state of the stock.

The North Sea herring experience, along with a number of other fisheries with similar problems in using VPA, have provided fisheries scientists with quite a bit more skepticism about our ability to detect stock trends, as they develop, by the analysis of catch data. The blame for the collapse of the North Sea herring does not fall solely on the stock assessment biologists. They were slow in detecting the problem, but, once it was detected, the political decision makers were even slower in heeding their advice. Saetersdal (1980) provides a review of the management advice offered and the

actual management taken. By 1970, the stock assessment biologists were recommending major cuts in fishing pressure, and, by 1974, the managers had agreed to a total quota of 494,000 tons (which was larger than the total stock at the time). However, it was not until 1977 that effective regulation was enforced. Between the biological recommendation for reduction in fishing pressure in 1970 and the implementation of effective regulation in 1977, the stocks had dropped to less than 200,000 tons.

The North Sea herring fishery illustrates two of the major problems in fisheries stock assessment. Biologically, we cannot usually detect overfishing until it has already become quite severe. This is the principle cited earlier. The North Sea herring illustrates how the point remains valid even when quite detailed data and assessment procedures are used instead of just catch and effort data. Socially and economically, it is difficult to effectively reduce fishing pressure even after we recognize that such reduction is necessary.

1.5. Summary and Critique

If fisheries science is to be successful we must learn from and avoid the mistakes of the past. We must recognize that stock assessment involves understanding and making predictions about the response of fishery systems to alternative management actions. We must help managers make *choices* about *dynamic* fishery systems in the face of *uncertainty*.

This is a difficult task. However, we are fortunate that our predecessors have made lots of mistakes, and in many cases they have documented these mistakes, so that we can learn from them. We cannot avoid making mistakes, but we do our predecessors a great disservice if we do not take advantage of what has been learned and try not to repeat the same mistakes.

In the context of this chapter, building on historical experience involves a recognition that stock assessment does not consist of making static predictions about optimum efforts and sustainable yields, but concerns the assessment of time trajectories of fish and fishermen in response to management and other changes. It also involves a recognition that stock assessment biologists must educate managers and decision makers to ask appropriate questions and to think of the dynamic response of fisheries to change.

Bibliographic Notes

This chapter has provided our view of the role of stock assessment. Other views can be found in Gulland (1974, 1983), McHugh (1984), Rothschild (1986), and Royce (1987). Details of the Peruvian anchoveta fishery can be found in Pauly and Tsukayama (1987) and Glantz (1979). Saville and Bailey (1980) and Saetersdal (1980) discuss the North Sea herring.