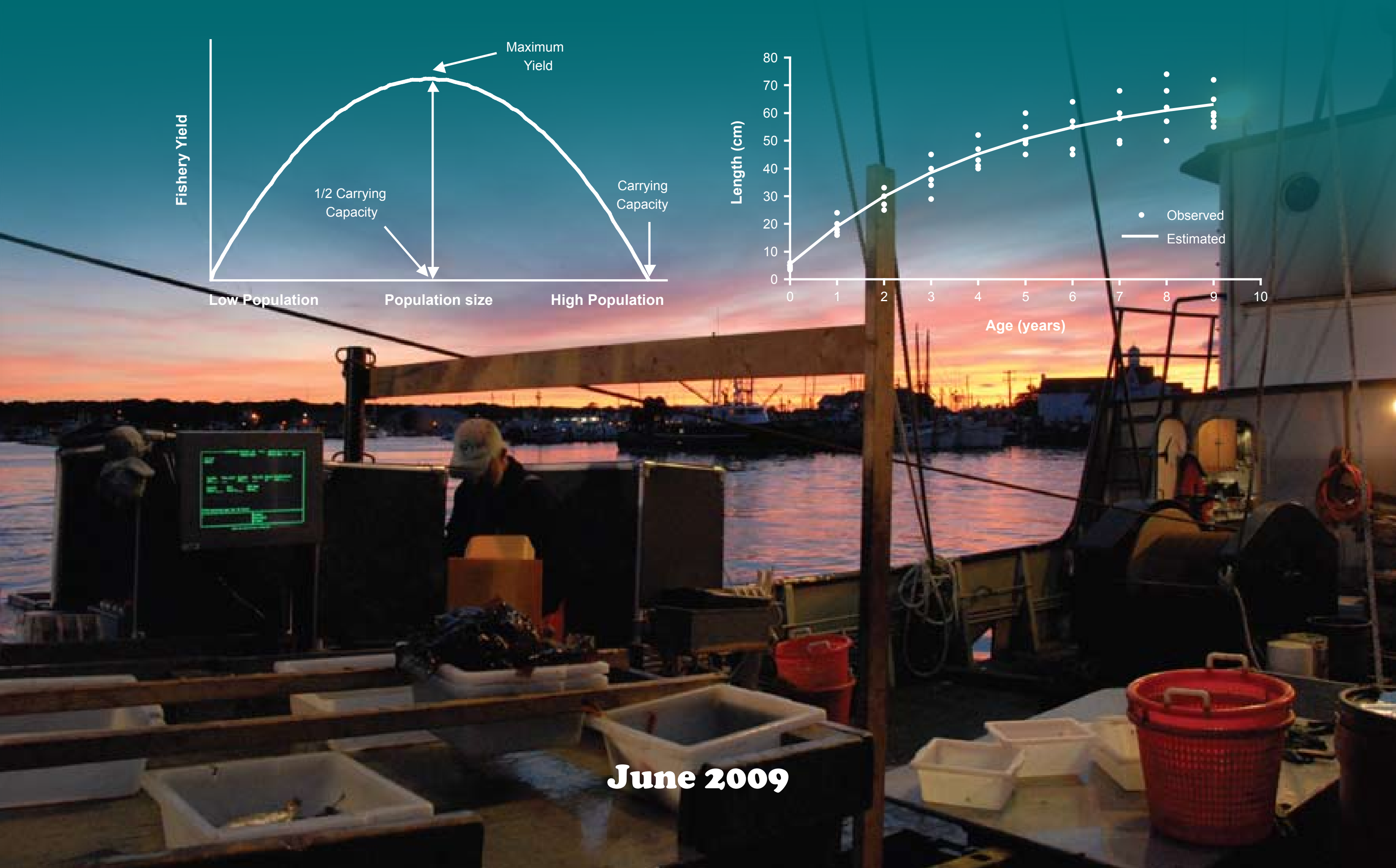
ATLANTIC STATES MARINE FISHERIES COMMISSION

Guide to Fisheries Science and Stock Assessments



June 2009

Guide to Fisheries Science and Stock Assessments

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Guide to Fisheries Science and Stock Assessments

Common Fishery Acronyms

ACCSP	Atlantic Coastal Cooperative Statistics Program
ACFCMA	Atlantic Coastal Fisheries Cooperative Management Act
ASMFC	Atlantic States Marine Fisheries Commission
B	Biomass
BRD	Bycatch reduction device
BRP	Biological reference point
CPUE	Catch per unit effort
EEZ	Exclusive economic zone
EPR	Eggs per recruit
F	Fishing mortality
FMP	Fishery management plan
GARM	Groundfish Assessment Review Meeting
ISFMP	Interstate Fisheries Management Program
JAI	Juvenile abundance index
M or M_1	Natural mortality
M_2	Predation mortality
MAFMC	Mid-Atlantic Fishery Management Council
MRFSS	Marine Recreational Fisheries Statistics Survey
MRIP	Marine Recreational Information Program
MSVPA	Multispecies virtual population analysis
MSVPA-X	Expanded multispecies virtual population analysis
MSY	Maximum sustainable yield
NEAMAP	Northeast Area Monitoring and Assessment Program
NEFMC	New England Fishery Management Council
NEFSC	Northeast Fisheries Science Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
q	Catchability coefficient
SAFMC	South Atlantic Fishery Management Council
SAW/SARC	Northeast Regional Stock Assessment Workshop and Stock Assessment Review Committee, respectively
SCA	Statistical catch at age
SEDAR	Southeast Data, Assessment, and Review
SEAMAP	Southeast Area Monitoring and Assessment Program
SEFSC	Southeast Fisheries Science Center
SPR	Spawning per recruit or spawning potential ratio
S-R Curve	Stock recruitment curve
SSB	Spawning stock biomass
TAC or TAL	Total allowable catch or landings
TRAC	Transboundary Resource Assessment Committee
U	Exploitation
USFWS	U.S. Fish and Wildlife Service
VPA	Virtual population analysis
YPR	Yield per recruit
Z	Total mortality

Preface

Marine fisheries management is a complex process incorporating fisheries biology and stock status information, food web and predator/prey relationships, habitat needs, socioeconomic needs of recreational and commercial fishermen, and law enforcement issues. Understanding how all of these factors interact is a challenging task, even for experts in fisheries science and management. The purpose of this document is to explain the fisheries biology and stock status parts of the equation. It is intended for fishermen and other stakeholders interested in fisheries management issues, and serves as a primer for the technical basis of the Atlantic States Marine Fisheries Commission's decision-making process.

The following chapters provide:

- An overview of fisheries population dynamics - Chapter 1
- Fundamental data sources for fisheries stock assessments, as well as fishery gear types and how they are used - Chapter 2
- Fish biology and life history information - Chapter 3
- Factors that affect fish population size, including recruitment, growth and mortality - Chapter 4
- Common stock assessment models - Chapter 5
- Biological reference points and their use in evaluating stock health and the effectiveness of management measures - Chapter 6
- The connection of all these elements to the Commission's interstate fisheries management process - Chapter 7
- A glossary of common fisheries terms, including all terms in **bold** text found throughout the document – Final Chapter.

This guide explains some technical aspects of stock assessments that may be unfamiliar to those not directly involved in fisheries science and the analysis of fish populations. In particular, it is written for stakeholders involved in Commission activities who have never been exposed to formal fisheries science training, but are interested in better understanding complicated fisheries concepts. An enhanced knowledge of fisheries science and assessment concepts will promote an increased understanding of fisheries management, lead to more informed decision making, and give stakeholders greater confidence as they participate in the fisheries management process.

Tips for using the Primer

- Definitions and uses of **bolded** terms can be found in sidebars and in the glossary.
- Common **acronyms** for fisheries language and resource management agencies are found on the previous page.
- **Main points** are highlighted at the beginning and end of each chapter.

In 1942, the 15 Atlantic coast states from Maine to Florida formed the Atlantic States Marine Fisheries Commission (ASMFC or Commission) to promote and protect coastal fishery resources. The Commission actively coordinates **fishery management plans (FMP)** for 24 species or species groups through its interstate fisheries management, fisheries science, habitat conservation, and law enforcement programs. The Commission's long-term vision is to achieve healthy, self-sustaining populations for all Atlantic coast fish species, or successful restoration well in progress, by the year 2015.

Why Assess Fish Stocks?

Coordinating the efforts of the Atlantic coastal states in the development and implementation of interstate **fisheries management** programs is the primary role of the Commission, with **stock assessments** forming the basis of these programs. The Commission assesses fish stocks to determine their status, to evaluate how they may be affected by potential management actions, and to forecast their future conditions.

In fisheries, determining stock status means estimating one or more biological characteristics of the stock, such as **abundance** (numbers of fish) or **biomass** (weight), and comparing estimated values to reference values that define desirable conditions. Although there are many possible reference values or benchmarks to indicate status, most fishery management plans use two biologically-based indicators. The first is stock biomass (i.e., the weight of all fish in a stock). A current estimate of stock biomass is compared to a reference biomass value that has been defined as sufficient to produce enough young fish during the next spawning period. Maintaining biomass above the reference level promotes sustainability of the stock. If the biomass is below the reference value, the **population** is considered overfished. The second measure is the rate of fishing (i.e., **exploitation** or **fishing mortality**). If fishing mortality is above the reference level, overfishing is occurring. If fishing mortality is below the reference level, overfishing is not occurring. Management actions are typically concerned with finding measures to stop overfishing when it occurs and rebuilding stocks considered overfished. Management also strives to avoid overfishing and prevent viable stocks from becoming overfished. Forecasts, or **projections**, are an important part of the management program used to establish future catch allowances, evaluate alternative management strategies, and timeframes for rebuilding overfished stocks or protecting healthy stocks.

Although personal computers and continued advances in mathematics and statistics have greatly advanced stock assessment analyses, fisheries stock assessments still contain considerable uncertainty. Moreover, a large portion of this uncertainty can be directly attributed to three conditions that cannot be solved through computing power or analytical prowess: (1) fisheries data are imperfect, (2) it is impossible to replicate the actual dynamics of a fish stock occurring in a large natural ecological system, and (3) fisheries assessments require projections of future events.

Fisheries data are imprecise because collecting information on marine fish populations is difficult and expensive. The very nature of marine fish populations dictates that collecting data for even the most modest of assessment methods is a considerable undertaking. For starters, consider the magnitude of the potential sampling area and the range of potential resource users. If you are a fisheries manager, it is a relatively simple undertaking to determine how many fish are removed from a 15-acre lake with one access point and only recreational anglers. Alternatively, imagine you are charged with managing a marine fish stock whose range spans the entire Atlantic coast that is exploited by both recreational and commercial fishermen. Simply tabulating the most basic fishery statistic, total catch, is obviously difficult. Furthermore, it is virtually impossible to make direct observations of all individuals, or even substantial portions, of most populations of fish.

The quality of information from fisheries and related research programs directly impacts how well scientists can use this information to estimate stock status. The poorer the quality and quantity of data, the harder it is to estimate how many fish are out there. That is why data collection and management is such an important part of the fisheries management process. It is also why monitoring programs are a fundamental component of the Commission's fishery management plans. The Commission has been a driving force behind the creation and continuance of fishery data collection and management programs like the **Southeast Area Monitoring and Assessment Program** (SEAMAP), the **Northeast Area Monitoring and Assessment Program** (NEAMAP) and the **Atlantic Coastal Cooperative Statistics Program** (ACCSP) (see Chapter 2).

Fisheries scientists strive to increase the types and amounts of data collected from fisheries and research projects in order to improve the accuracy of stock assessments. Fisheries managers then consider results of the stock assessment when taking management action, which in turn may affect stock abundance or productivity. If a stock is overfished, actions need to be taken to reduce fishing pressure. This allows the stock to rebuild to an acceptable level and promotes a healthy fishery in the future. On the other hand, if a stock is healthy, managers take steps to ensure the stock is harvested at a level allowing for long-term sustainability. Because stock assessments are directly linked to management actions, it is important to understand appropriate uses of data, different options for analyses, and how to apply assessment results.

The public may find stock assessments to be complex and mysterious. The truth is assessments are complex. They require the collection, analysis, and synthesis of massive quantities of information. Stock assessments may be perceived as mysterious because the underlying technical work involved requires advanced training in biology, math, statistics, and computer programming. However, this training is not necessary to understand the main concepts of assessments and their results. This guide is designed to help stakeholders and other interested parties feel better understand the concepts and methods forming the basis of assessments. Readers are presented with assessment techniques currently used to develop scientifically-based stock status information for making fisheries management decisions.

In this chapter you will learn:

The difference between stocks and populations.

What a stock-recruitment relationship is.

Why carrying capacity and surplus production are important.

Stocks and Populations

As mentioned previously, fisheries management offers special challenges because all fish cannot be directly seen or counted, nor are they confined to a specific area or time. Species managed by the Commission have a variety of different geographic ranges. Some have a broad geographic range along the Atlantic coast, such as sturgeon and American shad. Other species have a smaller range. Northern shrimp, for example, are only found in the Gulf of Maine. It is important to understand the difference between a fish population and a fish stock. A population is a biological unit referring to individuals of a species living in the same area. A unit stock refers to a specific group of fish lumped together for management purposes and must be clearly defined when conducting a stock assessment.

Fish populations do not adhere to the political boundaries drawn by people. Instead, their ranges are defined by environmental preferences and tolerances (e.g., freshwater versus marine, tropical versus temperate regimes, and benthic versus pelagic habitats). Since biological and political boundaries often differ, management of a species often requires interjurisdictional arrangements to coordinate management efforts among states, between state and federal governments, or among nations. This is why the Commission and the other interstate fisheries commissions were created – to balance the biological needs of the resource with the political demands of stakeholders (including the states and their broader constituencies).

Do you know what distinguishes a population of fish from a fish stock?

A fish **population** is a *biological* unit referring to individuals of a species living in the same area.

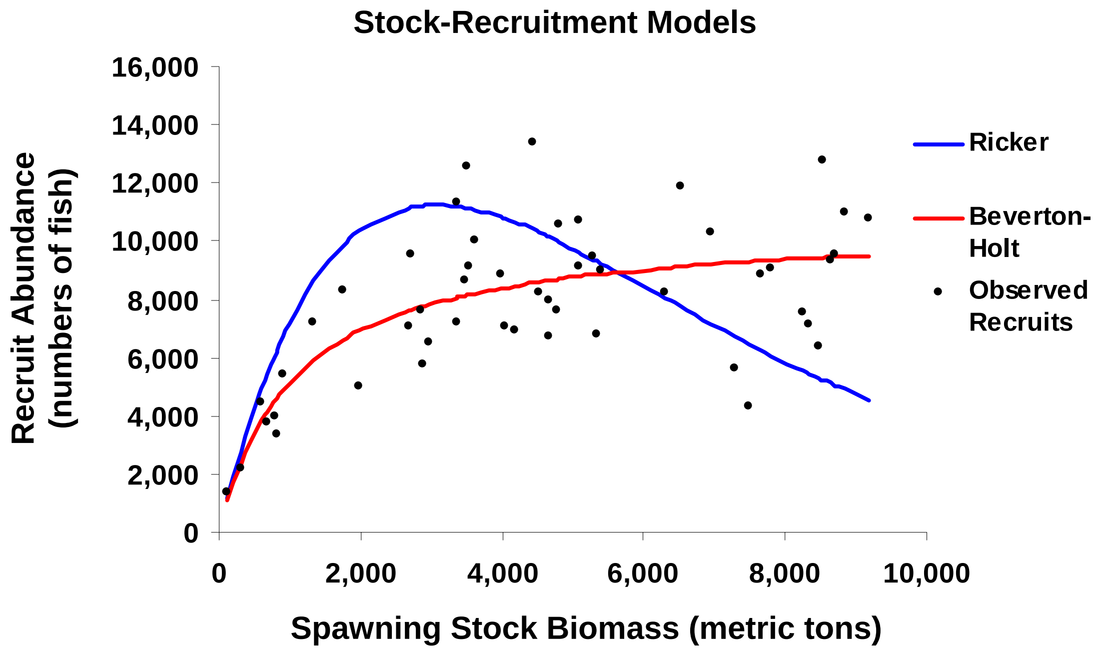
A fish **stock** is a *management* unit grouped by genetic relationship, geographic distribution, or movement patterns

Stock and Recruitment

For many stocks, there is a relationship between the size of the **spawning stock** (number or biomass of mature fish) and the number of fish ultimately **recruiting** to, or entering, the fishery. Understanding this relationship is one of the most important questions in fisheries science because it permits scientists and managers to project stock size and take management steps to ensure fish will be available in the future, thus avoiding "crashing" the fish stock due to a recruitment failure. Comprehending the relationship is not easy, as environmental and biological processes affecting recruitment are susceptible to large year-to-year variations. Fisheries scientists have developed several models to describe **stock-recruitment relationships**. The two most commonly used models are: (1) the Beverton-Holt model, and (2) the Ricker model.

Stock-Recruitment Relationship

In a nutshell, this answers the question, "Given how many adult fish are out there, how many new fish can be produced?"



Beverton-Holt (red) and Ricker (blue) stock recruitment models fit to the same data set of spawning stock biomass (SSB) and abundance of recruits (R). An important distinction is that in the Beverton-Holt model, the number of recruits approaches a maximum value, or asymptote, and remains high as spawning stock size increases. In the Ricker model, the number of recruits decreases at high spawning stock sizes, suggesting a limited availability of resources to support large recruitments beyond stock sizes at the peak of the Ricker curve.

Surplus Production and Carrying Capacity

Surplus production is the foundation of fisheries management. The concept of surplus production describes a population's capacity to produce more than is needed to simply replace itself. The extra, or 'surplus', production is what is left over and available for harvest.

To understand the concept of surplus production, we must first define the bounds of possible population sizes. At one extreme is the minimum size of a population: zero (i.e., extinction). The other extreme, the maximum population size, is referred to as the **carrying capacity**. The concept of carrying capacity is not as easy to quantify but is based on the idea of an upper-limit to population size given the limited resources needed to sustain the population (i.e., sufficient food and suitable habitat).

In theory, the population size of an unexploited species will vary slightly around its carrying capacity due to variations in natural processes. Populations exceeding the carrying capacity in one year will soon return to levels at or below the carrying capacity, as resources are not available to sustain the increased population for long. On the other hand, a population falling below its carrying capacity tends to rebound. This concept drives fisheries management - a stock fished below its carrying capacity has the ability to generate **surplus production** that can be sustainably harvested over time. The challenge is to a find the level of harvest that is both sustainable and produces the desired management goal.

How to Read a Graph

Graphs are a great way to convey a lot of information in a form that is often easier to understand than a long table of numbers… but that does not mean all graphs are easy to read! Here are some things to keep in mind when reading graphs.

