UNDERSTANDING FISHERIES MANAGEMENT

For the:
Great Lakes Fisheries Leadership Institute

Adapted by Jeff Gunderson from:

UNDERSTANDING
FISHERIES
MANAGEMENT:
A Manual for understanding the Federal Fisheries Management Process, Including Analysis of the 1996 Sustainable Fisheries Act
Second Edition

By Richard K. Wallace and Kristen M. Fletcher

A publication of Auburn University and the University of Mississippi, the Auburn University Marine Extension and Research Center, the Mississippi-Alabama Sea Grant Legal Program, and the Mississippi Law Research Institute. Full text of document available at:
http://www.olemiss.edu/orgs/SGLC/fisheries.html

Table of Contents

Appendices

FISHERIES MANAGEMENT

WHOSE FISH ARE THEY, ANYHOW?

Many members of the fishing community, frustrated by unwanted regulation, wonder why government officials have the right (or the nerve) to tell them how much fish they can catch, where and when they can catch it, and how they can catch it. The answer is found in something called "the tragedy of the commons."

Common Property Resources

Hundreds of years ago, community leaders observed that when a resource was owned by the people, no one took responsibility for maintaining the resource. Human nature being what it is, each person tended to use the resource to the maximum extent. There was little incentive to conserve or invest in the resource because others would then benefit without contributing to the welfare of the resource. In the case of common (public) grazing areas in England, grass soon disappeared as citizens put more and more sheep on the land held in common. Everyone lost as "the commons" became overgrazed and this became known as "the tragedy of the commons." To prevent "the tragedy of the commons" most common property resources are held in trust and managed for the people by state or federal government agencies. Fish living in public waters are a common property resource. The government has the responsibility of managing the fish for the benefit of all citizens, even those who do not fish.

So who owns the fish? You do — along with the other 290 million citizens of the U.S. In order for all to benefit from this renewable resource, the fish are managed using some basic principles. This manual explains these principles and the regulatory scheme that puts them into action.

Government Management

Managing fishery resources is ultimately the responsibility of elected officials. Elected officials in most states and in the federal government, however, have delegated much of that responsibility to resource agencies that employ people trained in the sciences of fishery biology, economics, and natural resource management.

WHAT MAKES FISH A RENEWABLE RESOURCE?

Renewable resources like finfish and shellfish are living things that replenish themselves naturally and can be harvested, within limits, on a continuing basis without being eliminated. The scientific principles behind this renewability are well known and provide the basis for fish and wildlife management.

Survival

All animals produce more offspring than survive to adulthood. This is a kind of biological insurance against the natural calamities all animals face. Actually, for a fish species to maintain itself, each pair of fish only has to produce two offspring that survive to reproduce. Most individual fish and shellfish produce tens of thousands to millions of eggs. Most of their eggs do not survive to become juveniles and even fewer live to become adults.

Surplus Production

The theory of surplus production goes something like this. In an unfished population, the biomass (total weight) of fish in a habitat will approach the carrying capacity (maximum amount that can live in an area) of the habitat. Furthermore, this population will have a lot of older, larger fish compared to a fished population. These fish dominate the habitat and their presence prevents all but a small percentage of the young fish produced each year from surviving to become old fish. When fishing begins, many large older fish are removed. Removal of these older fish and other fish reduces the biomass below the carrying capacity and increases the chances of survival for smaller, younger fish. This extra production together with the effects of harvesting fish can result in surplus or sustainable production.

The unfished population can be viewed as a relatively stable population with moderate production. The fished population, on the other hand, is a dynamic population with a higher turnover of individual fish as the older fish are replaced by younger, faster growing fish. Some of this new production must be allowed to survive and reproduce to maintain the population. The remaining or surplus production is available for harvest. Surplus production is illustrated in greater detail in Appendix 1.

How Many Fish Can We Catch?

The basic goal of fishery biology is to estimate the amount of fish that can be removed safely while keeping the fish population healthy. These estimates may be modified by political, economic, and social considerations to arrive at an optimum yield. Overly conservative management can result in wasted fisheries production due to under-harvesting, while too liberal or no management may result in over-harvesting and severely reduced populations.

More on Surplus Production

As you may have guessed, surplus production is a complex biological process that is influenced by several factors. These factors merit further discussion.

Carrying Capacity

One factor is that of carrying capacity. Carrying capacity can be thought of as the amount of fish an area of habitat will support. Habitat that historically supported 8 million pounds of lake trout is unlikely to support a lot more or a lot less lake trout unless conditions change. For example, if the amount or quality of habitat is reduced, carrying capacity likewise will be reduced.

Natural Variability

Nearly all fisheries that rely on the natural reproduction of fish, rather than stocking, to produce the majority of fish harvested vary naturally from year to year. Often the number of offspring produced each year is dependant upon things like weather conditions during spawning, food availability for fry and fingerlings, water flow, or other factors. The variations in the number of young produced in a given year (year class strength) are generally not apparent to fishermen until they attain a size typically caught by fishermen (recruit to the fishery). Depending on the species, it may take one to five years or longer before a significant variation in year class strength may become apparent. The variation in year class strength is also much more obvious when one to two year classes make up the bulk of the catch than when many year classes contribute to the fishery. For example, a year class failure will be much more noticeable and catch will decline more dramatically if the fishery is dependant on two year classes than if it is dependant on four year classes.

Habitat Loss

There is no question that human activity has altered, and in some cases, reduced, fish habitat. Water pollution, loss of coastal wetlands, destruction of spawning areas, blocking of rivers by the construction of dams, and changes in water flows are some habitat alterations that have led to habitat reduction. Unfortunately, fishery managers and fishermen have had little say in habitat alterations. Fishery managers are saddled with managing the fish populations that the habitat can support today, not the fish populations that past habitat conditions supported.

Summary

Harvesting fish lowers the population below the carrying capacity of the environment. Continued harvest depends on the ability of the population to produce enough offspring to move toward the maximum carrying capacity. Variations in natural conditions can alter year class strength, resulting in good years and bad years for survival of young.

Time Out for a Few Definitions

We have jumped straight into the theory behind renewable fishery resources without too much worry about definitions. We have used words like species and population rather loosely. Biologists define these words as follows:

Species - A group of similar organisms that can freely interbreed.
Population - A group of individuals of the same species living in a certain area.
Stock - A harvested or managed unit of fish.

Fish Stocks

A species may have several populations. Ideally each fish population would be managed separately; however, this is rarely practical and fishery biologists often refer to stocks rather than populations. For example, whitefish occur through a large portion of Lake Michigan. Research has shown that the population that spawns off the Door County, Wisconsin peninsula near Bailey's Harbor is more migratory than the whitefish population that spawns in Big Bay de Noc, Michigan. While there is recognition that these are separate populations, they mingle together and make separate management of the populations nearly impossible. Therefore, they are managed more as a single stock of fish. Sometimes one species is divided into several stocks because they experience different natural conditions and/or harvesting pressures. In other cases, different species are treated as a single stock and managed together for convenience.

More Definitions

Most technical terms are defined within the text where they are used. Additional definitions may be found in Appendix 2.

Summary

A stock of fish is the practical unit of a population that is selected for management or harvesting purposes. In some cases a managed stock may include more than one population and in some cases may include more than one species.

STOCK ASSESSMENT

Stock assessment is all of the activities that fishery biologists do to describe the conditions or status of a stock. The result of a stock assessment is a report on the health of a stock and recommendations for actions that would maintain or restore the stock.

Some Basics

Stock assessments often consist of two nearly separate activities. One is to learn as much as possible about the biology of the species in the stock. The other is to learn about the fishing activities for the stock. Historically, the demand for a stock assessment has usually come after a stock is already in decline. When a stock assessment begins, there may be little or no information on the biology of the species or the fishery. Meanwhile, there is pressure to complete some kind of stock assessment so that the stock can be managed. This leads to preliminary stock assessments which provide for initial management recommendations until more information is available.

A Stock Assessment Based on the Fishery (Catch and Effort)

One of the simplest stock assessment methods requires almost no knowledge about the biology of the stock. However, good information about the fishery is required. In this assessment, the manager only needs to look at the history of landings for the stock and the effort expended to catch the stock. The key word here is effort. Landings data (the amount of fish caught and landed per year) alone are not very useful. Landings can fluctuate up and down for a variety of reasons. A trend of decreased landings may be a cause for concern, but the amount of effort made by fishermen to catch the stock tells the real story.

In order to account for effort, fishery biologists use the terminology catch-per-unit effort (CPUE). To determine the CPUE, the catch is divided by the amount of effort expended to make the catch. For example, if three fishermen go out on a boat for four hours and catch five chinook salmon weighing a total of 60 pounds, then their CPUE could be expressed as either 0.41 fish per angler hour (5 fish caught in 12 angler hours) or as 5 pounds per angler hour (60 pounds caught in 12 angler hours of fishing). Fishery biologists often express effort in ways that may be foreign to fishermen. For example, lake trout caught in gill nets are reported as pounds per foot of net. The catch-per-unit effort is directly related to the amount of fish in the stock. While CPUE doesn’t tell you how many fish are in the stock, it provides an index of abundance that can be easily compared from one year to the next. A decline in CPUE usually indicates a decline in the stock.

A number of fisheries have followed a pattern in relation to the catch-per-unit effort. At the beginning of a new fishery, the catch-per-unit effort is high and the effort is low. As interest in the fishery grows, the effort increases, the catch increases and the catch-per-unit effort usually levels off or declines. Finally, as more effort is applied, the catch declines and the catch-per-unit effort declines even more. When both the catch and the catch-per-unit effort decline, it is an indication that the stock is probably overfished. This means that too many fish are being removed for the stock to maintain itself. Landings decline despite increasing effort. The obvious solution is to reduce the amount of fishing until the catch-per-unit effort returns to the earlier stages of the fishery. This seems simple enough. But why isn't this assessment used more often? The reasons include:
__Insufficient landings data.
__Insufficient effort data
__Fishermen using new technology that makes it hard to compare the effort today with the effort of several years ago.