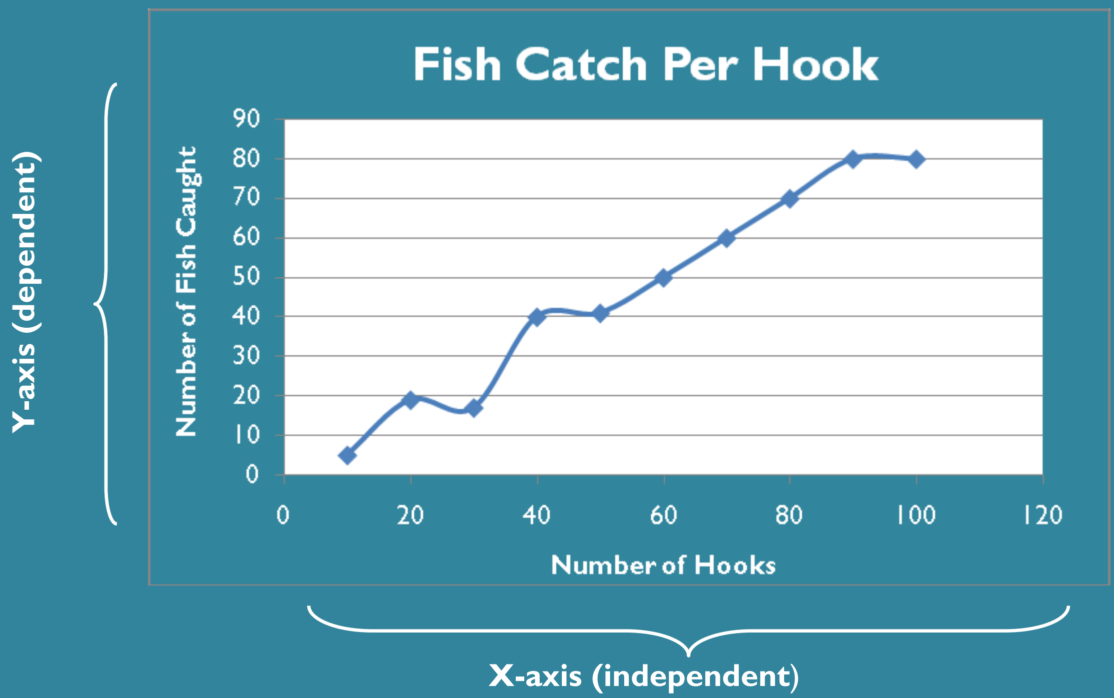
X-Axis vs. Y-Axis

Most graphs have two sides to them that are labeled and have numerical scales. The x-axis is horizontal on the bottom of the graph, and usually represents the **independent variable**. The y-axis is vertical on the left side, and usually represents the **dependent variable.**

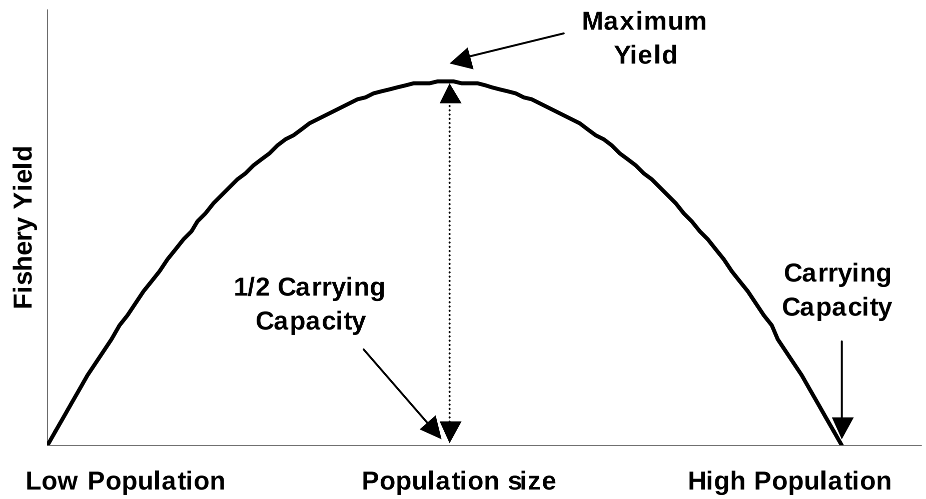
Typically the independent variable is whatever is *CAUSING* the phenomenon you are investigating, and the dependent variable is what we think is the *EFFECT*. In this graph, it is the number of hooks that determines how many fish are caught, and not the other way around. The next time you read a graph, look for the independent (cause) variable on the bottom and the dependent (effect) variable on the side.

Other Things to Look for:

Always consider the units on both axes. These can make a big difference if the data points are being measured in numbers of fish caught versus metric tons caught!



A primary goal of managers is to maximize surplus production. This can be achieved by determining the amount of fishing that will produce a population (or stock) size yielding the most extra production or harvest. Achieving this goal is difficult because we lack a complete understanding of the impacts of fishing pressure and environmental fluctuations on fish populations. For example, fishing alters a population's ability to reproduce itself, as harvesters tend to selectively remove the oldest and largest individuals (i.e., those that produce the most eggs) from the population.



The concept of surplus production. Population size is on the x-axis (horizontal axis), increasing from left to right. Fishery yield is on the y-axis (vertical axis). At low population sizes, fishery yield is low because there are few fish and little production. As population sizes approach carrying capacity (maximum population size), there is little yield because the population has limited resources for more production. In theory, the maximum yield occurs when population size is at half of carrying capacity. It is important to note that maximum productivity of a stock may occur at larger or smaller population sizes than half of the carrying capacity.

Chapter 1: "Some Basic Concepts" Summary

- Due to their incredible collective abundance in the ocean, fishes are typically managed by species; species are further divided into stocks and populations.
- A fish species is divided into stocks for management purposes.
- A fish species is divided into populations to reflect actual differences in geographic range or biological characteristics.
- An evaluation of the stock-recruitment relationship (the relationship between the number of adult fish in a stock and the number of new fish entering the stock) allows scientists to estimate the carrying capacity and surplus production of a stock. This information forms the basis of management decisions designed to maximize the output and sustainability of a fishery.

Chapter 2. Data Sources

In this chapter you will learn:

The difference between fishery-dependent and fishery-independent data.

How these data are collected and by whom.

How scientists use these data.

Stock assessments are demanding efforts, requiring lots of data (boat loads of data, you could say). Without a doubt, the better the data, the better the stock assessment. Stock assessments rely on two primary data sources: (1) **fishery-dependent data**, or information collected from fishermen and dealers on catch, landings and effort; and (2) **fishery-independent data**, or information collected by scientists via a long-term research survey or other scientific study. When combined, fishery-dependent and -independent data provide scientists with an overall picture of the fishery and stock status.

This chapter explores these data sources in detail and their uses in monitoring fishery resources.

What are fishery-dependent data?

Fishery-dependent data are collected from commercial sources (vessel or dealer reports) and recreational sources (individual anglers, party or charter boats). Information is gathered on the total amount of fish removed from the ocean (catch and landings) and the level of fishing participation (effort). Additionally, information is collected about the fishing trip itself – who, what (target species), when (season), where (location) and how (gear type); related economic information (the cost of fishing trips); and biological information (species, age, length, weight, maturity of fish caught in a fishery). In some cases, information is also gathered on fishing gear interactions with **protected species** (marine mammals, sea turtles, and sea birds), bycatch of non-target species, and discards – fish returned to the sea dead or alive.

There are several terms to describe the removal of fish from the sea, and it is important to recognize distinctions between each of these terms:

Target species refers to a single species or a group of species that certain gear and strategies are designed to catch (i.e., what a fisherman is trying to catch).

Catch is the total number or weight of fish captured, including all fish retained and those that are discarded. Total removals of a fish species from the sea must be determined when calculating the total catch for a species (i.e., commercial catch + recreational catch + unintentional removals of a species from fisheries targeting other species).

Bycatch is the portion of a non-targeted species catch taken in addition to the targeted species. It may include non-directed, threatened, endangered, or protected species, as well as individuals of the target species below a desired or regulatory size.

Discards are what is caught and returned to the sea unused. Discards may be either alive or dead. There are many varieties of discards: **economic discards** - the portion of the catch not economically valuable to land; **regulatory discards** – the portion of the catch prohibited from being retained due to size or trip/bag limit regulations; and **high-grade discards** - the portion of the catch temporarily retained but later discarded due to its lower value in comparison to more valuable (e.g., larger) fish captured later during a trip or day of fishing.

Harvest is the total number or pounds of fish caught and kept from an area over a period of time (harvest does not include discards and releases).

Landings are the number or weight of fish brought to dock (commercial) or shore (recreational). Landings are reported at the points at which fish are brought to shore.

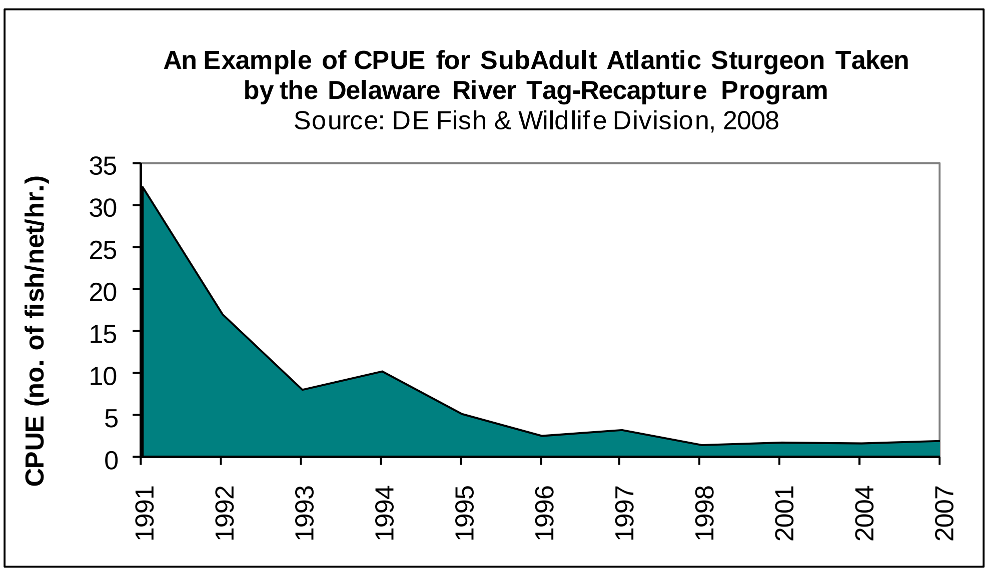
Effort is a quantitative measure of fishing pressure, usually the amount of time and fishing power used to harvest fish. Fishing power can be described in terms of gear size, boat size, and horsepower.

Fishing mortality (F) is the rate at which fish in a stock die because of fishing. This may include fish that die after being caught and returned to the water (i.e., discard mortality).

Why collect fishery-dependent data?

Fishery-dependent data form the basis of stock assessments by describing the catch (or removals), fishing effort, and biological information. Catch is the primary data element, describing the total amount of fish removals, including bycatch and discards. Bycatch and discards may include undersized or undesirable individuals of a species caught or discarded either in a **directed fishery** for that species or in another fishery.

Effort, or fishing pressure, is the amount of time and fishing power used to harvest fish. **Fishing power** is characterized by gear, boat size, horsepower, and other technological advances affecting fishing efficiency. The ratio of catch to a standard unit of effort is known as the **catch per unit effort**, or **CPUE**. It can be used as a measure of relative abundance or to track changes in abundance of the fish caught in a fishery. If you catch more fish one year than the year before and fish about the same amount of time, you would likely reach the conclusion that more fish are out there. Thus, as CPUE increases it is assumed that overall abundance has increased as well, while decreases in CPUE suggest declines in abundance. It should be noted, however, that commercial fishing is not a random process. Rather, fishermen select the areas to fish where they think they will catch the most fish. Effort must be clearly defined in terms of both gear and time. Gear consists of all the equipment utilized in a fishery and time measures the duration of gear deployment in the water.



Catch per unit effort (CPUE). In the figure above, the declining trend in CPUE indicates sturgeon abundance is lower in 2007 than in 1991, suggesting an overall decrease in abundance.

Biological information allows scientists to characterize the catch in a fishery (i.e., the different species caught, their sizes, ages, and maturation state). Additionally, fishery-dependent data can provide information on where fish are caught, when they are caught, and how they are caught – yielding detailed insight into interactions between fishermen and the fish they catch. This information is also critical in the development of a fishery management plan because it provides the link between fishing activity and the resource.

How are fishery-dependent data collected?

Fishery-dependent data are obtained from commercial and recreational fisheries in a number of ways - fishermen and dealer reports, observer programs, and broad surveys of the recreational sector. The goal is to obtain the most complete profile of the catch and effort of a fishery possible. It is critical to understand the methods used to collect data. Proper analyses and evaluation of stock status require an understanding of how data were collected and should be used.

Commercial fishery data

The first step in collecting fishery-dependent data is to define the number of fishermen, the number and types of fishing vessels in a particular fishery, and the number of dealers. These define the groups from which scientists collect commercial fishery data. For most fisheries, catch data are collected using landings records, logbooks, or dealer reports. Commercial catch may also be estimated by trained fishery **observers** who measure the catch at sea or when it is landed. Depending on the fishery, at-sea observers may measure the entire catch or take a sub-sample of the catch. Although observers provide a direct record of the catch, the availability of trained observers is limited, and the cost of observer time on vessels is expensive.

Observers at work. Fishery observers collecting samples from both the kept and the discarded catch during a bottom trawl fishing trip. Photo courtesy of NOAA Fisheries Service, NEFSC, Fisheries Sampling Branch.

Information on commercial catch and effort on the U.S. Atlantic coast is collected for state and federally permitted fisheries. Permits are issued to vessels and dealers, and these permit holders may hold a state permit, a federal permit, or both. Information for permitted fisheries conducted in state and federal waters is reported back to the appropriate regulatory agency. The Atlantic Coastal Cooperative Statistics Program (ACCSP) coordinates and helps to standardize state and federal landings reporting on the Atlantic coast. Currently, there is a range of reporting requirements among federal and state governments that can lead to discrepancies in the landings data between state and federal records. The ACCSP has developed coastwide standards for commercial and recreational fishery data and a single integrated data management system.

The ACCSP is intended to encompass commercial, recreational, party and charterboat fishery-dependent statistics for its partners. These include all Atlantic coast states, the Potomac River

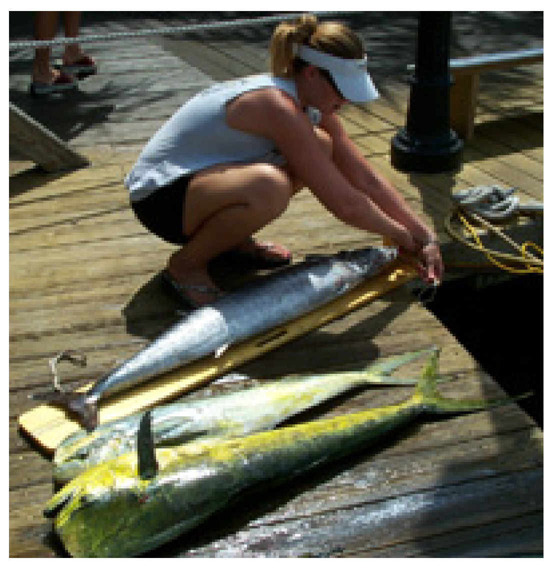
Fisheries Commission, the District of Columbia, the Commission, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the three Fishery Management Councils (New England, Mid-Atlantic and South Atlantic) along the East Coast. ACCSP partners have committed to implementing ACCSP data collection and data management standards within their own jurisdictions. For more information on the ACCSP, please visit its website at www.accsp.org.

Another factor to consider when using data is whether or not they are **confidential**. Certain types of fishery-dependent data must be treated as confidential in order to protect individual economic information. Confidential data may be aggregated and lumped into a more general category for public dissemination. When there are three or fewer vessels/dealers, the data are combined to ensure the confidentiality of an individual vessel's activities or an individual dealer's records.

An alternative method of fishery-dependent data collection is done through **cooperative research programs** between scientists and fishermen. Cooperative research is an arrangement between scientists and fishermen where a commercial vessel and crew are employed by researchers to gather data instead of fish. These efforts can be valuable in promoting collaboration between the two groups by allowing them to work together and understand the other's role in maintaining healthy fisheries. Cooperative research enhances the "transparency" of fishery data collection and research and taps into the on-the-water experience of commercial fishermen.

Recreational fishery data

Recreational fishery data in the U.S. are gathered by the National Marine Fisheries Service's (NMFS) **Marine Recreational Fishery Statistics Survey (MRFSS)**. MRFSS consists of two independent statistically-designed surveys to collect catch and effort data from recreational anglers. These recreational fishing surveys were initiated by NMFS in 1979 to obtain standardized and comparable estimates of participation, effort, and catch by recreational anglers in the marine waters of the U.S. Recreational fishing statistics are very difficult to collect because these fisheries typically have high numbers of participants utilizing many different strategies to catch fish. However, it is necessary to monitor recreational fishing activity because, in some cases, recreational fishing can account for the removal of more fish than commercial fishing.



MRFSS Interviewer at work. Interviewer collects biological information on recreational catch following an angler fishing trip. Photo courtesy of Florida Fish and Wildlife Conservation Commission.

MRFSS collects recreational fisheries data via **intercept interviews** and **telephone surveys**. The survey is divided into six, two-month periods termed 'waves'. Trained interviewers conduct the intercept survey, collecting information on: (1) the numbers, weights, and lengths of fish caught by species; (2) the state and county of angler residence; (3) the frequency of fishing trips per year; (4) the type of fishing (shore vs. boat, private vessel vs. charter vessel); and (5) fishing location. These data provide information about the recreational catch and are also used to develop an estimate of catch per trip. Catch per trip is one example of a CPUE used to evaluate trends in abundance. The intercept interview is conducted dockside as an angler returns from fishing. The telephone survey is designed to collect data on recreational fishing effort, such as the presence and number of recreational anglers within a household, or number of fishing trips taken in each wave.

Data from the two surveys are combined to produce estimates of fishing effort, catch, and participation. Using the complemented surveys approach, marine recreational fishing estimates are calculated for each wave every year. MRFSS data provide standardized state, regional, and coastwide estimates of participation, catch, effort, and landings for many species.

MRFSS also conducts a "For-Hire" survey of the Atlantic coast's charter and head boats. Catch data dates back to 1981, but validation efforts began in 2003. The "For-Hire" survey is designed similarly to the standard MRFSS – a sample of for hire captains are called each week to collect effort data; catch data are collected through dockside interviews; and the data are compared to check for reporting errors and validation.

In addition, recreational data are obtained from several separate volunteer angler surveys targeting more specific fisheries than the all-encompassing MRFSS survey. There are also a number of recreational tagging programs and studies gathering data that can be used to estimate abundances, mortality rates, migration, and stock structure.

Measuring carapace length (CL) of an American lobster (*Homarus americanus*). For lobsters, the carapace length is measured from the base of the right eye to the end of the carapace. The measurement determines whether or not the lobster is of legal size.

Following a review of MRFSS and recommendations for improvement, a new recreational fishing survey, the **Marine Recreational Information Program (MRIP),** is being developed to replace MRFSS. MRIP is designed to increase accuracy in recreational catch and effort estimates. In addition, a new national saltwater angler registry, scheduled for implementation by January 1, 2010, will help to better characterize the economic value of saltwater recreational fishing and provide a more complete picture of how recreational fishing is affecting fish stocks. Until MRIP is fully implemented, MRFSS remains the most complete coastwide recreational data set available and is used in stock assessment and fisheries management planning. For more information on MRIP's development go to http://www.st.nmfs.noaa.gov/mrip/.

Biological data

Commercial fisheries provide important sources of biological data on fish stocks, especially in determining size and age composition of both the catch and the stock. It is good practice to have standardized data collection methods for a stock for measures such as length (**fork length, total length or standard length**) and age (using either scales or otoliths – fish "ear bones"). When measured accurately, fish ages are perhaps the most important biological data we can obtain because they allow scientists to determine the age structure of the population. **Age**

structure refers to the numbers of fish at each age, also known as a **year-class** or **cohort.** Typically, the number of older individuals in a fished population is much less than in an unfished population. This effect is caused by the increased likelihood of an individual being caught in each year of its life. In addition to age and length, other important measurements include weight, sex, maturity, stomach contents (for information on diet), and genetic composition.

Measuring an Atlantic croaker (*Micropogonias undulates*) on an electronic fish measuring board; total length (TL) of a fish is measured from the tip of the snout or jaw (whichever sticks out farther) to the end of the tail (Photo courtesy of NEAMAP).

What are fishery-independent data and why are they collected?

Fishery-independent data are collected by scientists conducting long-term resource monitoring projects known as **fishery-independent surveys**. These surveys are specifically designed to follow consistent methods using the same gear for the duration of the survey in order to develop unbiased and independent indices of abundance. State, federal, and university scientists typically conduct fishery-independent surveys over many years to track long-term abundance trends of fishery resources. These data, when combined with fishery-dependent data from fishermen reports, provide a more accurate picture of stock status. Since the data are not influenced by specific management measures (size and bag limits, season closures, mesh sizes) or socioeconomic factors, they present an unbiased accounting of stock health. These surveys often collect biological data and other information used to describe juvenile and adult abundances, fish habitat characteristics, and environmental factors.

SEAMAP & NEAMAP

Along the Atlantic coast, fishery-independent surveys are conducted at state, regional, and federal levels. However, the amount of data needed to properly conduct fisheries assessment and management is often very extensive. No single fishery management agency has the fiscal, personnel, or physical resources to meet the multiple objectives of state, interstate, and federal fishery management plans currently in place. To minimize or overcome the problems associated with insufficient funding and other limitations, agencies often combine resources and share responsibilities to gather information they would not have been able to gather independently. Benefits of cooperative sampling efforts include: reduced costs, efficient sampling, and the ability to collect samples over large geographic areas for long periods of time using consistent protocols.

The Commission, its member states, and federal partners are actively involved in two cooperative sampling programs - the Southeast Area Monitoring and Assessment Program (SEAMAP) and the newly established Northeast Area Monitoring and Assessment Program (NEAMAP). Since the 1980s, the South Atlantic component of SEAMAP has collected fishery-independent data from Cape Hatteras, North Carolina to Cape Canaveral, Florida (SEAMAP also includes data collection programs for the Gulf of Mexico and the Caribbean). SEAMAP itself is not a research program, but provides a platform for the development and implementation of research programs. Its goals are to:

- Collect long-term, standardized, fishery-independent data on the condition of regional living marine resources and their environment in a manner consistent with established fisheries data management systems
- Cooperatively plan and evaluate SEAMAP-sponsored activities
- Operate the SEAMAP Information System for efficient management and timely dissemination of fisheries-independent data and information
- Identify and describe existing non-SEAMAP databases and activities that are of value to fishery-independent assessments of regional living marine resources
- Coordinate and document SEAMAP activities, and disseminate programmatic information

Based on the success of the SEAMAP Program and concern regarding large gaps in data collection coverage along the Northeast U.S. coast, the Commission, all members from Maine to North Carolina, including Washington, D.C., the New England and Mid-Atlantic Fisheries Management Councils, the NMFS and the USFWS, and the Potomac River Fisheries Commission have established a coordinated fishery-independent sampling program for the Northeast. Like SEAMAP, its mission is to facilitate the collection and dissemination of fishery-independent information. Data obtained in the Northeast is for use by state and federal fisheries management agencies, the fishing industry (commercial and recreational), researchers, and others requesting information. The intent of NEAMAP is not to change existing programs, but to coordinate and standardize procedures and improve data quality and accessibility.

The first undertaking of the program was to develop a nearshore trawl survey to address the lack of adequate survey coverage and coordination in the coastal waters of the Mid-Atlantic Bight. A pilot survey was completed in the fall of 2006 by investigators from the Virginia Institute of Marine Science (VIMS), working aboard the F/V *Darana R,* owned and operated by Captain James Ruhle. Since then, NEAMAP researchers have completed surveys each spring and fall from Cape Hatteras, North Carolina to Aquinnah, Massachusetts, beginning with the first full survey in the fall of 2007.

Because of the survey's ability to sample inshore waters in the Mid-Atlantic, its data may be used to augment NEFSC's long-running time series (conducted by the R/V *Bigelow*, and previously for many years by the R/V *Albatross*). With additional years of sampling, the nearshore trawl survey has the potential to become a valuable source of fishery-independent data to support and improve stock assessments for scup, black sea bass, and other Commission managed species.

How are surveys designed & how are fishery-independent data used?

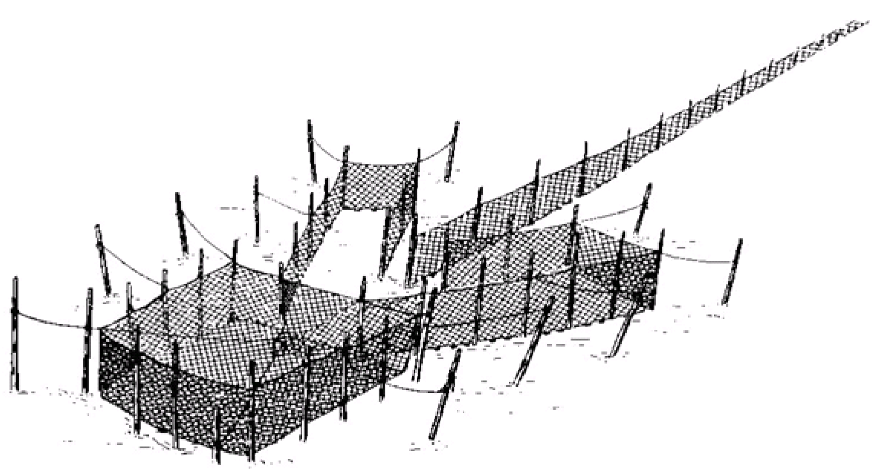
Fishery-independent surveys must be carefully designed to obtain a scientific estimate of abundance, called an **abundance index**. This index can be used to monitor trends in the abundance and distribution of a fish stock or stocks over time and over the entire range of the species. If a survey catches only young fish, the resulting index is called a **juvenile abundance index**, or JAI. Depending on the objectives of a survey, the data collected can include information on abundance, age, growth, location of spawning aggregations, maturity, gender, fecundity, stock structure, habitat usage, and feeding habits. Fishery-independent surveys often provide information on the portion of a stock that is not caught by the commercial fishery - for example, smaller fish not yet selected by fishing gear. In general, longer fishery-independent survey time series are of greater utility in stock assessments because their extended duration provides a long-term index of stock abundance derived from unbiased and consistent sampling methodology.

What gears are used to capture fish?

One could say there are as many ways to catch fish as there are fishermen. However, the gears used to catch fish can be grouped into a few basic categories.

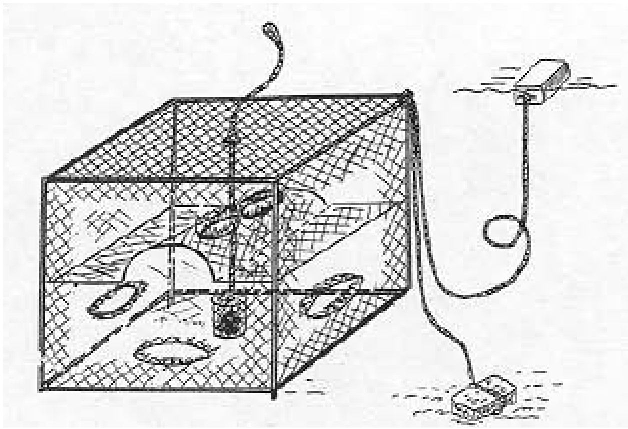
Weirs and Pound Nets

These gears are passive - they are not hauled, towed, or reeled by a vessel or fisherman - and can be set either temporarily or permanently to catch fish. Weirs and pound nets, typically found in river systems, take advantage of fish behavior to catch fish. A weir is a barrier set across a river or stream directing fish into a trap. Weirs capture fish as they migrate up or down rivers. Pound nets consist of a vertical mesh wall designed to redirect fish to deeper water, funneling them into a trap. The redirecting wall runs perpendicular to the coast from shallow to deeper water, since a fish encountering an obstacle in its path tends to move to deeper waters before continuing up or downstream in hopes of finding a way around it.



Schematic of a pound net (Dumont and Sundstrom, 1961)

Weirs and pound nets can be large and require significant labor and equipment to install, so they are typically set up for a season or may even be permanent. These gears can select for different sizes of fish depending on the trap size and mesh size. Culling rings or escape vents can be used to allow the escape of undersized animals. Pound nets are used to catch striped bass, river herring, Atlantic menhaden, and other anadromous and estuarine species.



Schematic of a pot (Dumont and Sundstrom, 1961)

Pots

Pots are a passive gear set and retrieved periodically. Pots are three-dimensional and are often referred to as traps. They capture fish and crustaceans seeking shelter or food and may be baited to attract fish. Finfish (black sea bass and tautog), crustaceans (lobsters and crabs), and mollusks (conchs) are caught in pots. The size of animals captured (**selectivity**) depends on the size of the entryway (maximum size) and the size of the trap's mesh or escape vent (minimum size).

Gill Nets

Gill nets are a floating mesh wall set vertically in the water column. Gill nets catch fish by wedging, "gilling," or entangling them. Wedging occurs when fish are caught with the net mesh around the body. Gilling occurs as a fish tries to swim through the net and mesh slips behind the gill plates (opercula) holding the fish. If a fish is not caught by either of those methods, it may become entangled in the gear. Gill nets may be set to float in the water column or be anchored to the bottom. Further, floating gillnets may be staked in place or drift freely. Striped bass, weakfish, croaker, and river herring are examples of Commission managed species captured in gill nets.

Retrieving a haul from a gill net (Photo courtesy of Chris Hager, VIMS)

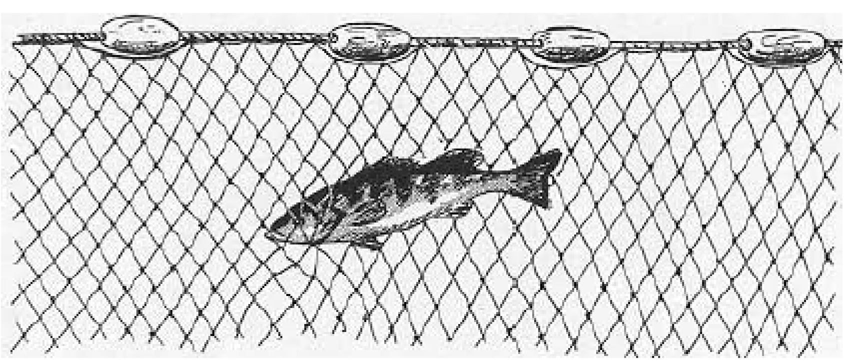
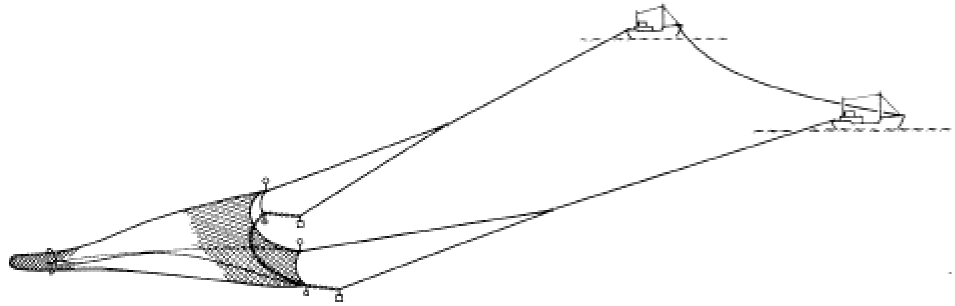


Diagram of a gill net (Dumont and Sundstrom, 1961)

Trawls and Dredges

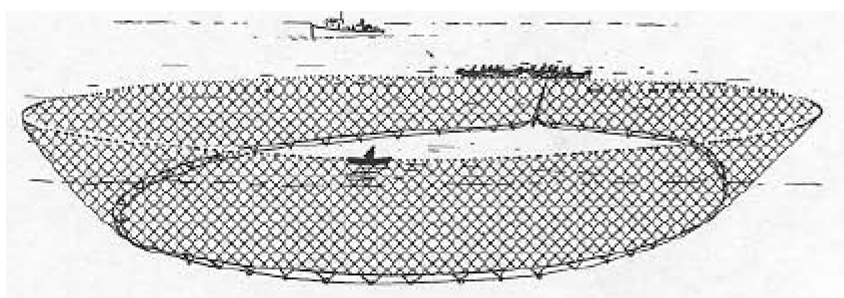
Trawls and dredges are active fishing gears capturing fish by either sweeping them from the seabed (dredges) or filtering them from the water column (trawls) as gear is dragged through the water behind a vessel. Dragged gear includes a bag constructed of mesh webbing or rings and chain links collecting the catch. Towed gears were historically deployed from hand-powered boats, then sailing vessels, and finally from large ships with powerful engines. Mechanization of both gear and vessels has led to increased fishing power and efficiency. These technological improvements helped fishermen catch fish. Groundfish such as flounders, cod, and haddock are caught using trawls.



Bottom paired trawl (DeAlteris, 1998)

Trawls are bag-shaped nets towed behind a fishing vessel. The closed end of the trawl is referred to as the cod end, where the catch collects as gear is retrieved from the water. Dredges are rake-like devices equipped with bags to collect the catch. They typically harvest molluscan shellfish (clams, sea scallops) from the seabed, but occasionally target crustacean, finfish, and echinoderm species (sea urchins and sea cucumbers).

Seines



Purse seine (Dumont and Sundstrom, 1961)

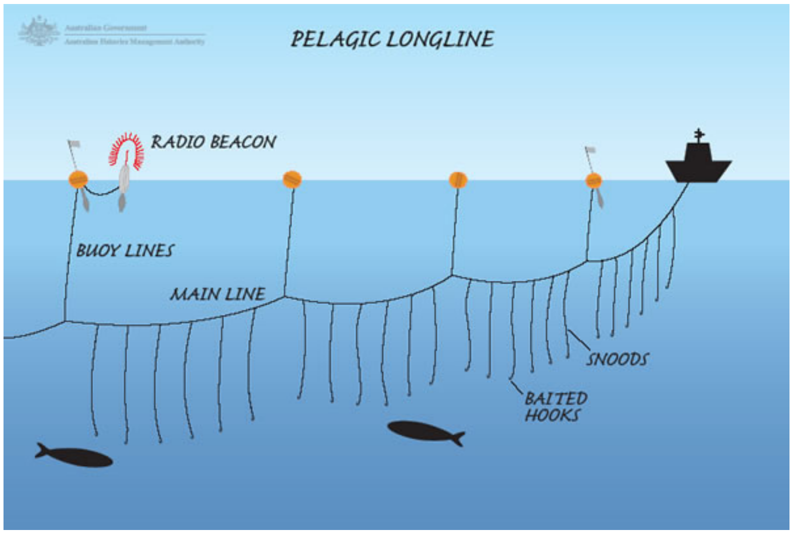
Seines are deployed to encircle target species either on the seabed or in the water. Seines are mesh nets deployed by hand or from a vessel. A simple form, the beach seine, consists of a wall of mesh connected at each end to poles that is set from shore by hand.

These small beach seines are pulled through shallow water collecting finfish, crustaceans, and mollusks. The catch is landed and sorted on shore. Larger seines are set from a boat and can be used to target coastal and pelagic species like Atlantic menhaden and Atlantic herring.

Menhaden purse seine vessels and net (Photo courtesy of Robert K. Brigham, NOAA, Dept. of Commerce)

Hook-and-line

Hook-and-line fishing is the most familiar method of fishing to most people. Hook-and-line methods range from the simple bamboo "cane" pole to large commercial longline vessels. These larger operations deploy several thousand baited hooks fished at the same time that are set and retrieved daily. Rod-and-reel is the most widely used recreational fishing gear. It is used in freshwater and marine fisheries in a wide variety of forms, from shallow water fly-fishing to offshore trolling for large pelagic billfish.



Pelagic Longline (Image: Australian Fisheries Management Authority)

Commercially, some fisheries are executed using rod-and-reel gear, but the longline is the dominant hook-and-line gear used. The principle element of this gear is the mainline or groundline that can extend for several miles. Branching off the mainline at regular intervals are leaders (snoods or gangions) and hooks. Anchors hold each end of the mainline in place and surface buoys attached via float lines to the anchors mark the location of the gear. Bottom-set longline gear is considered fixed and passive since it does not move once it is set and fish voluntarily take the hook.

Using different gears at different times and places

Different gears may be used to exploit a species at different times of the year depending on changing vulnerabilities of a species to a type of gear. In Chesapeake Bay, baited traps (crab pots) are deployed to catch actively feeding blue crabs throughout shallow waters of the Bay and its tributaries during the summer. Alternatively, fishermen have used dredges to catch over-wintering female blue crabs that have migrated to deeper waters in southern Chesapeake Bay. Information on how much fish are caught by each gear and user group provides further details on the interactions of fishermen and fish. These data are also useful because historical levels of catch by gear can be used to partition fishing effort and, thus, to determine allocation among user groups (recreational vs. commercial, trawlers vs. dredgers, or among different states).


Photo courtesy of NEAMAP

Chapter 2: "Data Sources" Summary

- Data used in stock assessments come from two sources: fishery-dependent (fishermen/dealers) and fishery-independent (scientific surveys).
  - Fishery-dependent data:
    - Are collected from both commercial and recreational fishermen through observer programs, dealer reporting, phone surveys like MRFSS, etc.
    - Give stock assessment scientists information about catch size, fishing effort, catch per unit effort, age structure, and other variables
  - Fishery-independent data:
    - Are collected by scientists conducting long term surveys like SEAMAP and NEAMAP, and other specific studies and programs
    - Are independent of management measures
    - Provide stock assessment scientists with biological data and other information describing juvenile and adult abundances, fish habitat characteristics, and environmental factors

In this chapter you will learn:

Why it is important to understand the biological characteristics of fish.