Adequate landings data are often available, but the effort data is usually missing, incomplete or unusable. The other problem is that by the time there is a clear decline in catch-per-unit effort, stocks may be well overfished. Modern fisheries management has moved away from using CPUE because of the above problems or, if used, employs more sophisticated methods of analysis. If fishing effort is too high, it usually means that there are too many boats in the fishery. Fishery managers call this over-capitalization. This means more money (capital) has been invested in boats than the fishery can support. Over-capitalization can also refer to the ability of fishermen to increase effort without increasing the number of boats. If no new boats are added to a fishery, but each boat doubles its fishing power by carrying twice as much gear or using new technology (sonar, GPS, etc.) the new effort can have the same effect as doubling the number of boats.

Summary of Catch and Effort

Landings data are often used to suggest that there are problems in a fishery. Declines in landings or increases in landings are signals that something has changed in the fishery. In either case, the effort by fishermen to catch the stock must be considered. The catch-per-unit effort is the appropriate way to evaluate changes in catch because CPUE is an indicator of stock abundance. Problems arise in measuring effort over time in a fishery that may have changed from sailboats pulling one net to diesel-powered vessels with sophisticated electronics pulling multiple nets.

Assessment Based on a Little Biology (Age at First Spawning)

When little is known about the biology of a fish stock, one of the first questions asked is, “At what age do the fish spawn?” The second question is, “What proportion of the fish caught are one-year, two-years, and three-years old?” If some of the fish spawn when they are two-years old, and all spawn at age three, and most of the fish caught are two-years old, then there is a danger that too many fish may be caught before they can spawn and replace themselves. This is called recruitment overfishing.

Harvesting some fish before they spawn does not automatically doom the stock, but it is something that needs to be evaluated. Declining landings, greater effort to catch the same or smaller amounts of fish, or declines in average size of fish are all signs of possible problems. Determining the age of spawning and the age of fish caught is one step toward management. When fishermen appear to be catching fish before they have a chance to spawn and there are other signs of trouble in the fishery, the usual management response is to protect small fish. Protection most often comes in the form of length limits or gear restrictions that favor the catch of larger fish. Minimum mesh size limits for gill nets is a gear restriction that allows smaller fish to escape.

Unfortunately, protecting small fish does not necessarily solve the larger problem of overfishing. Remember, recruitment overfishing occurs when more fish are being removed than can replace themselves. Overfishing can still occur on the remaining fish in a stock even when the small fish are protected because small fish produce fewer eggs than large fish.

Fishermen sometimes suggest a closed fishing season during the period when a stock is spawning. This would seem logical but the idea is usually rejected by biologists. A fish caught before, during, or after the spawning season is still not available to spawn the next year. As a result, the focus is more on protecting fish until they are old enough to spawn and then determining how many fish can be safely removed without harming the stock. Exceptions to this approach are cases where spawners gather in certain locations and are very vulnerable to being caught in unusually large numbers. Protected areas or reserves are sometimes suggested to protect fish.

Summary of Age at First Spawning

Knowing the age of first spawning and the age of fish being caught is an important aspect of fishery assessment. Size limits and gear restrictions can be put in place to protect fish until they have a chance to spawn at least once. Protecting small fish, however, still does not guarantee against overfishing.

Information for a More Complete Assessment

Few fish stocks, if any, have been fully assessed. Fishery biologists and managers always wish they knew more about the fish and the fishermen. A full assessment would include some of the following information about the fishery:

1. The kinds of fishermen in the fishery (trawlers, charter fishermen, netters, recreational anglers, etc.).
2. Pounds of fish caught by each kind of fisherman over many years.
3. Fishing effort expended by each kind of fisherman over many years.
4. The age structure of the fish caught by each group of fishermen.
5. The ratio of males to females in the catch.
6. How the fish are marketed (preferred size, etc.).
7. The value of fish to the different groups of fishermen.
8. The time and geographic area of best catches.

The biological information would include:

1. The age structure of the stock.
2. The age at first spawning.

3. Fecundity (average number of eggs each age fish can produce).
4. Ratio of males to females in the stock.
5. Natural mortality (the rate at which fish die of natural causes).
6. Fishing mortality (the rate at which fish die of being harvested).
7. Growth rate of the fish.
8. Spawning behavior (time and place).
9. Habitats of recently hatched fish (larvae), of juveniles and of adults.
10. Migratory habits.
11. Food habits for all ages of fish in the stock.
12. Estimate of the total number or weight of fish in the stock .

When the above information is collected by examining the landings of fishermen, it is called fishery-dependent data. When the information is collected by biologists through their own sampling program, it is called fishery-independent data. Both methods contribute valuable information to the assessment. However, biologists rarely have the resources to collect a large number of samples of fish over large areas. As a result, there is a high reliance on fishery-dependent data for many fishery management plans.

Best Available Data
Even in the best assessments it is rare that everything that should be known about a stock is known. Assessments proceed with the assumption that the best available information (data) will be used. Fishermen often disagree with this assumption when they are adversely affected. Fishery managers respond that they are obligated to protect the stock and must use the best available data. The best available data principle sometimes creates a conflict for fishermen. In the past, when managers have asked for more and better data from fishermen, the result has usually been more regulations. The data appear to have been "used against the fisherman." From the managers' point of view the data were used to ensure that the fishery could continue.

When fishermen do not provide good data then the fishery will be managed on the data available, which may be incomplete. This can result in overly restrictive management which is wasteful or can result in continued overfishing and declining catches. It is in the long-term interest of fishermen to provide the best data possible.

AGE, GROWTH, AND DEATH

Any reliable information about the fishing process or the biology of the stock contributes to the stock assessment. Among the basic biological pieces of information that fishery biologists find most useful are the distribution of different ages of fish in a stock and the relation between fish length and age. Once this is known, then important characteristics of the stock such as growth rate and death rate (mortality) can be determined. This information is used to create a picture of the stock which describes the current status of the stock.

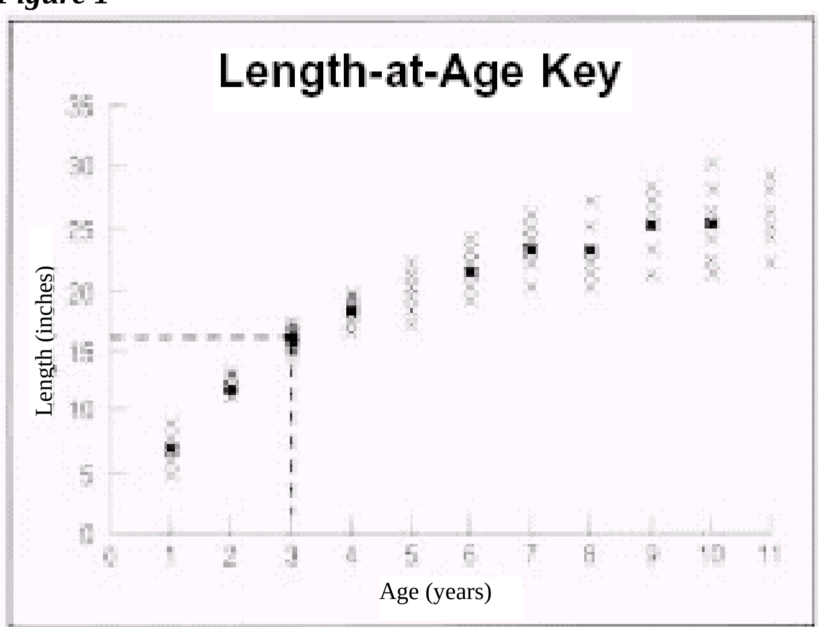
Aging Fish

You cannot tell the age of a fish by looking at it. Like people, some grow faster and get bigger than others and there are many differences between species and within a species.

Fish are normally aged by examining scales or bony parts such as otoliths (“ear bones”) that contain a record of growth like rings on a tree. Once it is established that each ring truly represents a year and then the age of a fish can be determined.

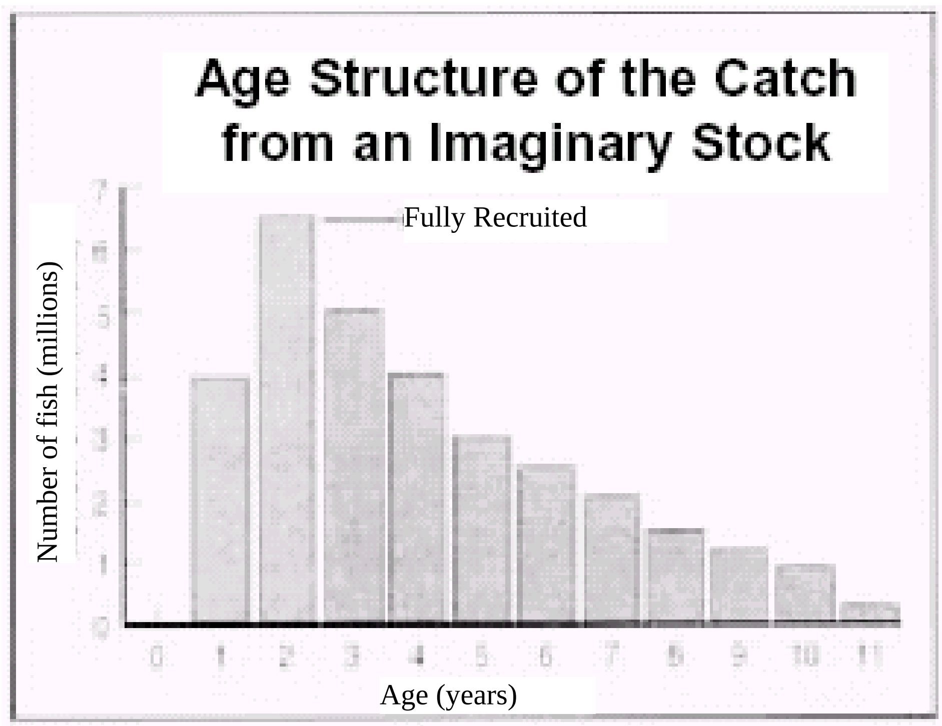
The usual procedure is to obtain fish from fishermen or from a fishery-independent sampling program, age them, and then compare the length and weight to the age of the fish. This results in a length-at-age key in which the age of a fish can be estimated from its length. (See Figure 1 in which each x represents the length of an individual fish.) Also, by looking at the change in length and weight from a one-year-old fish to a two-year-old fish etc., the growth rate can be estimated. The more fish that are aged, the better the picture of the stock will be. However, in the case of long-lived fish, growth usually slows in the older fish and past a certain point the age cannot be readily assumed by the length of the fish. For example, it would be hard to tell the age of 20-inch fish in Figure 1 because a 20-inch fish could be between four and eight years old. In these cases it is better to age as many fish as possible by scales or bony parts than to rely on the length, especially in the larger, older fish.