The importance of, and variability in, age and growth; feeding; reproduction; habitat and migration; and natural mortality among different fish.

Life history characteristics play an important role in the management and assessment of a species. They provide information on how a species grows and develops, senses its environment, captures food, avoids predation, and reproduces. Examples of life history questions that provide important information to both the general understanding of the species' biology and stock assessments are provided in the table below.

Information on fish life history is collected through fishery-dependent or -independent operations. In the following sections, species' life history and biology will be reviewed at the individual level rather than the fish population or stock level. This is done to acquaint the reader with factors affecting individual fish in order to provide a basis for future chapters describing the basics of fish population dynamics.

Age & Growth

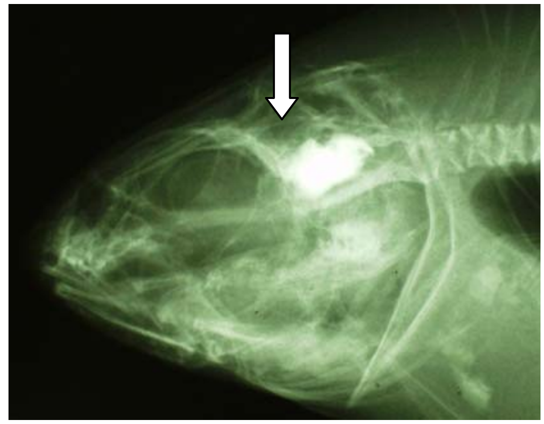
There are many factors affecting the growth of fish. Different species grow at different rates and have different life spans. Examples of large, long-lived species include the Atlantic sturgeon, that lives up to 60 years and reaches six feet in length, and spiny dogfish that may live to 50 years and reach four feet in length. At the other extreme, fishes like spot grow to only 16 inches in length and live only five years, and the bay anchovy may reach just four inches long and lives for one year.

Life History Parameters	Management & Assessment Uses
How long does it live?	To estimate natural mortality and set maximum age in assessment models
How large does it grow?	To set size limits
How fast does it grow?	Implications as to how fast it will reach the fishery's minimum size limit
Where does it live?	Identifies habitat needs and areas to protect
What is the age of first spawning?	To establish minimum size limits to ensure species reproduce at least once prior to being harvested
When, where, and how does it spawn?	Identifies areas and times of increased vulnerability to harvest; may lead to seasonal closures to protect spawning aggregations or specific habitat types
How many eggs are produced?	To develop egg per recruit estimates
How does it develop and what habitats does it rely on?	Identifies important habitats to protect during vulnerable life stages
What does it eat? How does it eat? What eats it?	Predator/prey, food web, and species interactions; multispecies and ecosystem management

Many fish species occupy environments that experience seasonal changes. During the spring and summer months, environmental conditions may promote large blooms of microscopic plankton forming the base of marine food webs. These food-rich conditions are optimal for fish growth. During the cold season, fish metabolism slows down, food availability decreases, and fish growth rates decline. The competition for scarce resources (food and habitat) also affects fish growth. Within species, certain individuals may physically dominate smaller or less aggressive individuals and, thus, obtain access to preferred feeding grounds. In other cases, competition may be indirect.

An individual may be better at capturing fast moving prey than another individual of the same species and, thus, is able to grow faster.

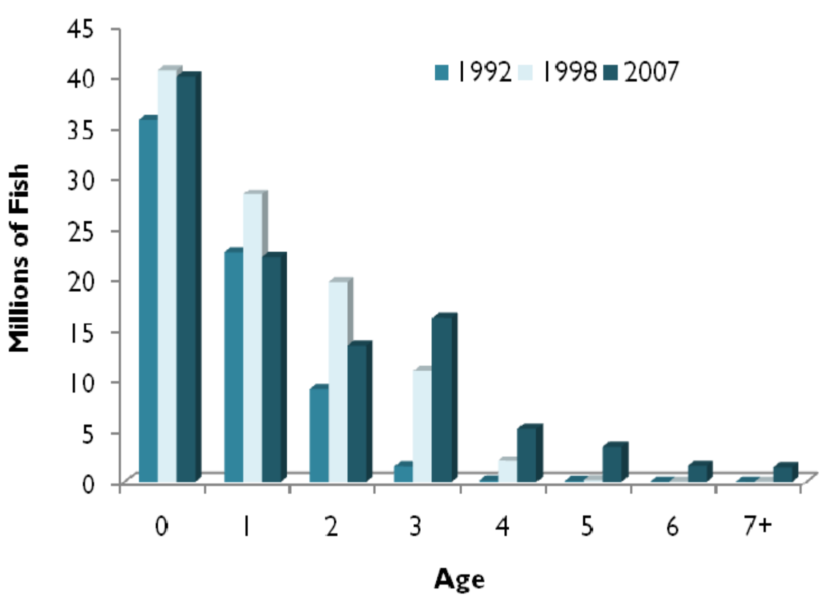
The rate at which a fish grows over the course of its life changes greatly. Typically, a young fish begins life extremely small and, therefore, is quite vulnerable to predation. This is because the probability of being preyed upon is related to the number of potential predators with mouths large enough to capture prey of a given size. Fish with small eggs that do not provide parental care to their offspring must produce tens of thousands to millions of eggs so that at least a few individuals survive to adulthood. Larval and juvenile fish display rapid growth rates because, as a fish grows, the number of potential predators decreases due to its larger size. For example, in its first year of life, a bluefish will increase in length from about 0.1 inches to 10 inches, quickly growing out of the smaller, more vulnerable life stages. Once a fish reaches maturity, it devotes less energy toward growth and more energy toward reproductive processes such as **gamete** (egg or sperm) production, migration to spawning areas, or courtship displays. An older fish will grow slowly, if at all, as it approaches its maximum age.



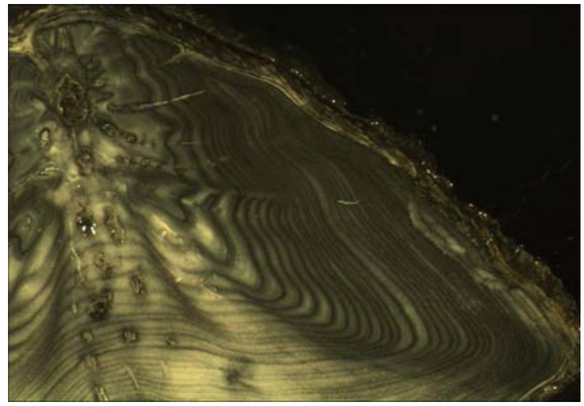
X-ray showing the position of **otoliths** in an Atlantic croaker (Photo courtesy of GSMFC).

The determination of fish age is based on counting annual markings of growth observed on one or more body parts. The most commonly used aging structures are fish scales, **otoliths** (ear bones), **opercula** (gill plates), fin spines, and vertebrae. As mentioned above, fish from temperate regions endure seasonal fluctuations in temperature and food availability. The seasonal changes result in variable growth rates, which produce uniquely identifiable marks in aging structures. These marks (called **annuli**, from the Latin word for ring) form because a fish and its age structures grow at different rates during the warm (faster) and cool (slower) seasons, producing alternating translucent and opaque bands. Annuli can be read in the same manner that bands of rings are counted to age trees.

Age structure refers to the number of fish in each age-group for a fish population. Chart below compares summer flounder abundance at age at three different points in time.



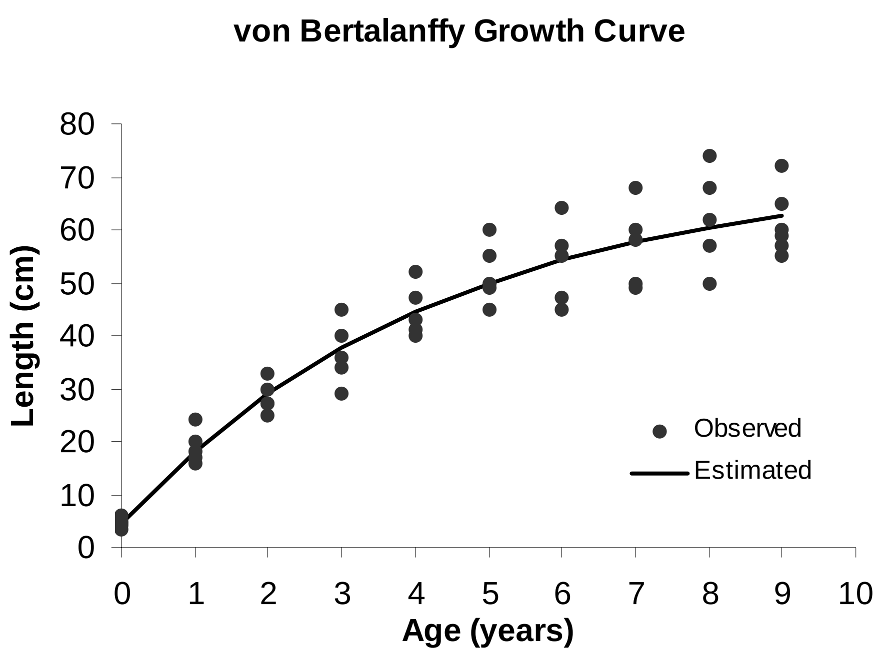
Fish age information is the basis for determining growth rate, longevity of a species, and size-at-age. Fish ages, when combined with length and abundance data, can be used to estimate the age structure of a fish population. Understanding how age influences the reproductive potential of a fish allows scientists to develop strategies to protect a sufficient number of fish from harvesting so the population can successfully replace what was harvested. A variety of harvest strategies may be evaluated by comparing different gear sizes that capture different ages of fish. The individual gear size catching the preferred ages of fish is then implemented to meet management goals.



Growth marks (**annuli**) on an otolith are used to estimate fish age (Photo courtesy of Wisconsin Dept. of Natural Resources).

Unfortunately, obtaining quality age data is challenging and expensive. Aging methods must be validated using controlled laboratory or tagging studies to confirm the observed markings are truly annual markings. Collecting age data requires staff and facilities to process samples and a sampling program that adequately covers the fishery or survey. Finally, not all species can be aged. Lobster, crab, shrimp, and other crustaceans grow by successive molting of their shell, leaving behind any record of their age. Several techniques have been attempted to estimate ages of molting animals, but none have gained widespread acceptance in the scientific community.

Scientists model the growth of fish over time in order to predict the expected size of fish at a given age. A common model used to describe the growth of fish with age is the **von Bertalanffy** growth curve. The von Bertalanffy curve assumes that as a fish grows older it will approach a maximum (**asymptotic**) size.

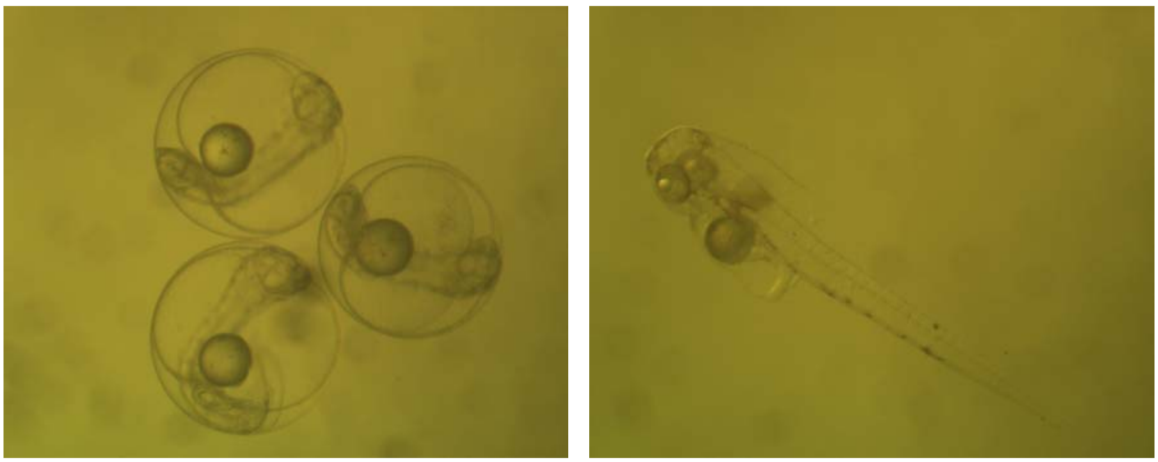


An example of a von Bertalanffy growth curve fit to length-at-age data. Data are often limited for the youngest and oldest fish. Note that as fish get older the growth rate slows and overlap among fish of different age-classes increases.

Feeding

If a fish is to reproduce and contribute to future generations, it must live to reach **maturity**. To reach maturity, an organism must consistently and successfully obtain energy for respiration, growth, and, upon maturity, reproduction. In many cases, the most critical point in this journey occurs when a young fish needs to capture its first meals.

Newly hatched fish or shellfish **larvae** are very small (typically about 1/16 of an inch for marine finfish) and look nothing like adults of the same species. Larvae hatch from their eggs with a yolk supply that lasts a few days to several weeks. Before nourishment from the yolk is exhausted, a larval fish must be able to capture live plankton and avoid becoming someone else's lunch. If a larva is adept at capturing planktonic prey and avoids predation, it will grow rapidly and transform to a juvenile. The larval stage is a transition between embryonic and juvenile stages. Larval fish must complete organ development and undergo other biological changes before completing transformation to the **juvenile** stage. Unlike larvae, juvenile fish are miniature replicas of adults, taking on the same physical features and patterns.



Eggs (Left) and 2-day-old larvae (Right) of spot, a pelagic broadcast-spawning marine fish (Photos courtesy Mike Oesterling, Virginia Institute of Marine Science).

Once a fish survives the trying times of the larval stage, it begins to utilize feeding strategies similar to those of adults. Different fish species are equipped to capture and digest a diverse assortment of prey. The torpedo-like body of Spanish mackerel and bluefish is ideal for high-speed pursuit of prey found in open water; the flattened body and cryptic coloration of flounders are excellent adaptations for a sit-and-wait hunting strategy on the sea bottom. Sturgeon has electrical sensors in their snouts and a keen sense of smell used to root through muddy river bottoms in search of benthic invertebrates (worms, clams). Tautog has a dense, compact body, with strong jaws and crushing molars for eating hard-shelled invertebrates attached to reefs and pilings. Striped bass and weakfish have a streamlined body with mouths situated on the front of their head, ideal for chasing and capturing pelagic forage fish. Many large, piscivorous (fish-eating) species sport a nice set of sharp teeth. Filter feeders, like adult menhaden, have modified gills used to sieve phytoplankton (microscopic single-celled algae) from the water column.

Understanding the specific feeding adaptations of a species is necessary to give scientists a complete picture of critical aspects of the species' biology. Though diet information is not always used quantitatively in a stock assessment model, it is valuable to consider when reviewing the applicability of data for use in the model. For example, many fishery-independent research programs use bottom trawls to conduct their survey, including several that collect bluefish data. Bluefish are fast-swimming, pelagic piscivores and are therefore unlikely to be captured frequently by a bottom trawl. If they are captured, bluefish tend to encounter the gear as it is being set or retrieved. A bluefish abundance estimate, or diet data derived from bluefish samples, resulting from such a survey must be carefully considered. The utility of a survey index in an assessment depends on how well the index reflects the actual stock being assessed. A survey index catching only juveniles or rare encounters does not provide an accurate picture of the adult portion of the population.

The use of multispecies and ecosystem-based models to analyze complex ecological and fishery interactions in marine ecosystems is becoming more common. Multispecies models are often extensions of traditional single-species models, but add descriptions of **trophic interactions** (i.e., feeding/predator-prey interactions) among a group of species to the data types typically used in stock assessments. Ecosystem models go a step further, adding environmental variables (e.g., temperature, oxygen, plankton production) in a series of sub-models to describe interactions among the environment and all species found in a particular **ecosystem**.

The bluefish has a streamlined body, a large powerful tail, and strong jaws with sharp teeth – ideal for capturing prey in the open ocean.

Tautog is found near structure, such as reefs, and eats barnacles and other shellfish. Tautog is stockier than bluefish and has a compact, powerful jaw suited for crushing the shells of its prey.

Reproductive Biology

Reproductive biology describes strategies employed by fish to contribute to future generations. Successful spawning requires the fertilization of eggs from females by gametes from males (sperm or milt). Fish species exhibit a variety of courting behaviors to maximize mating success. During annual spawning seasons males and females become "ripe" at the same time so that individuals maximize their opportunities for successful reproduction. Spawning periods may also coincide with periods of high prey abundance for newly hatched larvae to feed upon.

Most fish species have two separate sexes, male and female. However, some species are **hermaphrodites**, functioning as both males and females during certain phases of their life cycle. **Synchronous hermaphrodites** are functional as both male and female at the same time and have the capacity to produce both milt and eggs. **Sequential hermaphrodites** switch sexes. Black sea bass, for example, are **protogynous hermaphrodites** that begin life as a female before transforming into a male. Northern shrimp are **protandrous hermaphrodites**, maturing first as a male and then transforming to a female at roughly three and a half years of age.

The number of eggs a female fish or shellfish produces over time is referred to as **fecundity**. The fecundity of an individual changes with its age, size, and the environmental conditions it experiences. In general, larger, older individuals have the greatest fecundity. Species fecundity is usually inversely related to the amount of parental care given to offspring. For example, red drum is a prolific spawner, with large females capable of producing nearly two million eggs in a single season. They are also **broadcast spawners**, distributing gametes along beach surf zones, near inlets and passes, and in major rivers. They are called broadcast spawners because both males and females release their gametes into the water column where fertilization occurs. Eggs then hatch after 24 to 36 hours and newborn larvae are left to fend for themselves as currents carry them into estuarine nursery areas. Other species like Atlantic herring and winter flounder produce adhesive, demersal eggs (i.e., sticky eggs attached to the bottom or bottom vegetation).

Spiny dogfish, on the other hand, bear live young from eggs that develop and hatch within the female. Females first reach sexual maturity at eight years of age and have a two-year gestation period. Female spiny dogfish have a litter of only two to 15 pups once every two years.

Striped bass, Atlantic sturgeon, and American shad are **anadromous** species. Young of anadromous fish are spawned in freshwater, then move to brackish and marine waters for most of their life cycle before returning to freshwater as mature adults to spawn. American eel are **catadromous**. They spend most of their life in freshwater and return to the ocean to spawn. Anadromy and catadromy are specific life history strategies falling under the broader category of **diadromy**, which describes all reproductive strategies requiring migration between salt and fresh water to complete the reproductive cycle.

Stock assessment scientists use their understanding of fish reproductive strategies in a number of ways. Knowledge of a species' specific spawning needs (habitat, water quality, etc.) can be used to evaluate available spawning habitats and their capacity to support successful reproduction. The fecundity of a species provides information on the potential rate for populations to rebuild. Species producing low numbers of young (e.g., spiny dogfish) often require more time to recover from a period of low abundance; species with high fecundity (e.g., striped bass) may have greater rebuilding potential. Certain species form large spawning aggregations that are particularly vulnerable to fishing gear. Identifying time periods and geographic areas of high vulnerability allows scientists to understand catch and survey data, and also consider the impacts of fishing when the population is most vulnerable. Also, fecundity estimates are used to generate **biological reference points** such as eggs per recruit (more on this in Chapter 7).