Figure 1



When enough fish have been aged, either directly or indirectly, a picture (catch curve) of the age structure of the stock may be drawn (Figure 2). Note that in this imaginary stock there are more two-year-old fish than one-year-old fish. This does not seem to make sense. We expect that the younger fish will be the more numerous and there will be fewer fish at each subsequent age due to fishing and natural causes. There are several possible reasons why fishermen are not catching one-year-olds in proportion to their abundance. The one-year-olds may not be abundant in the same areas as the older fish or they may not be caught by the fishing gear, or they may be caught but thrown back. When fishery biologists see a graph like this, they say that the one-year-fish are “not fully recruited” to the fishery while the two-year-olds are considered to be “fully recruited.” The first year a fish is readily harvested in a fishery, it is referred to as a recruit.

Figure 2



A fishery assessment using the abundance of each age group is based on the portion of the stock that is fully recruited to the fishery. It would be desirable to know more about the unrecruited stock between the time of egg fertilization to the age of recruitment, but for many species there is little that management can do that would affect this part of the population. For other species, management could affect water quality, the amount of suitable habitat, or even the death rate (bycatch, power plant entrainment, etc.) to promote greater survival of young fish before they reach harvestable size (recruited to the fishery).

More Information from Age Structure

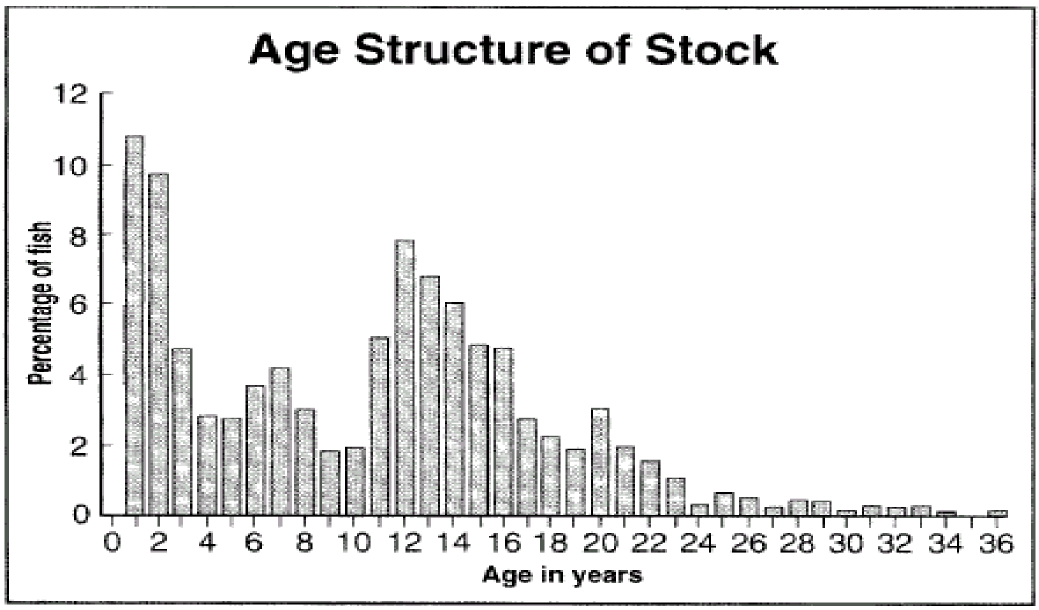
The age structure of a stock is a sort of historic picture of the stock. It reveals something about the current status of the stock as well the past history of the stock. Figure 3 is the age structure of a fish stock in 2000. What can be learned from just looking at this graph?

1. The fish are harvested starting at one year of age.
2. The species is a very long-lived fish – up to 36 years old.
3. The number of fish at each successive age (two to three, three to four, etc.) does not follow a smooth downward trend as previously shown in Figure 2.
4. Ages three to eleven appear to be particularly few in number. Eleven-year-old fish were hatched in 1989 (2000 - 11= 1989). Three-year-olds we hatched in 1997.
5. Even though one and two-year-old fish appear relatively abundant, if we look at

the age structure of 12-year-old fish out to 23-year-old fish (hatched between 1988 and 1977) we can see that they have not declined in numbers at the same rate as ages three to eleven appear to have declined. In fact, the number of fish that should have been alive from ages one to eleven can be estimated (see Figure 4) by drawing a line from around age twelve back to age one.

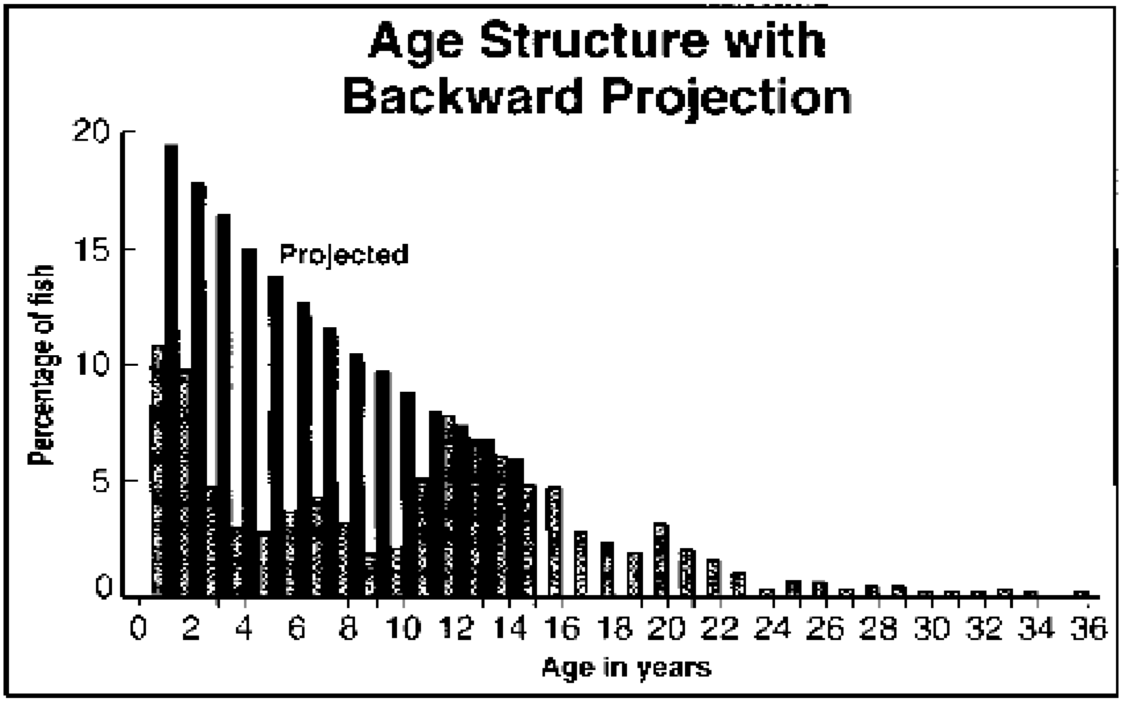
6. This backward projection suggests that not only are there not as many three to 11-year-olds as might be expected, but the number of one and two-year-olds may be less than what existed in the 1970s to the 1980s.

Figure 3



Fishery biologists take this kind of pictorial information and quantify it (put numbers on it) in order to further describe the stock and test ideas about the health of the stock. The graph cannot tell us why these age classes appear low. There may be information from other sources that suggest that fish of these ages are targeted by fishermen or there may have been fluctuations in climatic conditions (drought, flood, freezes, etc.) that affected the survival of these fish.

Figure 4



Summary of Age Structure
The age distribution of a stock provides a graphic picture of the stock as it exists today and, in the case of long-lived fish, can reveal something about the past history. The picture by itself does not reveal how much fish can be caught but provides information which leads to the answer.

Mortality and Spawning Potential Ratio (SPR)
Earlier we said the goal of fishery management was to determine how many (numbers) or how much (pounds) fish can be safely harvested from a stock. In simpler terms we want to know how many fish in a stock can die and still allow the stock to maintain itself. Fishery biologists refer to the rate at which fish die as mortality or the mortality rate. If 1000 fish are alive at the beginning of the year and 200 fish die leaving 800 at the end of a year, then the annual mortality rate is 20 percent (200 divided by 1000) and the survival rate is 80 percent (800 divided by 1000). Each year some fish die whether they are harvested or not. The rate at which fish die of natural causes is called natural mortality and the rate at which fish die from fishing is called fishing mortality.

While it is easy to understand these rates as annual percentages, fishery biologists must convert them to something called instantaneous rates to use them in mathematical formulas. As a result, in a fishery management plan you might see statements such as "The instantaneous fishing mortality rate is 0.67 (F=0.67)" or that, "The instantaneous natural mortality rate is 0.1 (M = 0.1)." Sometimes the word instantaneous is omitted, but F and M are conventional symbols for instantaneous annual rates. Natural mortality (M) and fishing mortality (F) can be added together to get total mortality (Z). Unless regularly dealt with, these numbers do not mean much relative to our more intuitive understanding of annual percentages. Table 1 gives some examples of annual percentages and the corresponding instantaneous rates (F, M or Z).

Sometimes F is written with a subscript such as F_{MSY}. In this case, the subscript refers to the management reference point, maximum sustainable yield (MSY). Then F_{MSY} is the fishing mortality rate that would result in the maximum sustainable yield for a stock of fish.

Table 1

Annual Percentage	Instantaneous Rate
0	0
10	0.1054
30	0.3567
50	0.6931
80	1.6094
90	2.3026

Determining Mortality from Age Structure

The age structure diagrams (Figures 2 and 3) are pictures of the stock at the time the information was gathered. It is often assumed that if conditions remain the same, then as the younger fish grow older they will decline through time at about the same rate as the older year classes appear to have declined. For example, in Figure 2, there are 6.5 million two-year-olds and 2.5 million six-year-olds. It would seem likely that the current crop of two-year-olds will also be reduced to 2.5 million by the time they are six years old. In this case the annual mortality can be estimated by subtracting 2.5 million from 6.5 million to get 4.0 million and then dividing by 6.5 million to get 0.62 or 62 percent mortality.