What species do you think produces the most eggs/year?

- **Atlantic Herring**
- **Horseshoe Crab**
- **Spiny Dogfish**
- **Striped Bass**

If you chose striped bass, you are right! Striped bass produce anywhere from 500,000 eggs (6 year old female) to 3 million eggs (15 year old female) a year.

How do others rate?

Female horseshoe crabs produce about 90,000 eggs per spawning season, while female Atlantic herring produce anywhere from 30,000 to 200,000 eggs per year.

Spiny dogfish give birth to live young, so they have the lowest fecundity, bearing 2 - 15 pups per 2 year gestation period.

Habitat and Migration

Habitat is all of the living and non-living components necessary for the survival and reproduction of a particular organism. Habitat is usually described in terms of major physical features, often vegetation or bottom substrate, in a particular area within an ecosystem. Habitat definitions may be broad (wetland habitat, marine habitat) or more specific (cobble bottom habitat, cold-water coral reef habitat). These descriptions identify features that are important for resident species.

Fish have specific habitat requirements during different life-stages. For example, anadromous fish like striped bass and American shad require freshwater to spawn. These species move into rivers and streams to spawn, and return to saltwater habitats after spawning. Horseshoe crabs spawn on sandy beaches with little wave action. When these and other essential habitats are degraded, fish stocks are at increased risk because there is insufficient habitat to support reproduction and growth. To protect and manage fish stocks, managers must understand habitat requirements because they directly affect a fish population's productive capacity. Managers must also account for other uses of a habitat and their impacts on fish populations.

Human development in close proximity to fish habitat is directly linked to problems causing habitat loss and degradation. For example, coastal wetlands serving as juvenile nursery grounds for many species have been lost or negatively impacted by increasing coastal development. Poor estuarine water quality, often linked to agricultural production and growing human populations, results in harmful algal blooms, large areas of oxygen depleted waters (**anoxic zones**), fish kills, and loss of aquatic vegetation. Dams prevent anadromous fishes from returning to spawning grounds and completing their life cycle. Also, fishing gears like bottom trawls and dredges disrupt habitat through direct disturbance of bottom substrates, vegetation, corals, and other structures. State and federal marine fisheries agencies along the Atlantic coast work to address these challenges to fish habitat.

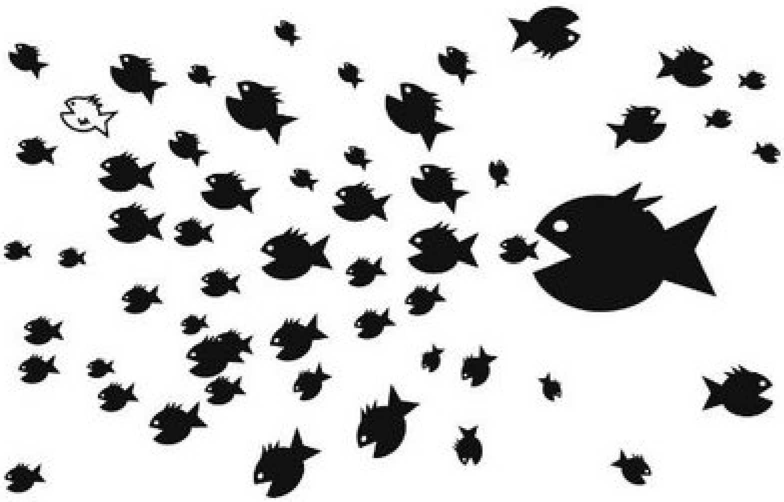
Different species have very different habitat needs. Photos from top to bottom: Juvenile blue lobster (NOAA/Dept. of Commerce); horseshoe crabs (S. Florida Water Management District); tautog (MA Division of Marine Fisheries); and migrating river herring (NOAA/Dept. of Commerce)

Commission stock assessments and management plans review the habitat needs of assessed species to incorporate important habitat considerations into management strategies. Typically, these reports contain information on spawning, nursery, and adult habitat requirements. A clear understanding of habitat requirements allows managers to evaluate the relative contributions of fishing or habitat degradation to the decline or recovery of fish populations and account for habitat considerations in proposed management measures.

Natural Mortality

Natural mortality refers to the loss of fish from a population due to all causes other than fishing or other impacts from human activity. Natural mortality rate (M) refers to changes in numbers of fish over time.

Natural mortality rate varies throughout the life of a fish. Larval fish typically experience extremely high natural mortality rates, juveniles have moderate rates, and adults experience low natural mortality. Natural mortality is difficult to measure directly. There is, however, a loose relationship between natural mortality and fish life history. In general, fish with early maturity, a fast growth rate, and short lifespan have high natural mortality (e.g., anchovy, mackerel, herring). Fish that mature after several years, have a slow growth rate, and live longer have lower natural mortality rates (e.g., tautog, sturgeon, spiny dogfish).



Chapter 3: "Life History and Biology" Summary

Information describing the specific biological and life history characteristics of fishes is important in assessing populations and managing stocks. Key elements include:

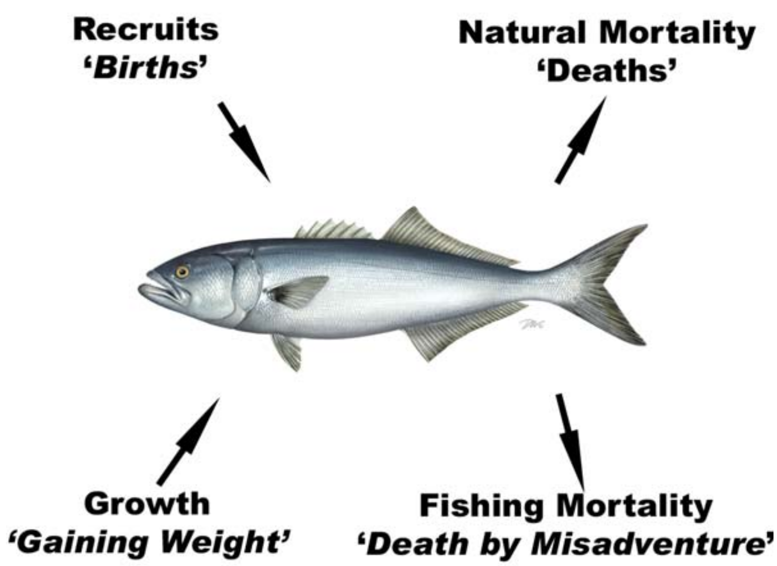
- **Age & Growth:** Age is typically determined by counting rings on scales, otoliths, or spines. As fish age and approach maximum size, their growth tends to slow.
- **Feeding:** A critical point in a fish's life occurs during the larval stage when it must capture its first meals of plankton. As juveniles and adults, fish exhibit a wide variety of feeding strategies.
- **Reproduction:** Fecundity, or egg production, is the most important factor in fish reproduction. Understanding the life cycle of a fish species is also critical, especially if it moves between fresh and saltwater during different life stages.
- **Habitat:** Loss of habitat and water quality significantly affects the health of fish stocks. Habitat considerations need to be included in management plans.
- **Natural Mortality:** Natural mortality (M), or death by natural causes, varies by species and fish age. Although challenging to determine, M is critical and therefore incorporated into most population dynamics models.

In this chapter you will learn:

What affects the size of a fish population.

About recruitment, growth, and mortality parameters.

Population size is determined by the amount of new individuals coming in, new growth in the weight of existing individuals, and the amount of old individuals removed from the population. In the simplest example, birth and growth add to the population and death subtracts from the population. Since all three factors act in unison, population size is constantly changing, or *dynamic*. Therefore, the study of populations and factors affecting them is called 'population dynamics'. The goal of fisheries stock assessment is to measure, or *assess*, the magnitude of additions and subtractions in order to estimate stock size. Fisheries stock assessment involves describing and understanding the basic dynamics of a particular fish population or stock. It also involves estimating various numerical quantities called **parameters** used to describe the population and its dynamics. **Recruitment** is one of the most important fisheries population parameters to estimate. Recruitment is the number of fish born within a given time period that survive to the juvenile stage. It is typically described in terms of 'annual recruitment', the number of survivors in each year, also known as a 'cohort' or 'year-class'. **Mortality** is the number of fish dying within a given time period. The net impact of recruitment and mortality determines the overall population abundance, the number of fish alive at a particular time. **Growth** in the population occurs as fish increase their lengths and weights. Growth influences the total **population biomass** (the total weight of all fish alive at a particular time). Although recruitment, mortality, and growth may differ among species, for any population these basic elements apply. As births occur, the population increases in numerical abundance. With new growth, the population increases in weight. As deaths occur, the population decreases in number and in weight.



In most instances, population parameters are estimated on an annual basis. Common techniques or 'modeling approaches' available to scientists for estimating population parameters are reviewed in Chapter 6. However, understanding the specific models and details of Chapter 5 will be made easier by first considering the basic concepts of populations and population dynamics. For this next section we will consider a population that is closed (i.e., there is no emigration or immigration).

Recruitment

Recruitment has multiple meanings in the vocabulary of fisheries science. There is recruitment to the population, which refers to births, and there is recruitment to the fishery, which means becoming vulnerable to a particular size or type of fishing gear. In this section we are concerned with the first usage, birth. The second usage will come into play in later sections describing population models and management evaluation.

Recruitment is the mechanism by which populations increase in abundance. In the life cycle of fishes, adults spawn eggs that hatch into larvae that develop into juveniles which then grow and mature into adults. Recruitment could therefore refer to several things: the number of eggs spawned, the number of larvae hatching from those eggs, the number of juveniles which survive from the larval stage, or the number of individuals surviving to any particular age. However, most stock assessments evaluate recruitment as the abundance of juveniles at age 0 or age 1. Usually, the properties of the population model being used and the nature of available data determine the life stage at which recruitment will be measured or assessed.

An 'age 0' fish is defined as a fish in its first year of life (aka 'young of the year').

An 'age 1' fish has survived its first winter and is in its second growing season.

Growth

The mechanism by which populations increase in biomass is growth. Individual fish grow in both length and weight, and the two are closely related, but growth in weight is more useful in understanding the population. Once individuals are added to the population through recruitment, they increase its biomass through growth. Knowledge of overall population biomass is important for both evaluating the stock's condition and evaluating a fishery's performance.

Mortality

Fisheries science separates **mortality** into two components -- fishing mortality and natural mortality. Natural mortality (M) is an inherent life history trait that was introduced in Chapter 3. **Fishing mortality (F)** encompasses all deaths from fishing activities, whether from direct removals (those fish which are caught and kept) or indirect removals (those fish which are not kept but nonetheless die from fishing activities).

While direct fishing mortality is easy to define, indirect removals become a bit more confusing. In the broadest sense, all indirect removals can be considered discards, since they represent fish that are caught in some way but not kept. However, two terms are often used: bycatch and discards. Bycatch refers to fish from one species that are caught while fishing for a different species, while discards refer to fish that are caught but not kept for some reason. The distinction between bycatch and discards is not always clear and often varies between regions and even fisheries. The difference between the terms may best be explained by a simple example considering stocks of two hypothetical species, red fish and blue fish. If a fisherman tries to catch red fish (i.e., "targeting" red fish), but catches a blue fish, then the blue fish would be considered 'bycatch'. Bycatch can be further divided into fish that are retained and fish that are discarded. If the fisherman catches a redfish he does not wish to keep and returns it to the water, then it is considered a discard. Such definitions become even more confusing in practice, since few fisheries truly target a single species. However, from a population dynamics perspective, it is only important that the stock assessment account for the total fish removals from the population. The various categories simply provide a way of tracking many components of a fishery.

Based on generalizations about species life history characteristics described in Chapter 3, several methods have been used to provide rough estimates of natural mortality. While the values for natural mortality obtained from these methods may not be exact, they do provide a relative sense of the rate of natural mortality. Natural mortality is influenced by other life history characteristics, such as species maximum age, growth, and female maturity.

In stock assessments, the removals from a fish stock are divided between natural mortality (*M*) and deaths caused by fishing, fishing mortality (F). The sum of fishing mortality and natural mortality is termed **total mortality (Z)**, that is, Z = F + M. Some common stock assessment methods require natural mortality as an input parameter. Also, most models assume natural mortality is constant over the life of a fish. Current assessment methods are often able to incorporate changes in natural mortality rates at different ages or times. However, these data are often limited or unavailable and require additional research. Recently, multispecies models have been developed incorporating feeding interactions of predators on prey, and break down natural mortality into two categories: mortality from predation (**predation mortality – M_2**) and mortality from other causes (starvation, disease).

Chapter 4: "Population Concepts" Summary

- The **size of a fish population** is determined primarily by the positive effects of growth and recruitment, and the negative effect of mortality, both natural and due to fishing.
- **Parameters** are numerical values describing a fish population and how it is changing.
- **Fishing mortality** includes targeted harvest, and bycatch and discards.
- **Total Mortality** (Z) equals fishing mortality (F) plus natural mortality (M). Z = F + M.

Chapter 5. Stock Assessment Models

In this chapter you will learn:

How stock assessment models describe the characteristics and behavior of fish stocks.

What the assumptions, data needs, and outputs are for several types of stock assessment models, and why they are useful in addressing different objectives.

Up to this point, we have focused on understanding the individual factors (growth, recruitment, natural and fishing mortality, reproductive biology, etc.) affecting fish stocks and the available data sets (fishery-dependent, fishery-independent, and life history) used to analyze these factors. With all of this information, how does one make heads or tails of it to determine the status of a fishery resource?

This is where stock assessment models come in. Using the available information, a stock assessment model estimates the absolute or **relative abundance** of a species and the exploitation rate of a stock. Often these models are viewed as 'black boxes' that scientists plug numbers into and get answers stakeholders have to live with, regardless of stakeholders' understanding of the science or the answer it provides. The truth is, fisheries scientists have been working to develop rigorous stock assessment models capable of handling the inherent difficulties of fisheries data while representing the complexities of fish population dynamics. Fisheries scientists do not have the luxury of conducting simple, controlled experiments to learn how the lobster or striped bass populations on the U.S. East Coast are doing – yet they still have to provide timely and accurate information to managers on stock status so appropriate management actions can be made. Assessments use available fisheries data to make the best estimates of abundance and fishing mortality possible. The available types and amounts of data are typically less than ideal. And, it is challenging to develop estimates in light of management regulations that change over time and/or across the range of the stock, year-to-year environmental fluctuations affecting fish behavior and reproductive success, and the unique set of factors associated with each fish stock.

No single method will provide the best answer for all stocks, and for that reason, different types of assessment models have been developed. This chapter presents an overview of the basic concepts in commonly utilized stock assessment models. It also provides a review of data requirements, statistical assumptions, advantages, and disadvantages of each modeling approach. The classes of models are covered in order of increasing complexity and include age-aggregated models, such as biomass dynamic models (aka surplus production models) and age-structured models, such as **cohort analysis**, virtual population analysis, and statistical catch-at-age. *Global models* lump the combined effects of recruitment, growth, and mortality on a population. *Structural models* break the population into age-classes and allow researchers to analyze the population in terms of abundance and mortality rates-at-age.

In recent years, models accounting for predator-prey relationships among trophically-related species and other environmental factors have been developed for use along the Atlantic coast. These multispecies and ecosystem models add to the level of complexity incorporated into stock assessments. With added complexity, scientists need additional data and expertise to successfully run these models.

This chapter provides a brief introduction to modeling approaches. For the curious reader, there are several texts available providing more detailed descriptions of individual stock assessment modeling approaches (see Useful References & Reading, p. 54).

Introduction to Mathematical Models

A **model** is a mathematical relationship used to describe a process. For example, F = ma is Newton's second law of physics. It states that force (F) is equal to the mass of an object (m) times its acceleration (a). In other words, if we accurately measure both the mass of an object and its acceleration, then we can predict its force. And, if we are able to measure all variables in the equation - the force of an object and its mass and acceleration, then we can determine if the observed force is equal to what is expected (predicted) using the equation above. If there is a difference in the two values, then we must examine the possible reasons for the difference.

Perhaps we made an incorrect measurement of force, mass, or acceleration of the object. This is called measurement error or observation error. Another possible scenario is the model fails to account for all processes affecting the result, which is called 'process error'. For example, what if we dropped a ball from a roof top, measured its force upon impact, and found it to be different than predicted by F = ma? In our search to find all possible explanations, we would learn this simple model does not take into account the friction encountered by the ball as it traveled through the air. We could either change the model to better reflect reality or we could go repeat the experiment in a frictionless chamber void of air.

Models incorporating changes over time are common in fisheries, so let's examine a mathematical model dependent on time. Say we just bought a machine that is supposed to fill 9 cans every minute. Since our supervisor bought the machine with that in mind, we want to test this claim. We observe the total number of cans filled at 5, 10, 15, and 20 minutes of production to see if the machine lives up to its promise. The formula we will use to describe this process is FC = 9(t). This translates to, "the number of filled cans is equal to 9 (cans/minute) times the number of minutes elapsed (t)". The table below contains the number of cans we would expect to be filled based on our model and the results of our observations from each of the observation periods. Our model worked pretty well, but it did not predict exactly what we observed – which is not surprising! The real world is always a little messy, and no model is ever truly perfect!

Time (min)	Filled cans - predicted	Filled cans - observed
5	45	51
10	90	82
15	135	148
20	180	169

Sometimes a table isn't the easiest way to view results. Plotting results on a graph can give us a visual sense of what's going on. In this case, we are trying to see how close our observations were to our predictions, so we put two lines on our graph (Figure 1).

The graph includes a horizontal axis (x-axis) representing time and a vertical axis (y-axis) describing number of filled cans. The point in the lower left hand corner of the graph represents the observation of 51 cans filled after 5 minutes. The point is labeled by its position on the x-axis followed by its position on the y-axis (x, y). Each point on the graph below depicts observations of (5,51), (10,82), (15,148), and (20,169). The solid line represents the expected results from our model. By extension, our model can be used to estimate the number of cans filled by the machine at any time.

In this graph, the observed data points do not exactly coincide with what was predicted by our model. When looking at the predicted outcomes, we can see that even though it does not exactly match up with the data, it does a reasonably good job of describing the observed outcomes. A model's "fit" describes how well it predicts an observed data set.