However, this mortality took place over a five-year period, so the average annual rate is 0.62 divided by 5 which equals 0.12 or 12 percent. This corresponds to a total instantaneous mortality (Z) of 0.13 Remember that in a fish population, the total mortality includes the fishing mortality and natural mortality. The above example for estimating total mortality from the age structure does not reveal how much of the total mortality is due to fishing mortality and how much is due to natural mortality.

Several methods are used to determine each mortality rate. For example, fishing mortality can be estimated from a tagging study. After a lot of fish from a stock are tagged, the percentage of tagged fish that are caught and reported is an estimate of the fishing mortality. Natural mortality is then calculated by subtracting fishing mortality from total mortality. Sometimes there is no available estimate of fishing mortality for a stock. However, fishery biologists may have a good idea what the natural mortality might be from studying other similar stocks. In this case natural mortalities (or a range of possible natural mortalities) can be subtracted from total mortality to get fishing mortality (or a range of possible fishing mortalities)

Spawning Potential Ratio

Most recent fishery management plans attempt to define a rate of fishing mortality which, when added to the natural mortality, will lead to the rebuilding of a stock or the maintenance of a stock at some agreed upon level. The level used in many management plans is based on the spawning potential ratio (SPR). The spawning potential ratio incorporates the principle that enough fish have to survive to spawn and replenish the stock at a sustainable level. Spawning potential ratio is the number of eggs that could be produced by an average recruit over its lifetime when the stock is fished divided by the number of eggs that could be produced by an average recruit over its lifetime when the stock is unfished. In other words, SPR compares the spawning ability of a stock in the fished condition to the stock's spawning ability in the unfished condition.

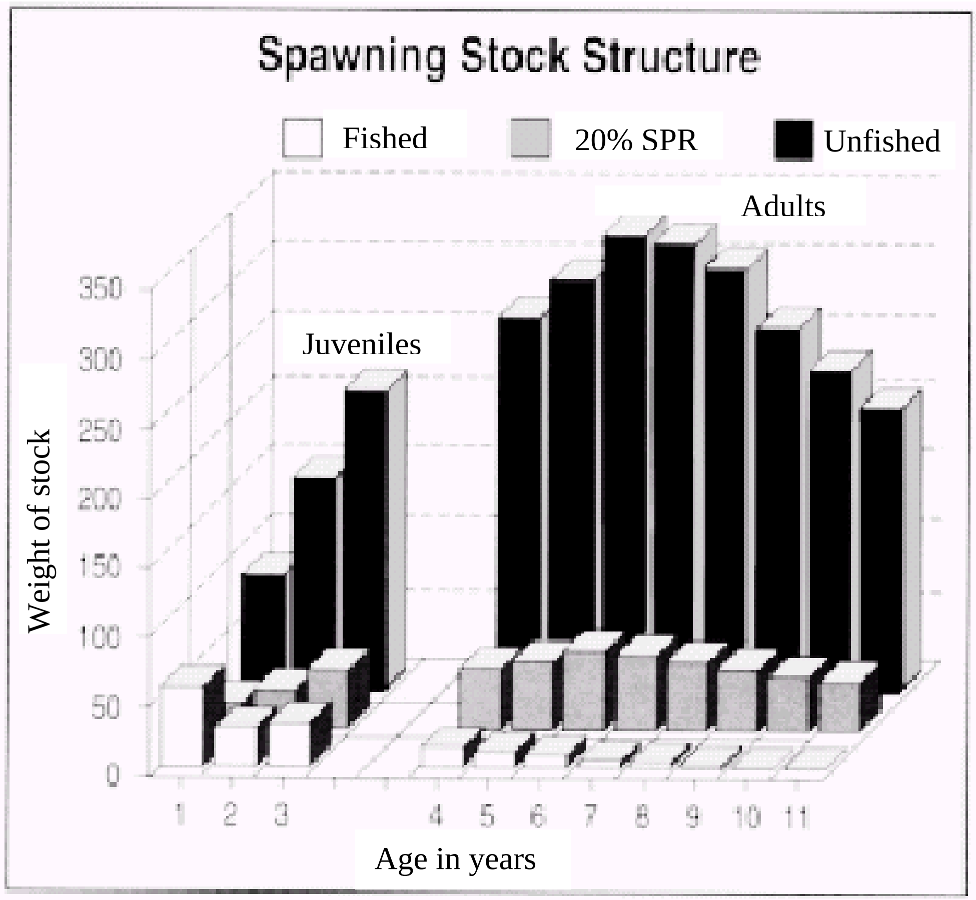
As an example, imagine that 10 fish survive the first couple of years of life and are now large enough to be caught (recruited) in the fishery. Four are caught before they spawn (no eggs produced), three others are caught after they spawn once (some eggs produced), and the last three live to spawn three times (many eggs produced) before dying of old age. During their lifetime, the 10 fish produced 1 million eggs and the average recruit produced 100,000 eggs (1 million divided by 10).

In the unfished population, 10 fish survive as before. Three die of natural causes after spawning (some eggs produced) and the other seven spawn three times (very many eggs produced) before dying of old age. During their lifetime, these 10 fish produced 5 million eggs and the average recruit produced 500,000 eggs (5 million divided by 10). The spawning potential ratio is then the 100,000 eggs produced by the *average fished* recruit divided by the 500,000 eggs produced by the *average unfished* recruit and is equal to 0.20 or 20 percent.

SPR can also be calculated using the biomass (weight) of the entire adult stock, the biomass of mature females in the stock, or the biomass of the eggs they produce. These measures are called spawning stock biomass (SSB) and when they are put on per-recruit basis they are called spawning stock biomass per recruit (SSBR). In the above example, the weight of fish that contributes to spawning could be substituted for eggs produced to get the SSBR for the fished stock. SSBR (fished) divided by SSBR (unfished) gives the SPR.

The concept of spawning stock biomass is illustrated in Figure 5. The graph shows the weight (biomass) of a stock at each age in the unfished condition compared to the weight of the stock when SPR = 20%. The adult fish in this stock spawn at age four so only the weight of fish four years and older contribute to the spawning stock biomass.

Figure 5



In a perfect world, fishery biologists would know what the appropriate SPR should be for every harvested stock based on the biology of that stock. Generally, not enough is known about managed stocks to be so precise. However, studies show that some stocks (depending on the species of fish) can maintain themselves if the spawning stock biomass per recruit can be kept at 20 to 35% (or more) of what it was in the unfished stock. Lower values of SPR may lead to severe stock declines.

Summary of Mortality and SPR

Fish die of either natural mortality or fishing mortality. Fishing and natural mortality added together equal total mortality. Total mortality can be estimated from age structure graphs. If either fishing or natural mortality can be estimated, then the remaining unknown mortality can be determined by subtraction from total mortality. Once fishing mortality and natural mortality are known, they can be used to examine the effects of fishing on the stock.

One way of looking at the effect of fishing mortality is to compare the spawning biomass of the fished stock to what it would be without fishing. The ratio of the fished spawning biomass to the unfished spawning biomass is called the spawning potential ratio (SPR). If the SPR is below the level considered necessary to sustain the stock, then fishing mortality needs to be reduced.

VIRTUAL POPULATION ANALYSIS (VPA)

At times, fishery biologists have more information available than is provided by the snapshot of the age structure. Sometimes the number of fish caught from a single year class is known for each year that the year class is fished. Year class refers to the group of fish born in the same year. Using the number caught each year from a year class and the mortality rate, the size of the year class can be reconstructed. For example, if the fish born in 1998 (1998 year class) were first harvested in 2000 and 1,000 fish from the year class were caught during the first year, 900 fish the second year, 800 fish the third year, 700 fish the fourth year, and 600 fish the fifth year (2004), then there had to be at least 4,000 fish alive (1,000+900+800+700+600) in the year class when fishing started in 2000.

If the natural and fishing mortality rates are known or can be estimated, then the number of fish in the year class that should have been alive to produce the catch of fish can be calculated. If 600 fish were caught in 2004, there had to be more than 600 fish alive at the end of 2003, because some would have died of natural causes during 2004 and it is unlikely that fishermen would catch all the fish in that year class (fishing mortality of 100%). For the purpose of illustration, assume that natural mortality equaled 20% and fishing mortality also equaled 20% (remember that these should be converted into instantaneous rates to be mathematically correct). Since a 20% fishing mortality removed 600 fish from the stock, then a 20% natural mortality would remove an equal number of fish (600) from the stock. This means at least 1200 fish were alive at the end of 2003. However, only some of the fish that were alive were caught or died, so there must have been more than 1200 fish alive. Dividing 1200 fish alive by the total mortality rate (20% + 20% = 40%) (1200/0.4) gives 3,000 fish alive at the end of 2003. This process can be continued backward until the total number of fish in the 1998 year class is estimated. The reconstructed year class then can be tested with different rates of fishing mortality to see what the effects might be, or the information can be used in other calculations such as determining the spawning stock biomass.

OTHER KINDS OF OVERFISHING

So far we have emphasized overfishing that leads to declining stocks. This is often referred to as recruitment overfishing. The name indicates that the mortality rate from fishing is severe enough to affect future recruitment to the extent that catches are reduced and the stock is jeopardized. Another type of overfishing is called growth overfishing. Growth overfishing occurs when the bulk of the harvest is made up of small fish that could have been significantly larger if they survived to an older age. The concern here is that the fishery would produce more weight if the fish were harvested at a larger size. The question biologists, economists, managers, and others must answer is how much bigger or older should the fish get before they are harvested.

Recall the length-at-age graph (Figure 1). The graph is typical of how most fish grow rapidly the first few years and grow more slowly in later years. One approach to getting the most out of a stock of fish would be to harvest them near the point where the growth rate begins to level off. But this approach is too simple because if you recall from our age structure graph (Figure 2), all the time fish are growing their numbers are going down due to mortality. There are two opposing forces at work in a stock of fish. Growth increases the weight of fish while mortality reduces the number of fish. These forces can be illustrated by following a year class (all fish hatched the same year) as they grow and die over a number of years. Instead of graphing the numbers of fish at each age as before, it is also necessary to graph the total weight of the year class.