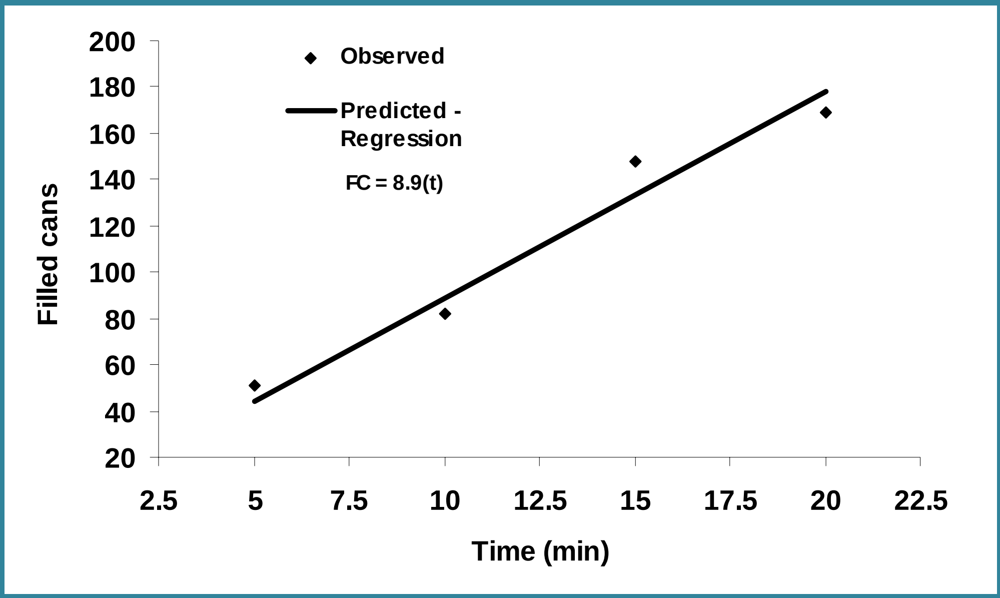


Figure 1. The horizontal axis of the graph (x-axis) represents time and the vertical axis (y-axis) is the number of filled cans. Each point represents the following data pairs (5,51), (10,82), (15,148), and (20,169). The line is the best fit of the regression that "predicts" the relationship of the expected number of filled cans for a given time, following the formula,

Filled Cans (FC) = 9 x Time.

Here's how we fit a line to the observed data points. The equation for a line is y = mx + b. In this example, x is time, y is the predicted number of observed cans, m is the slope (or steepness) of the straight line, and b is the y-intercept where the predicted line would cross, or intercept, the y-axis.

We also know that no cans will be filled at 0 minutes; therefore, we can refine the model so the line passes through the point (0,0).

It is important to note the same line can be fit to two different data sets. In Figure 2, there are two different sets of data points (black and red) predicting the abundance of recruits at a particular stock size. These data sets have different levels of variability – high (black) and low (red). The differences between the low variability data set and the stock-recruitment (SR) curve are much smaller than the differences between the SR curve and the black data points. The red data set with low variability is more precise; therefore, the expected outcome can be predicted with greater confidence than for the less variable data set.

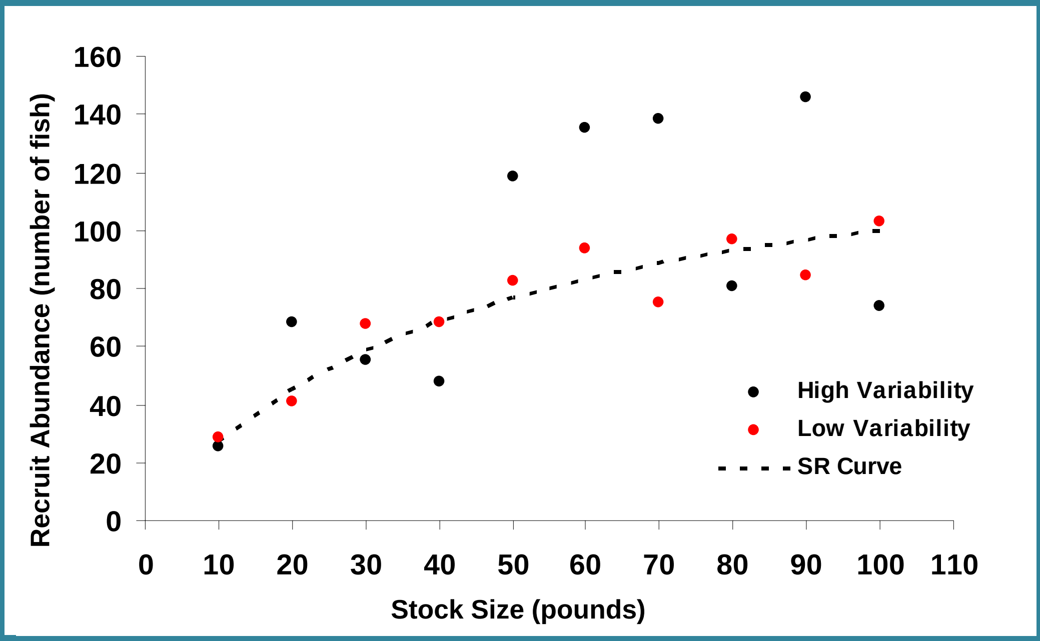


Figure 2. An example of how data with high (black) and low (red) variability can have the "same best fit" stock-recruitment curve (dashed line) – illustrating the need for providing estimates of uncertainty in assessments. The data set with low variability is more precise than the highly variable data set. We can predict the expected outcome with greater confidence for the less variable data set.

Catch Curve Analysis

Summary: **Catch curve analysis** was first developed in the early 1900s and is based on the observation that catches of a species decline as age or size increases. This makes sense, because once fish are fully recruited to a fishery the numbers in a cohort can only decrease with time – assuming no immigration or emigration of fish. To construct a catch curve, scientists plot the natural logarithm of catch of a cohort over time (see figures on the next page) or, alternatively, the natural logarithm of catch-at-age may be plotted from a single year. Converting raw data to the natural logarithm allows scientists to estimate a single mortality rate across all age classes. The slope of the regression line from the first fully recruited age-class to the oldest age observed in the catch provides an estimate of total mortality of the species.

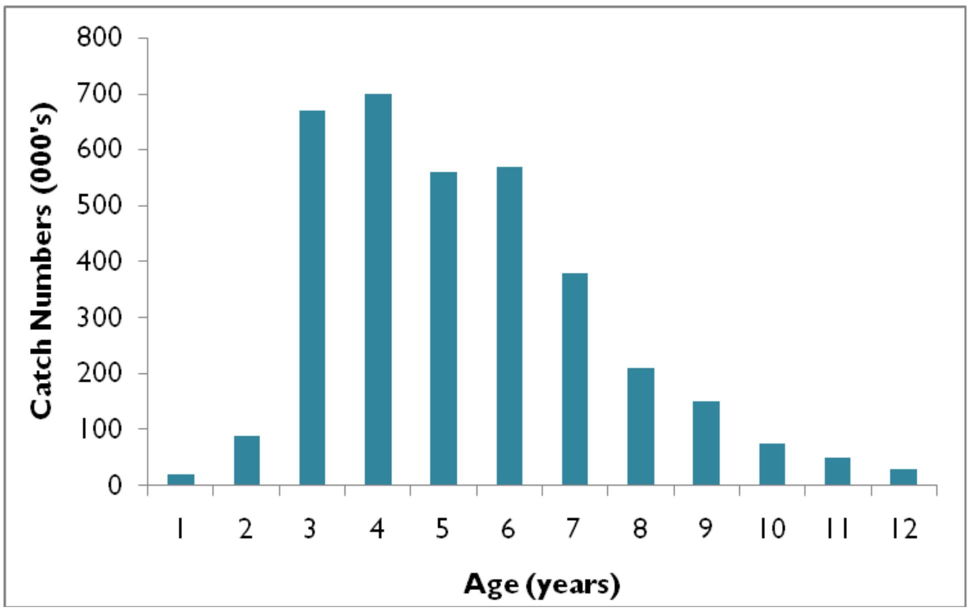
Utility: A simple model incorporating age-structure and accounting for the age-specific impacts of gear selectivity.

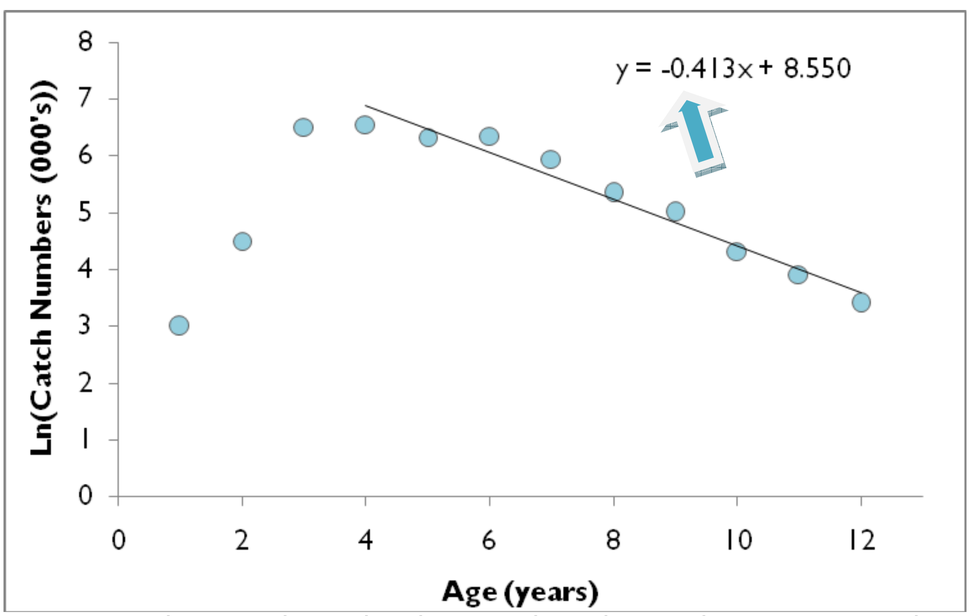
Assumptions: No (or minimal) immigration or emigration, constant selectivity of fish at and above the first fully recruited age-class, constant fishing mortality, catchability, and natural mortality. In addition, within-year catch curves require that there is no trend in recruitment over time.

Data Requirements: Catch curves require representative catch-at-age data (i.e., the number of fish caught at each age) collected in a single year or for a single cohort over several years.

Outputs: Generates estimates of total mortality (Z). If estimates of M are available, F = Z – M. Estimates of *Z* depend on the choice of the first fully recruited age-class to the fishery, which may change from year to year.

Commission Species Assessed by Model: Recently, catch curve analysis was used in the Commission's tautog stock assessment by several states to estimate mortality rates in their state's waters. Though catch curve analysis is a simple and useful tool for estimating mortality rates if the above assumptions are met, one should employ caution when comparing catch curve estimates of F or Z to estimates from other models. One reason for this is that different models estimate mortality rates on different age-classes of fish. The take home lesson is that when comparing estimates of fishing mortality from different stock assessment models, one must be sure to compare "apples with apples".





Top chart shows raw catch-at-age data, while bottom chart depicts the natural logarithm of these data. Catch-at-age data are used to provide an estimate of the total instantaneous mortality rate, which is equal to the slope of the linear regression line, Z = 0.41, and can be equated to a 34% annual mortality to the stock.

Surplus Production Models

Summary: **Surplus production models** are among the simplest stock assessment models commonly employed by fisheries scientists to model population dynamics and track biomass. These models are designed to characterize the dynamics of a stock in terms of changes in total biomass without regard to age or size structure. They are generally used to derive estimates of historical abundance and mortality. A disadvantage of surplus production models is they cannot provide possible explanations for changes in abundance, because the changes in standing stock biomass, recruitment, and mortality are all examined collectively.

Utility: Used to assess stocks lacking information on age or size structure. Also, used as a secondary model to corroborate results from age- (or size-) structured models. Biological reference points can be estimated directly from the estimated population parameters.

Assumptions: Stock is undifferentiated (e.g., no age, size, or gender differences). Also, the catch is assumed to be large enough to signal a response in the population and catch rates are linearly related to stock abundance. This linear relationship implies the catchability of the species does not change over time. Another important factor affecting how well a surplus production model will fit available data is the contrast in the data over the time series. Contrast in the data means the CPUE or abundance index time series should have both declining and increasing periods of abundance. A simple "one-way" decline in an index or CPUE series is common to many fisheries data sets but does not provide information on a population's ability to increase during favorable conditions. An additional consideration for surplus production models is if the data display sufficient coverage (how well do the data encompass the high and low ranges of stock size?). Good coverage and contrast in the data are necessary to produce reasonable parameter estimates.

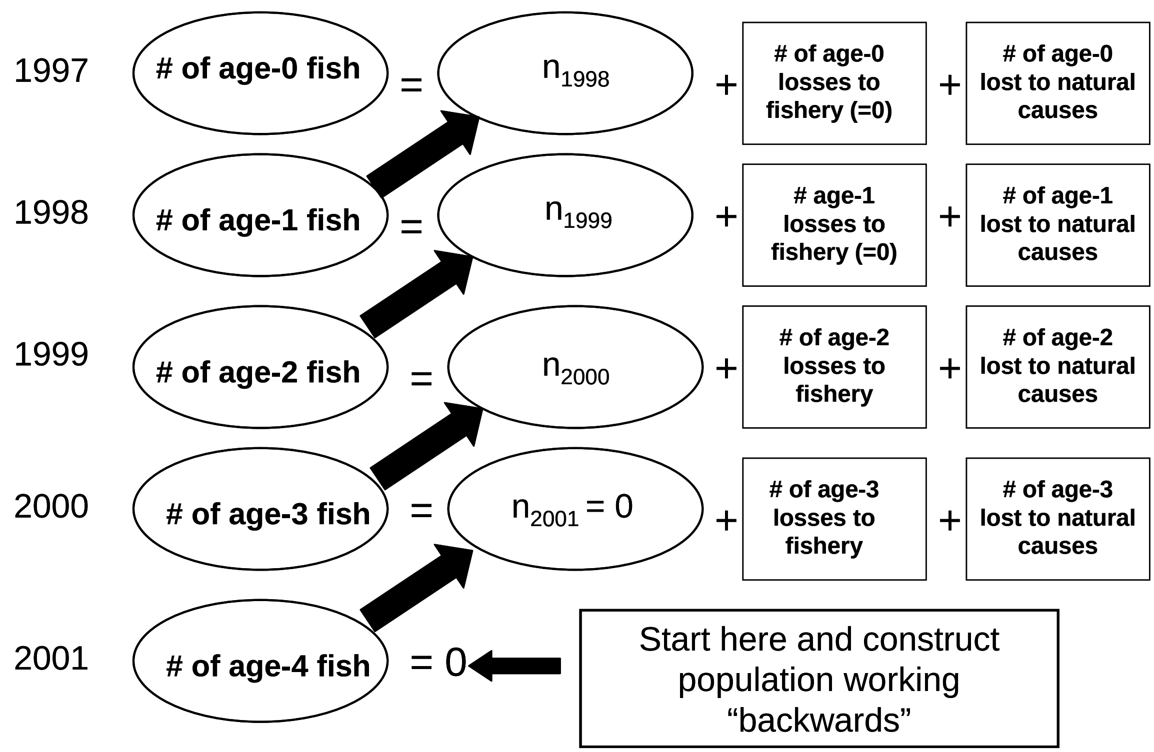
Data Requirements: Total catch is assumed to be known without error. Also, an index of relative abundance of the stock (not just a portion of it) is often required. Surplus production models do not require an estimated or assumed value of natural mortality in order to estimate exploitation rate.

Outputs: Estimates of stock size (generally in biomass), exploitation rate, and biological reference points (MSY, $\mathbf{B_{MSY}}$ (the biomass resulting in MSY), and E_{MSY} (the effort resulting in MSY)).

Commission Species Assessed by Model: A surplus production model is used as part of the Commission's northern shrimp stock assessment and was used in the past to assess bluefish. Surplus production models have also been used to assess Atlantic croaker.

Virtual Population Analysis

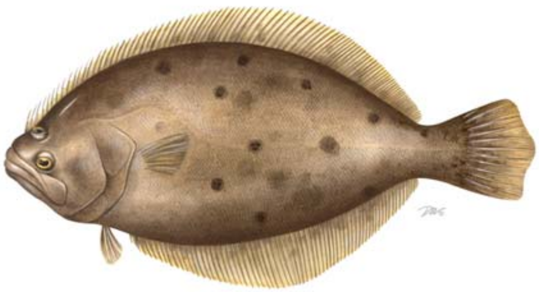
Summary: **Virtual population analysis (VPA)** is a method commonly applied to **catch-at-age** data to derive estimates of historical population size and fishing mortality. It is sometimes referred to as '**cohort analysis**' because the analysis is performed separately for each 'cohort' or 'year class' within the exploited component of the population. VPAs operate under the assumption that at some age no fish will be alive. Working backward in time from this terminal age to the youngest age it is possible to estimate the numbers of fish that should have been alive (this is the "virtual population"), if catch-at-age and natural mortality rate are known. The equations are fairly simple to understand, but the solutions to them are solved iteratively rather than by a statistical procedure like least squares regression. "Iteratively" means in order to find an answer, one starts with a best guess of the unknown value you want to find a solution for (e.g., number alive at the beginning of this year). This is done repetitively backwards through time to get abundance estimates of each age for the cohorts in a fishery. This iterative or recursive process is necessary because there are too many parameters compared to the observations in the VPA equation to solve statistically without additional information.



Virtual population analysis (VPA) for a cohort of fish with a maximum age of 4 that enters the fishery at age 2. VPA starts with the assumption that no fish live past a certain age (in this example, no fish live beyond age-3). If natural mortality and catch-at-age for the stock are known, then VPA can iteratively (by repetition) estimate the numbers of fish that must have been alive to support those losses and historical fishing mortality levels. Note the fishery does not catch age-0 and age-1 fish.

Utility: Age based models investigate age differences in contributions to stock dynamics. For example, the effects of large and small cohorts on stock size, the time between recruitment and maturity, and the contributions of fish of different ages to the catch.

Assumptions: Catch-at-age is known without error – this means all removals must be accounted for and reliable methods for age estimation are available for the stock. Catch-at-age data are needed for all years of the analysis. A common problem with VPAs is several cohorts will not have reached its maximum age in the last year of the model. Therefore, we lack information on mortality of younger fish in the final years of an assessment. Thus, we know the least about cohorts contributing to future abundance, which is often the most desirable information from a fisheries management perspective. Scientists use research surveys, catch and effort data, or tagging data to estimate fishing mortality for the most recent years, which can be used to estimate abundance in the 'incomplete' cohorts. The better this additional information is, the better our estimates of abundance in the last years of the assessment.



Data Requirements: In its simplest form, catch-at-age data are required for each year of a VPA-type analysis. As one might expect, the VPA has evolved over time. Originally, the model did not include natural mortality, though it was added in a later modification. There have also been improvements to allow the incorporation of auxiliary data, such as fishery independent surveys, to 'tune' the VPA population estimates.

Outputs: The basic outputs are cohort abundance at age and fishing mortality estimates.

Commission Species Assessed by Model: VPA is used in the stock assessments of several Commission managed species including red drum, summer flounder, tautog and winter flounder.

Retrospective Patterns in Fisheries Stock Assessment Models

Fisheries scientists use stock assessment models to estimate fish abundance and fishing-related impacts to stocks because these variables cannot be directly measured. Models have been very useful in estimating biomass, fishing mortality, and other parameters for consideration in management decisions. However, some inherent limitations of models necessitate an understanding of their outputs and how this information can be used properly to make sound management decisions.

Virtual population analysis (VPA) is a model used extensively in fish stock assessments. It utilizes catch-at-age (age-structured) data to back-calculate stock sizes and fishing mortality of different age classes (i.e., fish grouped by age). The model has difficulty in estimating the terminal (or most recent year's) parameters, such as fishing mortality, spawning stock biomass, and abundance. This sensitivity to the terminal parameters can be assessed by performing a retrospective analysis. Through this analysis, the model is calculated by going back one year at a time and removing the most recent year of data to see what the model would have estimated for stock size and fishing mortality for each previous year, given data only through that year. In some cases, a pattern is detected where the previous years' estimates of fishing mortality/abundance/spawning stock biomass are over- or underestimated; this is called a 'retrospective pattern', or 'retrospective bias'.

Retrospective patterns are most problematic for fisheries management when fishing mortality is consistently underestimated and abundance is overestimated. A well-known example of this extreme case was seen in the collapse of Newfoundland cod. It is also possible for the pattern to occur in the opposite direction, where fishing mortality is overestimated and abundance underestimated. Patterns may also switch back and forth between the two types of biases.

Possible Causes

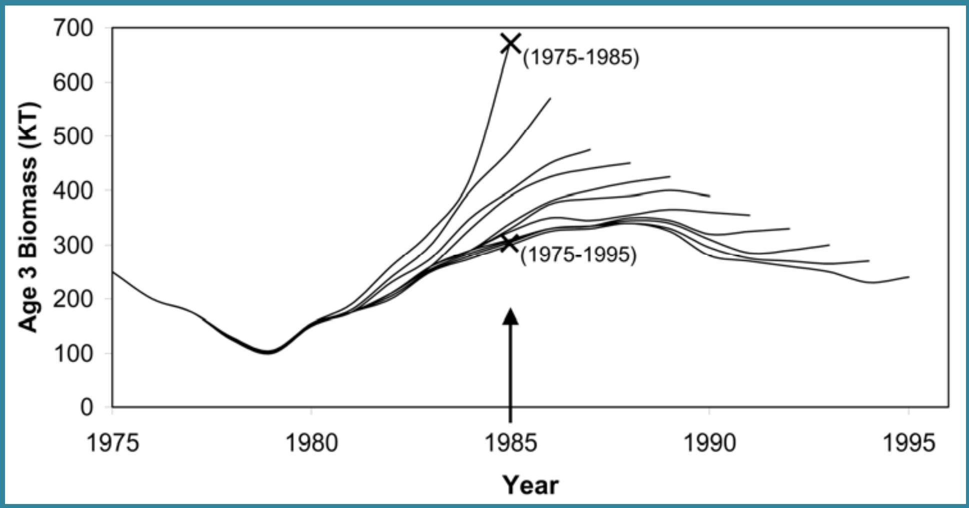
It is very difficult to identify the underlying problem of retrospective patterns because there are numerous reasons as to why they arise. Some possible causes include:

- A change in natural mortality rate in nature not accounted for in the assessment
- An error or bias in ageing older fish
- A bias in catch estimates that has changed over time
- An error in sampling
- Under-reporting of landings or discards
- The grouping of oldest age classes

While retrospective patterns have been observed in most age-structured assessments, they tend to be more apparent in VPAs than in forward-projecting statistical catch-at-age models.

Addressing Retrospective Patterns

Since there are many possible sources of retrospective bias, it is necessary for each case to be evaluated individually. There are techniques for making corrections to retrospective patterns, such as quantifying the amount of retrospective bias for possible adjustment of quota levels. However, this may not be advisable as patterns are not fixed and could switch to an opposite trend, or even disappear. At a minimum, retrospective patterns may be considered as an additional source of uncertainty in the assessment because they are indicative of inconsistencies in the data. Once managers are notified of retrospective patterns, the wisest approach is to employ precautionary management regulations such as lowering quotas.



The above chart depicts a retrospective analysis of a fictional fish stock showing a retrospective pattern in age 3 biomass estimates, where previous estimates (using data from 1975–1985) have drastically overestimated biomass. For example, the biomass estimate for 1985 was approximately 700 kilotons (KT) using 1975-1985 data, whereas the estimate using data from 1975-1995 was only about 300 KT. The data set of longer duration provides a more accurate biomass estimate in earlier years.

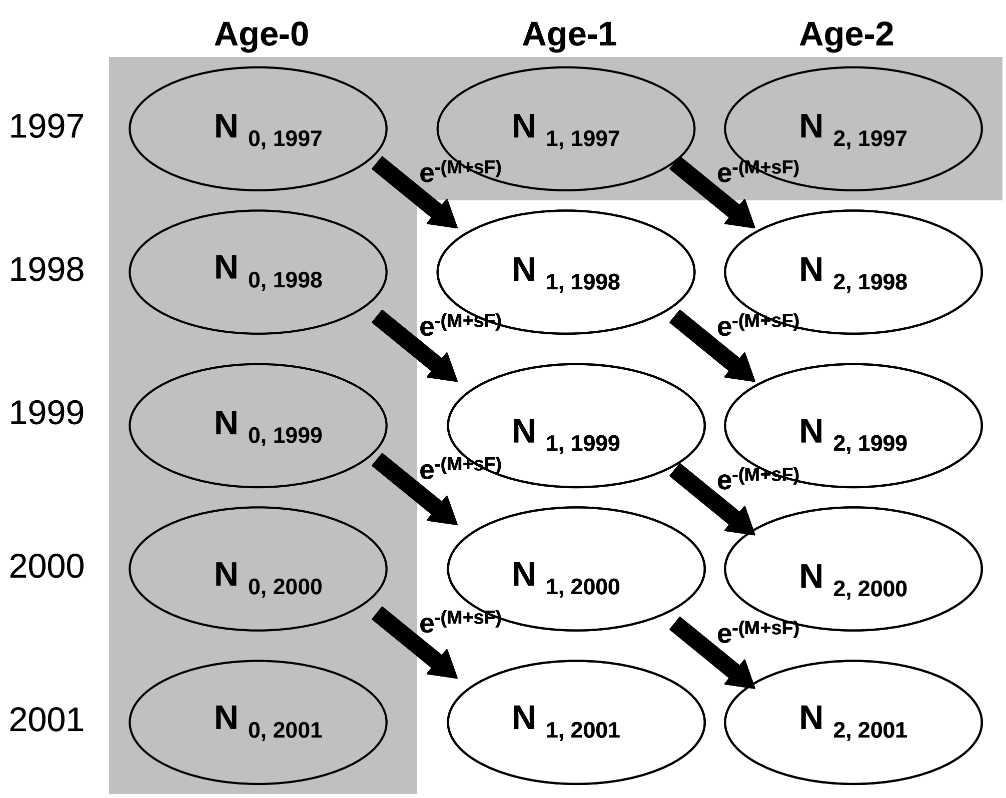
Statistical Catch-at-age

Summary: **Statistical catch-at-age analysis** is similar to VPA because it utilizes catch-at-age data to derive estimates of historical population size and fishing mortality. However, unlike VPA, model parameters estimated using catch-at-age analysis are done so by working forward in time, rather than backwards as is done in VPA analysis (see accompanying figure). One important distinction between these two age-structured assessment methods is that statistical catch-at-age analyses do not require the assumption that removals from the fishery are known without error. Although many fisheries have accurate accounting systems in place to document removals, in all fisheries there is some measurement error or unknown aspect to the catch. In statistical catch-at-age models, error in catch can be incorporated into the model.

Statistical catch-at-age models are very flexible and can have lots of parameters (10s, even 100s, or more!), but they have to estimate fewer parameters than observations, which permits the use of a statistical optimization routine (least-squares regression or maximum likelihood). This is the other major distinction between VPA and statistical catch-at-age analysis. Statistical catch-at-age models are fit by minimizing the difference between the estimated 'predicted' catch with the 'observed' catch, as well as the difference between the predicted and observed index of abundance. This is accomplished (with the help of computer power) by changing the model parameters until the 'fit' is best.

Utility: Similar to VPA models; however, since statistical catch-at-age models do not require catch-at-age is known without error, they might be better suited for fisheries without complete landings data or with fish that are difficult to age.

Assumptions: Does not require that catch-at-age is known without error, if error is specified or estimated. Many statistical catch-at-age models assume constant catchability and age-specific natural mortality (M) over time as well.



A schematic of how a **statistical catch-at-age model** works. The model estimates the numbers of recruits ($N_{0,year}$), the initial numbers-at-age ($N_{a,1997}$), fishery selectivity (s), and fully-selected fishing mortality (F) by fitting the predicted catch-at-age to the observed catch-at-age. Each cohort's survival over time is calculated based on the natural mortality (M) plus fishing mortality (F).

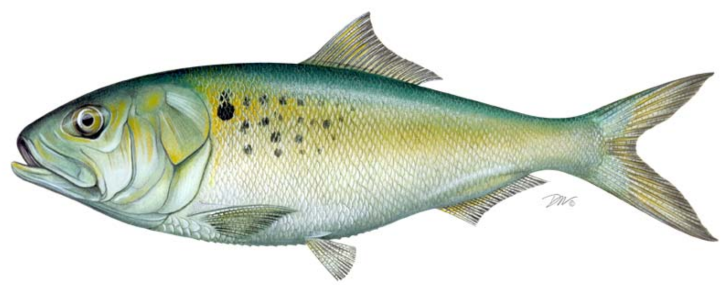
Data Requirements: Catch-at-age data and an index of abundance are the bare minimum data requirements. Additional information often incorporated into statistical catch-at-age models includes survey indices, effort or CPUE data, and length composition data. CPUE data from the fishery or surveys are often used to provide information on stock size.

Outputs: Estimates of initial abundance at age, annual recruitment, fishing mortality, fishery selectivity, and additional parameters as determined by available data and assessment needs.

Commission Species Assessed by Model: Species assessed using statistical catch-at-age models include Atlantic menhaden, Atlantic herring, and striped bass.

Multispecies Virtual Population Analysis (MSVPA)

Summary: Fisheries science and management has typically conducted stock assessments on a single species basis. One drawback of most fisheries stock assessment models is they assume a known or estimated value of *M* and keep it constant for all ages of fish and across all years modeled. In general, this is an oversimplifying assumption given that natural mortality rates are difficult to estimate.



The importance of natural mortality estimation in stock assessment models has motivated researchers to focus more attention on characterizing *M* in fish populations. Natural mortality occurs through a variety of causes, although predation is generally thought to be the dominant source of mortality. One approach to estimating natural mortality is to "link" multiple single-species analyses with feeding and food consumption data from trophically-related species. This method has been referred to as a multispecies virtual population analysis (MSVPA) that yields estimates of predation mortality (M_2, the component of a prey species' natural mortality attributed to predator species). The remaining sources of natural mortality (e.g., disease, lethal temperatures, lethal oxygen levels) are lumped together and called M_1. M_1 can be added to M_2 to get total natural mortality, or $M_1 + M_2 = M$.

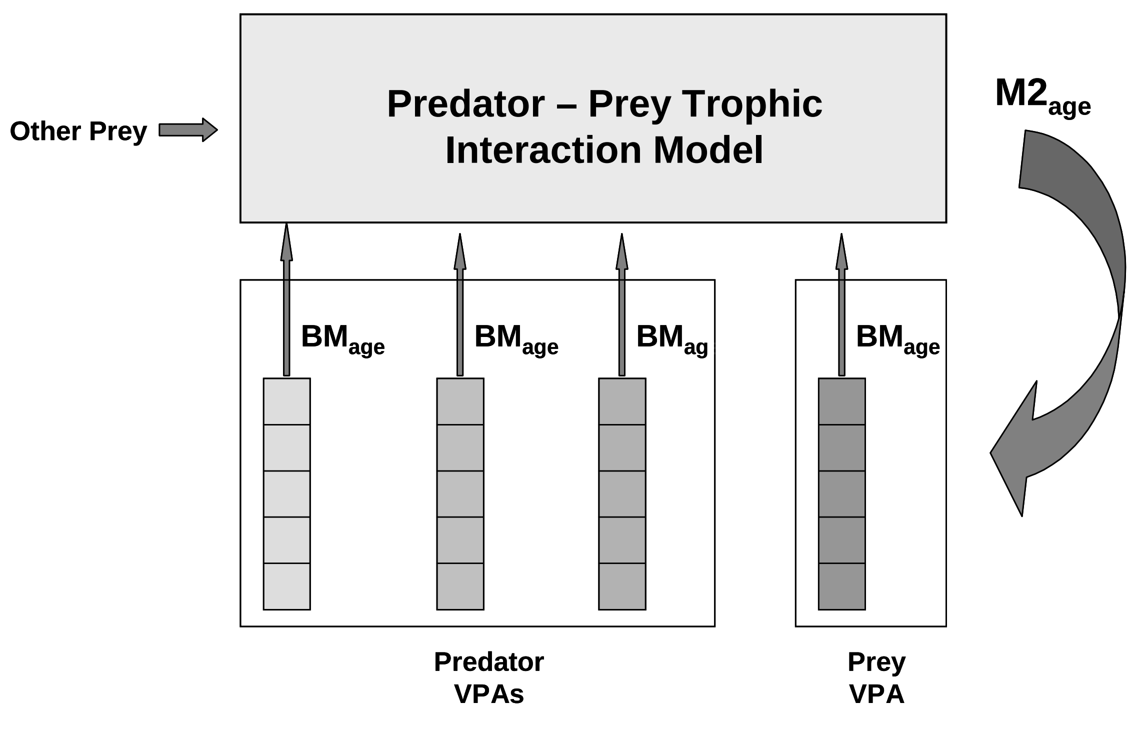
Utility: To compare predation mortality on a prey species with mortality from its fisheries, and/or to estimate age-specific rates of M.

Assumptions: MSVPA models have the same constraints as single-species VPA analysis, but also have assumptions regarding the predation model components (e.g., feeding behaviors of predators at different abundances of prey; size availability of prey; seasonal geographic location of predators and prey; and predator preferences for different prey types and sizes).

Data Requirements: The data requirements for an MSVPA vary according to the role each species plays in the model and the preferred model output (see figure on next page). If species' stock sizes are reconstructed using the MSVPA model, then these species are referred to as "full" MSVPA species. The data requirements for "full species" include catch-at-age in numbers, fishing mortality rates in the terminal year and for the oldest age class, non-predation natural mortality rates, predator consumption rates, body weights-at-age, and predator stomach contents. Within the MSVPA framework, it is possible to model species as "other predators" or "other prey" in cases where stock reconstruction is not necessary or possible given the available data, but these species are thought to be important components of the food web under study. For "other predators", the data requirements include minimum abundances in numbers, body weights, consumption rates, and stomach contents, while for "other prey", only minimum abundances in numbers and body weights are typically needed.

Outputs: The major difference between MSVPA model outputs and output from single-species models is that predation mortality is estimated for each age class. Currently, the estimate of predation mortality on Atlantic menhaden is used in the species' stock assessment to provide an improved estimate of natural mortality.

Commission Species Assessed by Model: The Commission has developed an Expanded MSVPA model (MSVPA-X) to investigate trophic interactions among three predator species (striped bass, weakfish, and bluefish) and a primary prey species (Atlantic menhaden). It is called "expanded" because the original MSVPA model design has been modified to handle the available data for this mid-Atlantic predator-prey complex. Several other prey groups are included in the model to provide a more realistic scenario of predation. Additional prey include, but are not limited to, croaker, spot, herring, lobster, and squid.



A schematic of the MSVPA-X developed for the Commission to conduct an assessment of the multispecies assemblage of a prey species (menhaden) and three predator species (striped bass, weakfish, and bluefish) to get age-specific estimates of predation mortality, M_2. The MSVPA begins by running a single species VPA for each species modeled and yields an estimate of biomass for each age class for all modeled species (BM_{AGE}). Biomasses are combined in the trophic model with diet data, until an estimate of M2 at each age is produced for the modeled prey species.

Tagging Models

Summary: Another method used to estimate population size, individual growth and mortality rates, and migration patterns in fisheries science is to physically tag fish and then harvest or recapture the tagged fish at a later time. Scientists carry out tagging studies to conduct or complement stock assessments. Tagging methods have been applied in several fisheries along the Atlantic coast and throughout the world (see side-bar).

Tagging studies can be separated into two very general categories: (1) studies where tagged individuals in population are killed upon recapture (a.k.a., tag-recovery studies) and (2) studies where tagged individuals are recaptured and released several times (a.k.a., capture-recapture studies). Tag-recovery studies where fishermen recover tags from harvested fish are typically viewed as fishery-dependent, since the data are obtained via fishing activities. However, it is best to use a fishery-independent sampling design to generate capture histories for tagged individuals in the capture-recapture approach. Tagging studies using electronic tags allow for real-time tracking or remote monitoring of fish.

Utility: These studies can provide estimates of mortality rates or population size (if assumptions are met) independently of assessments based on catch, effort, and survey data. Tagging studies are also conducted to investigate movement and migration of fish.

Assumptions: Standard assumptions of tagging models include: (1) the tagged sample is representative of the target population, (2) there are no tag-losses; or a known, constant fraction of tags from each cohort is lost and all tag-losses occurs immediately after tagging, (3) the time of recapture for each tagged individual is reported correctly, (4) all tagged individuals within a cohort experience the same annual survival and tag-recovery rates, (5) the fisherman's decision to return or not return a tag is independent of when the fish was tagged, (6) survival rates are not affected by the tagging process, or the effect is restricted to a constant fraction dying immediately after tagging, and (7) the fate of each tagged individual is independent of the other tagged individuals.

Data Requirements: Basic data for tagging studies include the number of fish tagged and the number of fish recaptured. This can be expanded to include multiple years (or other relevant periods) of tagging and tag recovery.

Various ASMFC species rely on tagging data to assess stocks. Photos from top to bottom: horseshoe crab (Sheila Eyler, USFWS); striped bass; red drum (Robert Wiggers, SC DNR); and Atlantic sturgeon (Albert Spells, USFWS)

Outputs: Tagging studies can estimate rates of fishing and natural mortality, exploitation rate, population size, survival, migration rates, and rate of recruitment to the population. In marine fishes, estimation of population size using tagging studies is difficult due to the large geographic ranges and migrations/movements typical of many species.

Commission Species Assessed by Model: Many Commission managed species assessments and monitoring efforts incorporate information from large-scale tagging programs (e.g., striped bass, black sea bass, horseshoe crabs, red drum).

ASMFC Stock Assessment Training Workshops

The Commission's Science Program organizes multiple stock assessment training workshops each year to meet the specific training needs identified as most pertinent to support Commission stock assessments. The Commission facilitates two levels of workshops for agency scientists. The first is a basic stock assessment training taught by Dr. Joseph DeAlteris of the University of Rhode Island that is usually offered every year. The second level of training workshops targets seasoned fisheries scientists interested in enhancing their analytical and stock assessment skills. Since 1999, the Commission has held ten advanced workshops covering a variety of topics including understanding sources of uncertainty in stock assessment, advanced modeling techniques, tagging study design and analysis, estimating natural mortality, new population modeling software, and research survey design.