As shown in Figure 6, the weight of the year class is greatest when the fish are six to seven years old. In later years, the death rate overcomes the growth rate and the weight of the year class declines. The point is that even though there are more fish to be harvested at a younger age, there is more weight of fish to be harvested at a later age. The shape of the curve in Figure 6 is determined by the growth rate and the mortality rate. Different rates of harvest (fishing mortality) will give different curves. Using computers, fishery biologists can generate a great number of these curves to make a composite graph called a yield diagram. These diagrams show the harvest (also called yield) that can be expected from different combinations of harvest rates and the age of the fish when they are first captured. As with spawning stock biomass, biologists often like to put the calculations on a per-recruit basis and so the graphs are often called yield-per-recruit diagrams (Figure 7).

Another type of overfishing occurs when fishermen catch fish before they reach their maximum price per pound. The idea here is that the catch will have a higher value if the harvest is delayed when there is a premium paid for larger size fish. For example, large lake whitefish are worth more per pound than lake whitefish just meeting the legal length limit. As with growth overfishing, the point of maximum value of the stock may be determined. Beyond that point, individual large (called jumbo) lake whitefish may be more valuable but there will not be enough left to equal the value of catches of the more abundant but less valuable smaller whitefish.

This is also true for recreational fisheries managed for quality of fish rather than quantity or maximum pounds of fish caught. Similar to the example above, recreational anglers may value large or trophy fish much more highly than fish harvested at a size to provide the most pounds of fish. However, the longer fish are allowed to grow before they can be harvested, the more natural mortality and hooking mortality (of released fish) will reduce their numbers. Therefore, there will be a point where the maximum value of the stock is reached below the highest trophy size. While larger fish may be more highly valued, their decline in numbers will mean that the more abundant, but somewhat smaller fish will have a greater overall value.

Figure 6

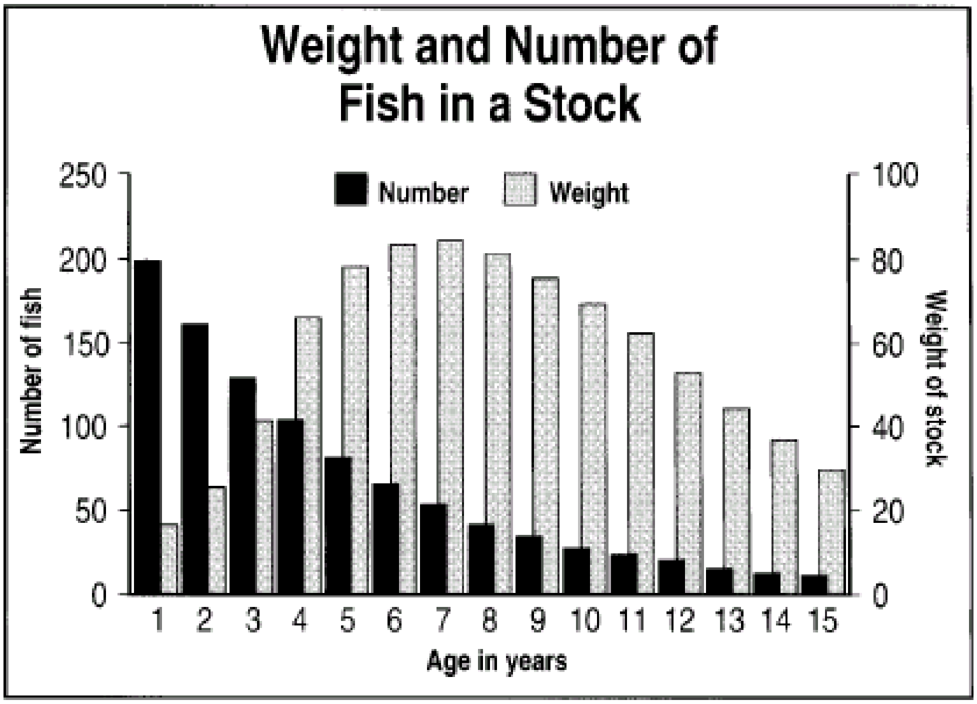
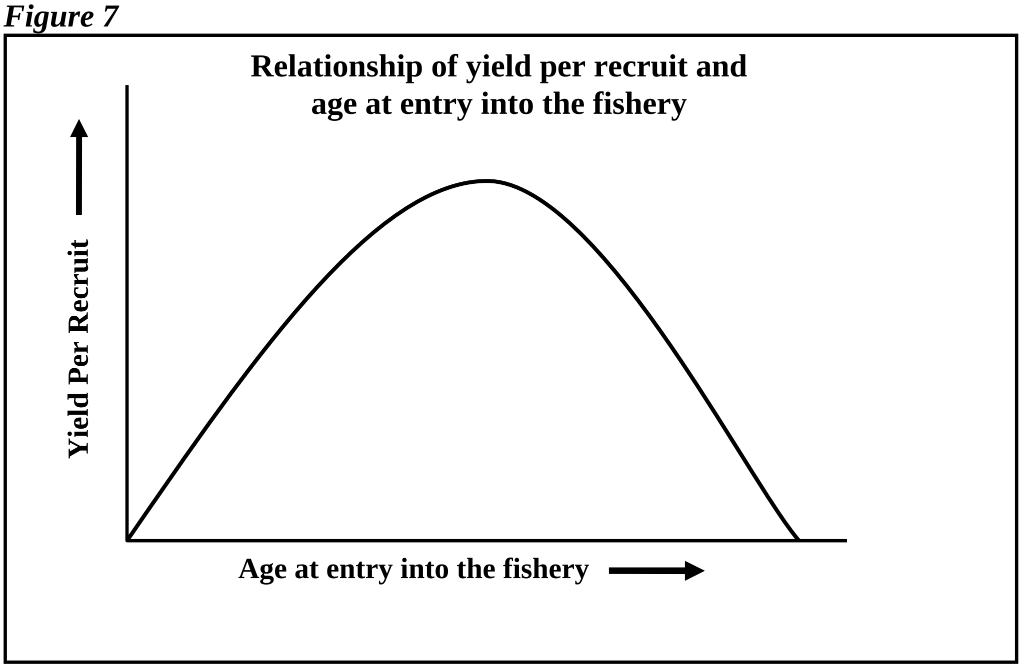


Figure 7



Summary of Other Kinds of Overfishing

Management aimed at growth overfishing has more to do with getting the most benefit out of a stock than ensuring the renewability of the stock. This is a legitimate goal for fishery management as long as recruitment overfishing is not a problem.

INDICES

Fishery biologists sometimes employ an index to help assess the general state of a stock. The index is usually an indirect measure of the stock taken the same way at the same time over many years. The index can be compared to the catch in the fishery or other data to see if there is a relationship between the index and the health of the fishery.

One of the better-known fishery indices (plural of index) in the Great Lakes is the lamprey wounding rate. Since the 1960s biologists have recorded the lamprey wounding rate on lake trout. The index closely follows the abundance of lamprey in the Great Lakes. The index has been able to show the effectiveness of lamprey control strategies as well as to document lamprey increases in areas that need more control efforts. A similar index has been used on Lake Superior to assess lake trout rehabilitation. The number of native lake trout capture per thousand feet of assessment net has been used to document the successful rehabilitation of lake trout in Lake Superior.

Other indices use number of eggs, number of larval fish, or actual counts of fish through aerial, underwater, or acoustic (fish finder) surveys. When an index is based on the early life history of a fish, it must be remembered that many things can happen to the fish before they are large enough to harvest. Despite some drawbacks, indices are usually easy to understand and can be useful indicators of changes in a fish stock.

BYCATCH

Bycatch (also called incidental catch) is all of the animals that are caught but not wanted or used. Almost all commercial and recreational fisheries have an associated bycatch. When the bycatch includes endangered or protected species, then regulations are made to reduce or eliminate the bycatch as required by the Endangered Species Act. When the bycatch includes species that are targeted by other fishermen, the bycatch may be included in the overall quota for that species. In this case the bycatch is simply a part of the total allowable catch for that species.

A more difficult problem occurs when the bycatch contains undersized fish of desirable species. The undersized fish may be of the same species that the commercial or recreational fishermen are targeting but have no economic value at the smaller size. Alternatively, the undersized fish can be the target species for other fisheries when they reach a harvestable size. In these cases, the effects of the bycatch on the stocks are often unknown. However, it is generally accepted that catching large amounts of a stock before it is old enough to spawn or before it has economic value is wasteful and possibly harmful to the stock. Fishery managers try to account for bycatch mortality in their stock assessment because bycatch may be an important cause of mortality.

The practice of catch and release by recreational fishermen also results in mortality that can be significant for some species or increase during some times of the year (like during the warm summer months). Studies must be done to estimate the mortality rate of released fish. Once an estimate has been made of the mortality associated with released fish, it can be used with creel survey estimates to estimate total fishing mortality.

Fishery managers try to account for catch and release mortality in their stock assessment because the mortality associated with the practice of catch and release may be significant.

Bycatch and the Food Chain

The bycatch of species that have no current economic value may present problems that traditionally have not been addressed by fishery managers. The principles of community ecology tell us that each species has a role in the community. Consequently, the removal of large amounts of an important food item (prey species) through bycatch could adversely affect another species (predator) that eats that item. However, predators often eat a variety of food items. Reduction in the numbers of a single prey species may lead to an increase in another prey species that the predator will readily consume. As we move down the food chain (big fish eat little fish, which eat smaller fish, etc.), the link between prey species in the bycatch and an important predator species gets weaker and the relations get less clear. How can a fishery biologist take all of this into account? Understanding all the relations among predators and prey species may be impossible. However, it is generally thought that less bycatch, rather than more bycatch, is probably more desirable for maintaining a balance among the various species in a community. But just as surplus production provides an allowable catch for targeted species, there can also be an allowable catch for those species of no economic value found in bycatch.

ALLOCATION

When the harvest of a stock is restricted by management, the different groups of fishermen that use that stock often find themselves in conflict. The conflict occurs because each user group realizes it could harvest more fish if the other group did not exist or if the other group was restricted even further. These disagreements occur among different kinds of commercial fishermen or between commercial, recreational, and treaty fishermen. The decision as to how much fish each group gets to harvest is called allocation. From a strictly biological viewpoint, there is no fair or unfair allocation. It does not make any difference to the stock who catches the fish as long as the total allowable catch is not exceeded. Allocation is a political, social, and economic decision usually made by elected or appointed officials. In an attempt to be fair, allocation decisions are often made on the basis of historical catches. If Group A normally caught 60 percent of the landings and Group B 40 percent, then the fish are usually allocated on that basis. Disputes often arise over the accuracy of historical records, particularly when poorly documented fisheries are involved.

The determination of total allowable catch and the allocation decisions have not always been separated as described above. However, there is a movement to keep them as separate as possible. With this in mind, fishery biologists frequently do their best to determine the total allowable catch based on the scientific information available. Then states, boards or commissions are often responsible for the allocation. In the case of treaty fisheries, the courts have frequently set allocation percentages.

Summary of Allocation

When a fish stock cannot support the unregulated harvest by more than one group of fishermen, it becomes necessary to allocate the catch among the groups. This is not a biological decision but a political, social, and economic decision often based on the historical landings for each group or in some cases treaty law.

STOCKING

Fish stocking has long been a component of fisheries management and stocking certainly has an important role to play in fisheries management. Unfortunately, many anglers think that stocking fish is a silver bullet for improving fishing. Stocking fish can be effective, but only in specific instances. The carrying capacity of a body of water is not increased by stocking fish. Stocking fish in waters where there is an existing population of native fishes will not necessarily increase fish abundance or improve fishing and can sometimes be counterproductive.

There are, however, circumstances where stocking fish can benefit anglers and the ecosystem. Situations where stocking hatchery fish can have a positive impact include the following:

Stocking waters that contain no fish. The most obvious example of this situation is a newly constructed or renovated lake or pond. Another example of this type of stocking is to restore fish in public waters that have been depleted of fish by a fish kill.
"Put and take," or "put, grow, and take" stocking. When the fish being stocked will not spawn successfully in the water body, periodic restocking is necessary to maintain a population. An example of this type of stocking in the Great Lakes is the stocking of coho and chinook salmon that do not reproduce at a rate that would maintain their numbers at a level that the system can support or that is expected by anglers.
Stocking to restore a native species that has declined in numbers. The Great Lakes lake trout stocking program is a good example of this kind of stocking. Lake trout populations in the Great Lakes were decimated by the introduction of sea lamprey and overfishing. Stocking has continued in an effort to reestablish reproducing lake trout populations. Efforts in Lake Superior have been successful and stocking rates of lake trout has been reduced as natural reproduction increases.
Stocking to introduce a new species or new genetic strain. An example of this kind of stocking include the introduction of rainbow trout (steelhead) and brown trout into the Great Lakes over 100 years ago in an effort to create new fishing opportunities. Similarly, in an effort to control an exotic species, the alewife, and create new fishing opportunities pacific salmon were stocked into the Great Lakes in the 1960s.
Stocking for research purposes. Fisheries biology is a science, and there are many unanswered questions. Sometimes fish are stocked to aid in finding answers to these questions. Examples of this kind of stocking might involve the evaluation of introducing a new fish species or study of the exploitation of a specific fish species.

Stocking policies must be based on extensive research and follow-up, and must be readily understandable by management agency personnel and the public. Three primary objectives of any stocking program should be to maximize fulfillment of the public's desire for fishing, to ensure the sustainable production of native fish, and to maintain a balanced and functioning ecosystem. To formulate sound stocking recommendations, the following information (taken from the Principles of Fishery Science by Everhart and Youngs 1981) should be available:

1. *Other management measures, aside from stocking, that may be undertaken to achieve the basic objectives of the fishery (other population manipulations, habitat improvements, regulatory measures).*

2. *Species for which the habitat is particularly well suited. Information is needed on physical, chemical, and biological characteristics of the habitat. Fish should never be stocked where populations of suitable fish are already utilizing the carrying capacity of the water body. Particular care must be taken to avoid introducing species that will prey on desired species already present, or compete with them for food, shelter, or spawning habitat. The introduction of the carp represents a classic violation of this principle, and almost every geographical area in the United States can provide an illustration of an unwise introduction.*

3. *Characteristics of fishing demands. These can vary widely with geographical region, population density, and various socioeconomic factors, such as the kind(s), relative abundance, and sizes of fish desired, the quality of fishing experience desired (for example, wilderness fishing vs. put-and-take), and the diversity of fishing demands.*

4. *Costs of different stocking techniques.*

5. *Characteristics of the species and strain of fish being considered for stocking – their growth, longevity, reproductive capacity, vulnerability to angling—relative to characteristics of the habitat and the demand. To illustrate: for a put-and-take trout fishery subject to heavy exploitation in a low-quality stream, a trout strain with rapid hatchery growth and high vulnerability to angling is needed. Here longevity and reproductive capacity are of no importance, whereas they are likely to be paramount characteristics of the strain selected for stocking high-quality trout waters in remote areas.*

Stocking is an important fishery management tool, but it must be kept in perspective. In terms of fishery management priorities, habitat restoration, maintenance and improvement efforts generally take precedence over population manipulations like stocking. Habitat limits both the quality and the quantity of fishing that stocking can provide.

ENDANGERED SPECIES AND FISHERIES MANAGEMENT

The Endangered Species Act passed by Congress in 1973 requires all government agencies and private entities to consider whether or not their actions will affect species that are officially listed as “threatened or endangered.” The Act prohibits “taking” of listed species, where taking is defined to include almost any activity that will harm the species' chances of survival. For endangered species, the geographical area necessary for the species to survive is designated "critical habitat" and given special protection.

Confusion sometimes arises between managing harvestable fish stocks and managing endangered species. Most harvested species are not considered endangered in the sense of the Endangered Species Act. However, in discussing catch quotas or closed seasons, we often hear the media or others making statements such as, "Fishing for yellow perch was restricted today to protect this endangered fish." Because the word endangered is so closely allied with "Endangered Species", this statement brings to mind images of yellow perch becoming extinct if fishing is not halted. What has really happened is that harvest may have been restricted in order to allow recovery of a stressed fishery rather than save the fish from extinction.

Fishery management and endangered species regulations are made with separate goals in mind. Fishery management rules are meant to allow the continuing harvest of renewable species. The rules for endangered species attempt to prevent extinction of listed species and to ensure their recovery for long-term survival. Fishermen, however, can be strongly affected by the Endangered Species Act. The prohibition of "taking" makes even the incidental catch of a single individual of an endangered species a federal offense.

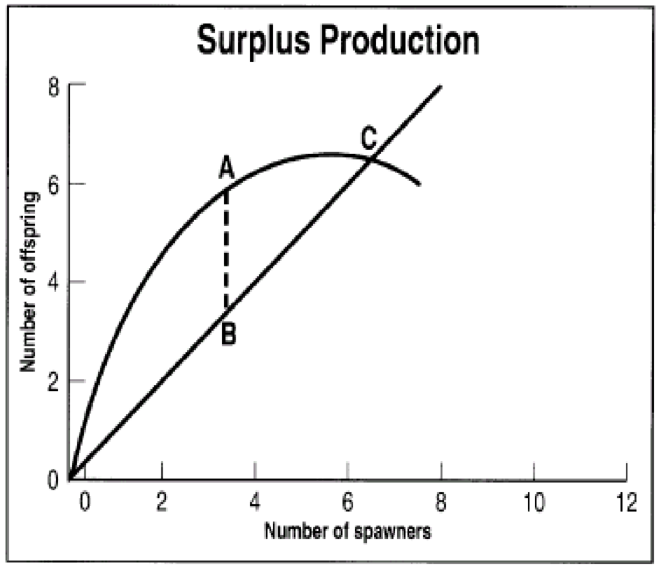
OVERALL SUMMARY

State and federal agencies act as trustees for public resources such as fish. Fishery biologists assess the health of fishery stocks by reviewing available data or conducting new studies. Catch per-unit effort, indices, age structure, growth rate and death rate are all-important elements of stock assessment. The stock assessment naturally leads to recommendations for conserving or rebuilding a stock. These recommendations often consider the value to and historical participation of users.

Appendix 1: Surplus Production

The concept of surplus production can be illustrated graphically (Figure 1). The straight line O to C represents the situation in which the number of offspring increases on a one-to-one basis as the number of adult spawners increases. The arching curved line indicates that as the adult spawners increase the number of offspring increases more rapidly than the number of spawners. This relation continues until the biomass of spawners begins to approach the carrying capacity of the habitat. This flatter part of the curve (A-C) indicates that additional spawners contribute few new offspring. At point C, the carrying capacity is reached. Spawners and offspring are in balance. Further increases in spawners do not necessarily result in more offspring. The part of the curve to the right of the carrying capacity indicates that the spawning biomass can overshoot the carrying capacity. This results in fewer young surviving and a return toward the carrying capacity.

Figure 1



When fishing begins on an unfished population, biomass is close to carrying capacity. As fish are removed (moving to the left along the curve), the population responds by increasing the number of offspring. This increase is represented by the difference between the straight line and the curved line. The greatest increase occurs at point A, the maximum distance (line A-B) between the curve and the 45_0 straight line. This coincides with the maximum amount of surplus production that might be available from this theoretical population. Removal of more fish by moving to the left of A results in less production.

This in itself might not be a disaster if the removal of fish stopped and the population was allowed to rebound (move back to the right along the curve). However, in the real world of fishing, harvesting sometimes continues until both spawners and offspring are removed faster than they can replace themselves.

Appendix 2: Definitions

DEFINING FISHERIES: A USER'S GLOSSARY

Kenneth J. Roberts, Jerald W. Horst, John E. Roussel, and Joseph A. Shephard
Louisiana Sea Grant College Program
Louisiana State University

* Denotes definitions added or modified by Wallace, et al.

A

A- See Annual Mortality.
ABC - See acceptable biological catch.
AP- See advisory panel.
Absolute Abundance - The total number of a kind of fish in the population. This is rarely known, but usually estimated from relative abundance, although other methods may be used.
Abundance - See relative abundance and absolute abundance.
Acceptable Biological Catch (ABC) - A term used by a management agency which refers to the range of allowable catch for a species or species group. It is set each year by a scientific group created by the management agency. The agency then takes the ABC estimate and sets the annual total allowable catch (TAC).
Advisory Panel (AP) - A group of people appointed by a fisheries management agency to review information and give advice. Members are usually not scientists, but most are familiar with the fishing industry or a particular fishery.
Age Frequency or Age Structure - A breakdown of the different age groups of a kind of fish in a population or sample.
Allocation - Distribution of the opportunity to fish among user groups or individuals. The share a user group gets is sometimes based on historic harvest amounts.
Anadromous - Fish that migrate from saltwater to fresh water to spawn.
Angler - A person catching fish or shellfish with no intent to sell. This includes people releasing the catch.
Annual Mortality (A) - The percentage of fish dying in one year due to both fishing and natural causes.
Aquaculture - The raising of fish or shellfish under some controls. Ponds, pens, tanks, or other containers may be used. Feed is often used. A hatchery is also aquaculture, but the fish are released before harvest size is reached.
Artisanal Fishery - Commercial fishing using traditional or small scale manually-operated gear and boats.
Availability - Describes whether a certain kind of fish of a certain size can be caught by a type of gear in an area.

B

***B* -** Biomass, measured in terms of spawning capacity (in weight) or other appropriate units of production.
***B_0 -** Virgin stock biomass, i.e. the long-term average biomass value expected in the absences of fishing mortality.

B_{MSY} - Long-term average biomass that would be achieved if fishing at a constant fishing mortality rate equal to F_{MSY}.
***BRP -** (Biological Reference Point). Benchmarks against which the abundance of the stock or the fishing mortality rate can be measured, in order to determine its status. BRPs can be categorized as limited or targets, depending on their intended use (see also Reference Points). There are also socio-economic reference points, but those are not treated in any detail in this document.
Bag Limit - The number and or size of a species that a person can legally take in a day or trip. This may or may not be the same as a possession limit.
Benthic - Refers to animals and fish that live on or in the water bottom.
Biomass - The total weight or volume of a species in a given area.
Bony Fishes - Fish that have a bony skeleton and belong to the class Osteichthyes. Basically, this is all fish except for sharks, rays, skates, hagfish and lampreys.
BRD - See Bycatch Reduction Device.
Bycatch - The harvest of fish or shellfish other than the species for which the fishing gear was set. Examples are blue crabs caught in shrimp trawls or sharks caught on a tuna longline. Bycatch is also often called incidental catch. Some bycatch is kept for sale.
Bycatch Reduction Device - Devices that are installed in trawl nets to reduce the take of incidental catch. Two types are the Gulf fisheye BRD and the Jones Davis BRD.

C
C/E - See catch per unit of effort.
CPUE - See catch per unit of effort.
Catadromous - Fish that migrate from fresh water to saltwater to spawn.
Catch - The total number or poundage of fish captured from an area over some period of time. This includes fish that are caught but released or discarded instead of being landed. The catch may take place in an area different from where the fish are landed. Note: Catch, harvest, and landings are different terms with different definitions.
Catch Curve - A breakdown of different age groups of fish, showing the decrease in numbers of fish caught as the fish become older and less numerous or less available. Catch curves are often used to estimate total mortality.
Catch Per Unit of Effort (CPUE; C/E) - The number of fish caught by an amount of effort. Typically, effort is a combination of gear type, gear size, and length of time gear is used. Catch per unit of effort is often used as a measurement of relative abundance for a particular fish.
Catch Stream - The catch statistics for a kind or stock of fish over a period of time.
Catchability Coefficient (q) - The part of a stock that is caught by a defined unit of effort.
Charter Boat - A boat available for hire, normally by a group of people for a short period of time. A charter boat is usually hired by anglers.
Cohort - A group of fish spawned during a given period, usually within a year.
Cohort Analysis - See virtual population analysis.
Commercial Fishery - A term related to the whole process of catching and marketing fish and shellfish for sale.* It refers to and includes fisheries resources, fishermen, and related businesses.
Common Property Resource - A term that indicates a resource owned by the public. It can be fish in public waters, trees on public land, or the air. The government regulates the use of a common property resource to ensure its future benefits.

Compensatory Growth - An increase in growth rate shown by fish when their populations fall below certain levels. This may be caused by less competition for food and living space.
Compensatory Survival - A decrease in the rate of natural mortality (natural deaths) that some fish show when their populations fall below a certain level. This may be caused by less competition for food and living space.
Condition - A mathematical measurement of the degree of plumpness or general health of a fish or group of fish.
Confidence Interval - The probability, based on statistics, that a number will be between an upper and lower limit.
***Controlled Access** - See limited entry.
Crustacean - A group of freshwater and saltwater animals having no backbone, with jointed legs and a hard shell made of chitin. Includes shrimp, crabs, lobsters, crayfish as well as many of the most important microscopic zooplankton.
Cumulative Frequency Distribution - A chart showing the number of animals that fall into certain categories, for example, the number of fish caught that are less than one pound, less that three pounds, and more than three pounds. A cumulative frequency distribution shows the number in a category, plus the number in previous categories.

D
Demersal - Describes fish and animals that live near water bottoms. Examples are siscowet lake trout and bloater chubs.
Directed Fishery - Fishing that is directed at a certain species or group of species. This applies to both sport fishing and commercial fishing.
Disappearance (Z') - Measures the rate of decline in numbers of fish caught as fish become less numerous or less available. Disappearance is most often calculated from catch curves.

E
EIS - See environmental impact statement.
ESO - See economics and statistics office.
Economic Efficiency - In commercial fishing, the point at which the added cost of producing a unit of fish is equal to what buyers pay. Producing fewer fish would bring the cost lower than what buyers are paying. Producing more fish would raise the cost higher than what buyers are paying. Harvesting at the point of economic efficiency produces the maximum economic yield. See maximum economic yield and economic rent.
Economic Overfishing - A level of fish harvesting that is higher than that of economic efficiency; harvesting more fish than necessary to have maximum profits for the fishery.
Economic Rent - The total amount of profit that could be earned from a fishery owned by an individual. Individual ownership maximizes profit, but an open entry policy usually results in so many fishermen that profit higher than opportunity cost is zero. See maximum economic yield.
Economics and Statistics Office (ESO) - A unit of the National Marine Fisheries Service (NMFS) found in the regional director's office. This unit does some of the analysis required for developing fishery policy and management plans.
Effort - The amount of time and fishing power used to harvest fish. Fishing power includes gear size, boat size, and horsepower.

***EFH** - See Essential Fish Habitat.
Electrophoresis - A method of determining the genetic differences or similarities between individual fish or groups of fish by using tissue samples.
Environmental Impact Statement (EIS) - An analysis of the expected impacts of a fisheries management plan (or some other proposed action) on the environment.
Escapement - The percentage of fish in a particular fishery that escape harvest and eventually spawn.
***Essential Fish Habitat (EFH)** - Those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.
Euryhaline - Fish that live in a wide range of salinities.
Ex-vessel - Refers to activities that occur when a commercial fishing boat lands or unloads a catch. For example, the price received by a captain for the catch is an ex-vessel price.
Exclusive Economic Zone (EEZ) - All waters from the seaward boundary of coastal states out to 200 nautical miles. This was formerly called the Fishery Conservation Zone.

F
***F_{MSY}** - Fishing mortality rate which, if applied constantly, would result in MSY.
***$F_{X\%}$** - Fishing mortality rate that results in x% equilibrium spawning potential ratio (e.g. $F_{30\%}$ is the mortality rate that will result in a spawning potential ratio of 30%.)
F - See fishing mortality.
Fmax - The level of fishing mortality (rate of removal by fishing) that produces the greatest yield from the fishery.
FCMA - See Fishery Conservation and Management Act.
FCZ - See fishery conservation zone.
FMC - See fishery management council.
FMP - See fishery management plan.
Fecundity - A measurement of the egg-producing ability of a fish. Fecundity may change with the age and size of the fish.
Fishery - All the activities involved in catching a species of fish or group of species.
Fishery-Dependent Data - Data collected on a fish or fishery from commercial or sport fishermen and seafood dealers.
Fishery-Independent Data - Data collected on a fish by scientists who catch the fish themselves, rather than depending on fishermen and seafood dealers.
Fishery Management Plan (FMP) - A plan to achieve specified management goals for a fishery. It includes data, analyses, and management measures for a fishery.
Fishing Effort - See effort.
Fishing Mortality (F) - A measurement of the rate of removal of fish from a population by fishing. Fishing mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous is that percentage of fish dying at any one time. The acceptable rates of fishing mortality may vary from species to species.
Fork Length - The length of a fish as measured from the tip of its snout to the fork in the tail.

G
GLM - See general linear model.
GSI - See gonosomatic index.

General Linear Model (GLM) - A mathematical formula that relates one biological factor to another. Once a mathematical relationship is established, scientists use the formula to predict one factor over another.
***Generation Time -** A measure of the time required for a female to produce a sexually mature female offspring.
Gonosomatic Index (GSI) - The ratio of the weight of a fish's eggs or sperm to its body weight. This is used to determine the spawning time of a species of fish.
Growth - Usually an individual fish's increase in length or weight with time. Also may refer to the increase in numbers of fish in a population with time.
Growth Model - A mathematical formula that describes the increase in length or weight of an individual fish with time.
Growth Overfishing - When fishing pressure on smaller fish is too heavy to allow the fishery to produce its maximum poundage. Growth overfishing, by itself, does not affect the ability of a fish population to replace itself.

H
Harvest - The total number or poundage of fish caught and kept from an area over a period of time. Note that landings, catch, and harvest are different.
Head Boat - A fishing boat that takes recreational fishermen out for a fee per person. Different from a charter boat in that people on a head boat pay individual fees as opposed to renting the boat.
Histogram - A method of showing data in a graph. The data appear as bars running up and down (vertical) or sideways (horizontal).

I
ITQ - See individual transferable quota.
Incidental Catch - See bycatch.
Individual Transferable Quota (ITQ) - A form of limited entry that gives private property rights to fishermen by assigning a fixed share of the catch to each fisherman. Sometimes referred to as an Individual Fishing Quota (IFQ).
Industrial Fishery - A fishery for species not directly used for human food. An example is alewife.
Instantaneous Mortality - See fishing mortality, natural mortality, and total mortality.
Intrinsic Rate of Increase (z) - The change in the amount of harvestable stock. It is estimated by recruitment increases plus growth minus natural mortality.
Isopleth - A method of showing data on a graph which is commonly used in determining yield-per- recruit.

J
Juvenile - A young fish or animal that has not reached sexual maturity.

L
Landings - The number or poundage of fish unloaded at a dock by commercial fishermen or brought to shore by recreational fishermen for personal use. Landings are reported at the points at which fish are brought to shore. Note that landings, catch, and harvest define different things.
Latent Species - A species of fish that has the potential to support a directed fishery.

Length Frequency - A breakdown of the different lengths of a kind of fish in a population or sample.
Length-Weight Relationship - Mathematical formula for the weight of a fish in terms of its length. When only one is known, the scientist can use this formula to determine the other.
***Limit Reference Points -** Benchmarks used to indicate when harvest should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low.
Limited Entry - A program that changes a common property resource, like fish, into private property for individual fishermen. License limitation and the individual transferable quota (ITQ) are two forms of limited entry.

M
mm - See millimeter.
M - See natural mortality.
***MFMT -** Maximum Fishing Mortality Threshold.
***MSST -** (Minimum Stock Size Threshold). The greater of (a) 1/2 B_{MSY}, or (b) the minimum stock size at which rebuilding to B_{MSY} will occur within 10 years of fishing at the MFMT.
MSY - See maximum sustainable yield.
Mark-Recapture - The tagging and releasing of fish to be recaptured later in their life cycles. These studies are used to study fish movement, migration, mortality, and growth, and to estimate population size.
Maximum Economic Yield (MEY) - This is the total amount of profit that could be earned from a fishery if it were owned by an individual. An open entry policy usually results in so many fishermen that profit higher than opportunity cost is zero. See economic rent.
Maximum Sustainable Yield (MSY) - The largest average catch that can be taken continuously (sustained) from a stock under average environmental conditions. This is often used as a management goal.**Mean** - Another word for the average of a set of numbers. Simply add up the individual numbers and then divide by the number of items.
Meristics - A series of measurements on a fish, such as scale counts, spine counts, or fin ray counts, which are used to separate different populations or races of fish.
Millimeter (mm) - Metric measurement of length 1/25 of an inch long.
Model - In fisheries science, a description of something that cannot be directly observed. Often a set of equations and data used to make estimates.
Mollusk - A group of freshwater and saltwater animals with no skeleton and usually one or two hard shells made of calcium carbonate. Includes the oyster, clam, mussel, snail, conch, scallop, squid, and octopus.
Morphometrics - The physical features of fish, for example, coloration. Morphometric differences are sometimes used to identify separate fish populations.
Multiplier - A number used to multiply a dollar amount to get an estimate of economic impact. It is a way of identifying impacts beyond the original expenditure. It can also be used with respect to income and employment.

N
NMFS - See National Marine Fisheries Service.

National Marine Fisheries Service (NMFS) - A federal agency with scientists, research vessels, and a data collection division responsible for managing the nation's saltwater fish. It oversees the actions of the councils under the Fishery Conservation and Management Act.
Natural Mortality (M) - A measurement of the rate of removal of fish from a population from natural causes. Natural mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous is the percentage of fish dying at any one time. The rates of natural mortality may vary from species to species.
Nursery - The part of a fish's or animal's habitat where the young grow up.

O
OY - See optimum yield.
Open Access Fishery - A fishery in which any person can participate at any time.
Opportunity Cost - An amount a fisherman could earn for his time and investment in another business or occupation.
Optimum Yield (OY) - The harvest level for a species that achieves the greatest overall benefits, including economic, social, and biological considerations. Optimum yield is different from maximum sustainable yield in that MSY considers only the biology of the species. The term includes both commercial and recreational yields.
***Overfished -** An overfished stock or stock complex is one "whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding." A stock or stock complex is considered overfished when its size falls below the MSST. A rebuilding plan is required for stocks that are overfished.
Overfishing - Harvesting at a rate equal to or greater than that which will meet the management goal, generally MSY.

P
Panel - See advisory panel.
Pelagic - Refers to fish and animals that live in the open sea, away from the sea bottom.
Population - Fish of the same species inhabiting a specified area.
Population Dynamics - The study of fish populations and how fishing mortality, growth, recruitment, and natural mortality affect them.
Possession Limit - The number and/or size of a species that a person can legally have at any one time. Refers to commercial and recreational fishermen. A possession limit generally does not apply to the wholesale market level and beyond.
Predator - A species that feeds on other species. The species being eaten is the prey.
Predator-Prey Relationship - The interaction between a species (predator) that eats another species (prey). The stages of each species' life cycle and the degree of interaction are important factors.
Prey - A species being fed upon by other species. The species eating the other is the predator.
Primary Productivity - A measurement of plant production that is the start of the food chain. Much primary productivity in marine or aquatic systems is made up of phytoplankton, which are tiny one-celled algae that float freely in the water.
Pulse Fishing - Harvesting a stock of fish, then moving on to other stocks or waiting until the original stock recovers.

Put and Take Fishery - The placing of hatchery-raised fish in waters to be caught by fishermen.

Q

q - See catchability coefficient.
Quota - The maximum number of fish that can be legally landed in a time period. It can apply to the total fishery or an individual
fisherman's share under an ITQ system. Could also include reference to size of fish.

R

Recreational Fishery - Harvesting fish for personal use, fun, and challenge. Recreational fishing does not include sale of catch. *The term refers to and includes the fishery resources, fishermen, and businesses providing needed goods and services.
Recruit - An individual fish that has moved into a certain class, such as the spawning class or fishing-size class.
Recruitment - A measure of the number of fish that enter a class during some time period, such as the spawning class or fishing-size class.
Recruitment Overfishing - When fishing pressure is too heavy to allow a fish population to replace itself.
***Reference Points -** Values of parameters (e.g. B_{MSY}, F_{MSY}, $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g. MSST) or targets for management (e.g. OY).
Regression Analysis - A statistical method to estimate any trend that might exist among important factors. An example in fisheries management is the link between catch and other factors like fishing effort and natural mortality.
Relative Abundance - An index of fish population abundance used to compare fish populations from year to year. This does not measure the actual numbers of fish, but shows changes in the population over time.
Rent - See economic rent.

S

s - See survival rate.
SPR - See spawning potential ratio.
SSBR - See spawning stock biomass per recruit.
Scattergram - A graph that shows how factors relate to each other. This is visual, not statistical, and is used when it is, necessary to compare two factors, like fish age and size.
Selectivity - The ability of a type of gear to catch a certain size or kind of fish, compared with its ability to catch other sizes or kinds.
Simulation - An analysis that shows the production and harvest of fish using a group of equations to represent the fishery. It can be used to predict events in the fishery if certain factors changed.
Size Distribution - A breakdown of the number of fish of various sizes in a sample or catch. The sizes can be in length or weight. This is most often shown on a chart.
***Shellfish -** General term for crustaceans and mollusks.
Slot Limit - A limit on the size of fish that may be kept. Allows a harvester to keep fish under a minimum size and over a maximum size, but not those in between the minimum and maximum; or size limits that allow a harvester to keep only fish

that fall between a minimum and maximum size.
Social Impacts - The changes in people, families, and communities resulting from a fishery management decision.
Socioeconomics - A word used to identify the importance of factors other than biology in fishery management decisions. For example, how a surplus of income is distributed between small and large boats or part-time and full-time fishermen.
Spawner-Recruit Relationship - The concept that the number of young fish (recruits) entering a population is related to the number of parent fish (spawners).
Spawning Potential Ratio (SPR) - *The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock. SPR can also be expressed as the spawning stock biomass per recruit (SSBR) of a fished stock divided by the SSBR of the stock before it was fished.
Spawning Stock Biomass - The total weight of the fish in a stock that are old enough to spawn.
Spawning Stock Biomass Per Recruit (SSBR) - The spawning stock biomass divided by the number of recruits to the stock or how much spawning biomass an average recruit would be expected to produce.
Species - A group of similar fish that can freely interbreed.
Sport Fishery - See recreational fishery.
Standard Length - The length of a fish as measured from the tip of the snout to the hidden base of the tail fin rays.
Standing Stock - See biomass.
Stock - A grouping of fish usually based on genetic relationship, geographic distribution, and movement patterns. Also a managed unit of fish.
Stock-Recruit Relationship - See spawner-recruit relationship.
Stressed Area - An area in which there is special concern regarding harvest, perhaps because the fish are small or because harvesters are in conflict.
Surplus Production Model - A model that estimates the catch in a given year and the change in stock size. The stock size could increase or decrease depending on new recruits and natural mortality. A surplus production model estimates the natural increase in fish weight or the sustainable yield.
Survival Rate (s) - The number of fish alive after a specified time, divided by the number alive at the beginning of the period.

T
TAC - See total allowable catch.
Total Allowable Catch (TAC) - The annual recommended catch for a species or species group. The regional council sets the TAC from the range of the acceptable biological catch.
Total Length - The length of a fish as measured from the tip of the snout to the tip of the tail.
Total Mortality (Z) - A measurement of the rate of removal of fish from a population by both fishing and natural causes. Total mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous mortality is that percentage of fish dying at any one time. The rate of total mortality may vary from species to species.

U
Uncertainty - Uncertainty results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of reference points, and management. Rosenberg and

Restrepo (1994) identify 5 types: measurement error (in observed quantities), process error (or natural population variability), model error (mis-specification of assumed values or model structure), estimation error (in population parameters or reference points, due to any of the preceding types of errors), and implementation error (or the inability to achieve targets exactly for whatever reason).
Underutilized Species - A species of fish that has potential for additional harvest.
Unit Stock - A population of fish grouped together for assessment purposes which may or may not include all the fish in a stock.

V
VPA- See virtual population analysis.
Virgin Stock - A stock of fish with no commercial or recreational harvest. A virgin stock changes only in relation to environmental factors and its own growth, recruitment, and natural mortality.
Virtual Population Analysis (VPA) - A type of analysis that uses the number of fish caught at various ages or lengths and an estimate of natural mortality to estimate fishing mortality in a cohort. It also provides an estimate of the number of fish in a cohort at various ages.

Y
Year-Class - The fish spawned and hatched in a given year; a "generation" of fish.
Yield - The production from a fishery in terms of numbers or weight.
Yield Per Recruit - A model that estimates yield in terms of weight, but more often as a percentage of the maximum yield, for various combinations of natural mortality, fishing mortality and time exposed to the fishery.

Z
z - See intrinsic rate of increase.
Z - See total mortality.
Z'- See disappearance.