Chapter 5: "Stock Assessment Models" Summary

- Stock assessment models are sets of mathematical equations and processes that use fishery data to paint a picture of the fish stock. This allows for projections to be made about how the stock will behave and respond to different management measures.
- There is no 'best' model. Different models have different strengths and weaknesses, and are appropriate for different types of data.
- The Commission uses a wide range of models varying in complexity and other characteristics based on data availability, model assumptions, and the questions being addressed.

In this chapter you will learn:

What are reference points

How reference points are chosen

Some specific reference points, including yield-based, spawning per recruit, spawning potential ratio, replacement, and maximum sustainable yield

The goal of most fisheries management plans is to protect the resource while providing the greatest benefit to users. When the users remove more from the population than can be replaced, **overfishing** occurs. There are two types of overfishing management attempts to prevent: growth and recruitment. **Growth overfishing** occurs when fish are removed from the population while they are relatively small, or when they are removed at such a high rate they cannot reach size at maturity. **Recruitment overfishing** occurs when fish are removed at a rate jeopardizing the ability of the population to replace itself. Overfishing can be explained with a simple gardening analogy. Say you plant potatoes. Harvesting them early at the size of golf balls instead of waiting for full size potatoes, when they may be the size of softballs, is equivalent to growth overfishing. Harvesting and eating all the potatoes this year, saving none to plant next year, is equivalent to recruitment overfishing.

Fishery reference points are tools used to measure the status of a fish population or stock relative to management objectives. In other words, reference points are the yardsticks of the management program allowing us to determine if overfishing is occurring. Since many reference points are tied to some biological characteristic of the population, they are often called **biological reference points**. Various references have been developed to bridge the gap between management needs and the often-limited data for a given stock. Fisheries with thorough data and demanding management objectives often have the most complex and complete reference points, while those with limited data and less complex management may have fewer and more basic reference points. Nonetheless, each reference point begins as a conceptual or management goal provided by managers, such as maximizing yield, that is then quantified through equations and modeling by scientists. Some scientists have tried to clarify this distinction by calling the management goal the *conceptual reference* and the quantified value the *technical reference*.

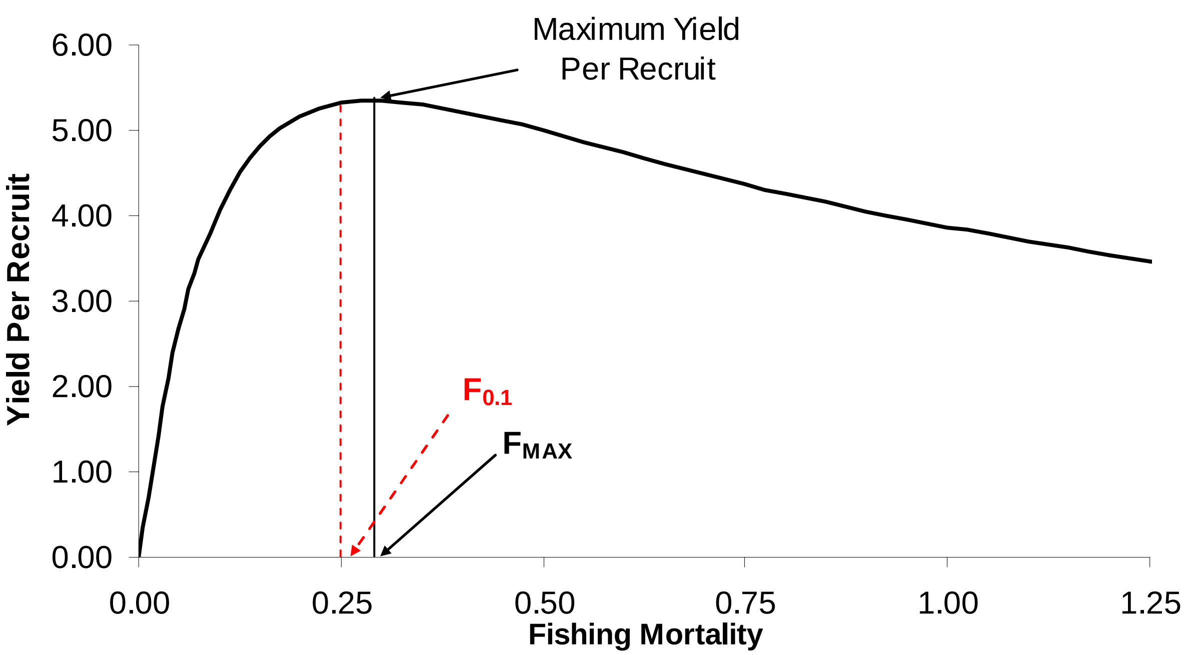
It will be easiest to explain the various reference points currently in use by starting with the simpler concepts and working toward the more complex. Although at times there seems to be an endless list of potential reference points, they can generally be classified into a few groups: references based on maximizing yield, references based on preserving the parent stock, and references based on maximizing sustained yield and thus striving to address both yield and preservation of spawning stock.

Yield-based Reference Points

Yield-based reference points are used to determine whether or not a stock is being exploited such that short-term yield (pounds harvested) is maximized. The standard yield-based conceptual reference point is "$\mathbf{F_{MAX}}$", denoting the exploitation rate maximizing the yield of each individual in the population. Many fisheries are managed through the concept of F_{MAX}, and in each instance there is a unique value of yield and exploitation associated with F_{MAX}. These values are technical reference points, and they are found through **yield-per-recruit** (YPR) analysis. YPR analysis has modest data requirements, only requiring knowledge of basic life history traits, natural mortality, growth rates, weight-at-age, and gear selectivity. The underlying concept of YPR analysis is that, even without knowing the absolute size of the population, information about the population's productivity can be gained by examining the yield a single individual can provide over its lifetime. Values for F_{MAX} are found by examining the effects of fishing over a range of exploitation levels. Initially the curves increase sharply, reflecting increased yield as exploitation increases. As exploitation continues to increase, the amount of yield gained for each additional unit of exploitation begins to drop and eventually total yield will decline, thus forming a maximum. The exploitation providing this maximum is F_{MAX} (see figure below).

Over the years, experience has shown long-term fishing mortality rates equivalent to F_{MAX} are excessive and lead to population declines. A more conservative reference, called $\mathbf{F_{0.1}}$, was developed, defining the point at which the slope of the yield curve is $1/10^{th}$ the slope at the origin. A further variation called 'Optimal $F_{0.1}$' simply involves varying the average size at harvest to find the $F_{0.1}$ providing the greatest yield. In practical terms, it is important to understand $F_{0.1}$ results in an exploitation level less than that of F_{MAX} while still providing nearly the same total yield (see figure below).

The biggest limitations of the yield-based references F_{MAX} and $F_{0.1}$ are they only address growth overfishing and cannot address recruitment overfishing. Yield-based references do not consider reproductive characteristics, and cannot account for the effect exploitation may have on the spawning stock and, ultimately, recruitment. This is a considerable concern, as experience has shown that, for some populations, the goal of maximizing yield is detrimental to spawning success. This results in an unsustainable rate of fishing mortality. Another drawback is that knowledge of the total number of recruits is necessary to extrapolate from 'per-recruit' yield to total yield of the population.

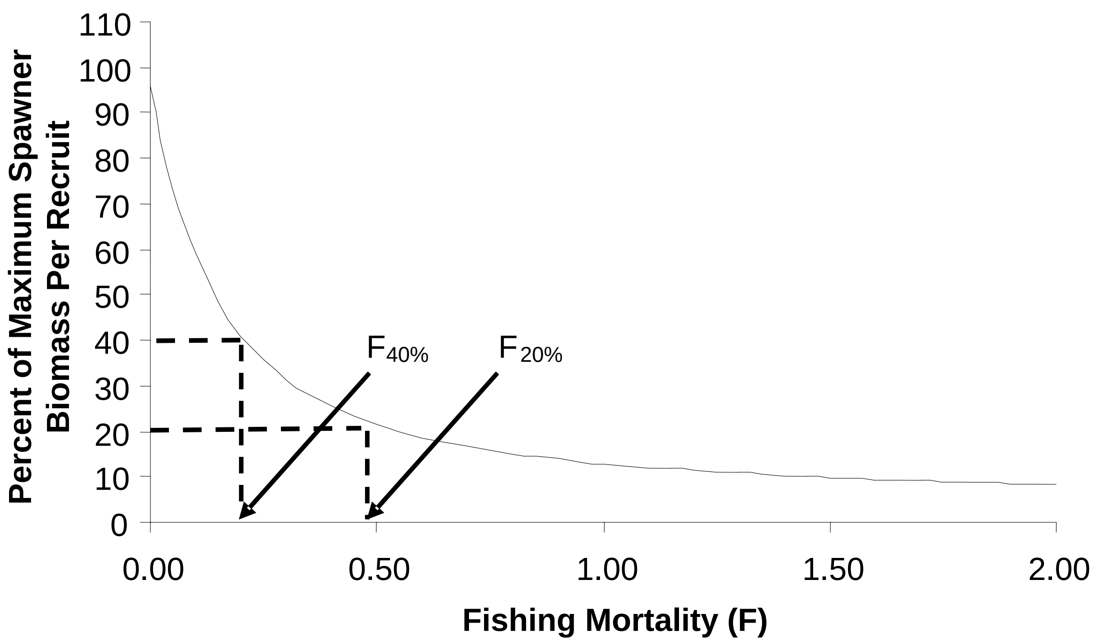


Yield per recruit (YPR) analysis. For a given age of entry into a fishery, and with knowledge of basic life history traits, growth rates, and an estimate of natural mortality, YPR analysis can be used to estimate the fishing rate producing maximum yield (F_{MAX}) or other reference points, such as ($F_{0.1}$).

Spawning Stock Biomass Per Recruit & Spawning Potential Ratio

YPR analyses expanded to include maturity and fecundity provide a group of reference points known as **spawning stock biomass per recruit**, or SSBR. The basic concept is that some minimum amount of spawning biomass should be preserved to ensure the population can replace itself. The spawning potential ratio (SPR) estimates the reproductive potential of a fished stock relative to its unfished condition, usually by dividing the SSBR at a given level of exploitation by the SSBR of the unfished stock. These reference points are generally presented as $\mathbf{F}_{X\%}$, where X refers to the percent reduction in lifetime spawning potential caused by fishing. Commonly selected %SPR levels are between 20% and 40%. Since any level of fishing removes potential spawners, a plot of %SPR is a declining curve as fishing mortality rates increase (see figure below). One drawback is that all input values (e.g. weight-at-age, age at maturity) are assumed constant over the time period assessed. **Egg per recruit (EPR)** analysis is an extension of the SPR method that estimates expected egg production of a female fish over her lifetime, rather than spawning fish biomass. EPR is typically presented as a percentage of egg production at distinct exploitation levels divided by egg production at virgin stock size.

The significant drawback to this approach is that the %SPR necessary to prevent recruitment overfishing and sustain adequate spawner biomass cannot be determined without either additional information and analyses (such as a stock-recruitment model) or trial and error. However, the intuitive appeal of accounting for spawning potential and the ease of calculation have lead to widespread use of SPR references in management. This in turn has lead to various rules of thumb for interpreting SPR levels, most of which suggest SPRs between 20% and 40% are the minimum acceptable values, although some stocks have been sustained at considerably lower levels.



Spawning potential ratio (SPR). The SPR method determines the percentage of unfished spawning potential preserved given a specific rate of fishing mortality. SPR is used in deriving reference points to address recruitment overfishing.

Replacement

While SPR references offer a convenient and intuitive approach to addressing recruitment overfishing, uncertainty around the appropriate amount of SPR that should be preserved limits their effectiveness. Researchers have attempted to address this shortcoming by combining spawning stock biomass per recruit results with stock-recruitment information. The goal is to find the level of SSBR necessary for the stock to replace itself given the history of spawning fish abundance and recruitment, which is called the replacement level. Replacement values can be presented as either SPR or F values, where the replacement %SPR represents the SSBR level necessary to maintain the stock, given the history of recruitment and exploitation, and the exploitation rate that produces the replacement %SPR is designated F_{REP} or in some instances F_{MED} (i.e., F_{MEDIAN}).

The replacement concept is commonly applied to overexploited or depressed stocks to find a minimum %SPR. Variations on this conceptual reference include values such as F_{LOW} and F_{HIGH}. Consider a plot of stock vs. recruitment observations, with overlaying lines through the origin indicating different levels of fishing mortality. F_{LOW} corresponds to an exploitation rate at which 90% of the observed recruitment values would be adequate to replace the parent stock and F_{HIGH} corresponds to an exploitation rate at which 10% of the observed recruitment values would be adequate to replace the parent stock.

Other Meanings of SPR

Most stock assessment scientists today use the acronym SPR to refer to the spawning potential ratio, as described above. However, other references may use SPR to refer to “spawners per recruit”, or “spawning-output per recruit”, which are the same or very similar to spawning stock biomass per recruit (SSBR). Check the context carefully to be sure you know which one is meant.

Maximum Sustainable Yield

A common principle of fisheries management is that a level of yield exists that a population can sustain over time. This conceptual reference is called maximum sustainable yield, or MSY. In theory, MSY strikes a balance between yield production and population preservation and is a long-term value that encompasses natural fluctuations in the population. Obviously, this is a tall order, and it should not be surprising that efforts to define the technical reference and actually calculate a reliable value of MSY for a particular population have lagged far behind the theory. MSY is typically calculated in one of two ways, either through a surplus production model or through scaling the yield per recruit values by average recruitment. Both methods can have significant limitations. Surplus production models require long time series of catch data, as well as either effort or an abundance measure to solve for MSY. Even then, such models are simplistic representations of a population. While YPR values are easily calculated, average recruitment is not, and the exploitation rate maximizing yield may not preserve adequate spawning biomass. Although MSY is a ubiquitous concept at the foundation of federal fisheries conservation, reliable estimates of MSY are available for very few stocks.

Chapter 6: "Reference Points" Summary

- Reference points are scientific benchmarks used to indicate the status of a fish stock. These reference points can be conceptual (maximum sustainable yield) or technical (specific biomass targets and thresholds).
- Reference points can serve as goals for fishery managers to aim for or triggers for management action if a fish stock crosses a certain reference point value.
- Like stock assessment models, there is no universal set of reference points; the set managers and scientists use is determined by the nature of the fish stock and the availability of data.
- Commonly used reference points include yield-based points, spawning stock biomass per recruit, replacement, and maximum sustainable yield.

Chapter 7. Using Stock Assessments in the Commission's Fisheries Management Process

In this chapter you will learn:

How the Commission goes about the task of understanding the nature and behavior of fish stocks it is responsible for.

How peer review and other processes evaluate the quality of stock assessment results.

Some limitations of stock assessments

The management implications of stock assessments.

To improve the quality of its benchmark stock assessments, the Commission conducts a series of workshops where fisheries stock assessment experts, biologists, and data managers convene to compile and review data (Data Workshops) and conduct stock assessments (Assessment Workshops). The Data and Assessment Workshop format has standardized the Commission's stock assessment process. Stock assessments are either referred to as 'benchmark assessments' or 'assessment updates'. A *benchmark stock assessment* is peer-reviewed by an 'external' group of independent, expert fisheries scientists. The need for a benchmark assessment can be prompted by new fishery management actions, a major change in the stock assessment model or data, or a management time-trigger preventing excessive time from elapsing between assessment peer reviews. This ensures management is provided with up-to-date benchmarks to gauge the effectiveness of management programs. *Assessment updates* are completed in order to monitor stock status during intervals between benchmark assessments.

Stock assessments require compiling and analyzing large quantities of fishery-dependent and fishery-independent data from state, federal, and other sources into a comprehensive report detailing the status of the fishery for Commission managed species. Data and Assessment Workshops are designed to improve stock assessments by increasing and broadening the scope of participation and expertise, providing a framework to guide the stock assessment process. At the Workshops, participants define the goals, products, and individual responsibilities associated with the development of a stock assessment report. By adopting an inclusive process, providing a framework, and clearly defining goals, Data and Assessment Workshops improve the quality, credibility, and public understanding of the Commission's technical processes in peer reviewed assessments.

The goals of the Data Workshop are to compile and organize all available data for the species' assessment, conduct preliminary analyses, and develop consensus on the best approach for modeling the species' population. Data Workshop participants include state and federal biologists, stock assessment experts from the Commission's species technical committee, the species' stock assessment subcommittee, Commission staff, and other interested or invited parties. Assessment Workshop participants include the species' stock assessment subcommittee, the technical committee chair, Commission staff, and other invited stock assessment experts. Collectively, these groups should have comprehensive knowledge of the existing fishery-dependent and fishery-independent data available for use in the stock assessment, and have the means to compile and analyze those data.

Peer Review

So what happens once a stock assessment has been completed? As you now understand, conducting a thorough stock assessment is a rigorous and highly technical job. Its results form the basis for management decisions regarding how much can be harvested from a fishery. Whether the assessment results indicate more fish, fewer fish, or the status quo can be harvested, the science behind the assessment must be defensible. There are always a variety of parties (commercial fishermen, recreational fishermen, and NGOs) interested in assessments and the resulting management decisions. The status of a stock may not be obvious, or there may be conflicting signals making it difficult to give clear, concise information on stock status. The process for determining quality control and assurance of work is a formal review by other experts in the field, also known as a **peer review**.

Peer reviews provide independent and expert judgment on the value and appropriateness of the science and methods that produced the assessment; provide recommendations for future research and improvements of future assessments; evaluate all input parameters and biological characteristics incorporated into the stock assessment model; evaluate stock assessment methods; and evaluate the status of a stock relative to current fishery management plan goals. In the Commission's process, peer reviews *do not* resolve all issues, answer all questions, provide specific management recommendations, or provide options to reach management targets.

The Commission's Stock Assessment Peer Review Process has been implemented to standardize the review process for all species managed by the Commission. The goals of the Commission's Peer Review Process are to: (1) periodically conduct formal peer reviews of stock assessments for each species managed by the Commission; (2) improve the quality of Commission stock assessments; (3) improve the

Generic ASMFC Terms of Reference for External Peer Review

1. **Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment.**
2. **Evaluate models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points.**
3. **State and evaluate assumptions made for all models and explain the likely effects of assumption violations on synthesis of input data and model outputs.**
4. **Evaluate uncertainty of model estimates and biological or empirical reference points.**
5. **Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters, reference points, and/or management measures.**
6. **Recommend stock status as related to reference points (if available).**
7. **Other potential scientific issues:**
    a. **Compare trends in population parameters and reference points with current and proposed modeling approaches. If outcomes differ, discuss potential causes of observed discrepancies.**
    b. **Compare reference points derived in this assessment with what is known about the general life history of the exploited stock. Explain any inconsistencies.**
8. **If a minority report has been filed, explain majority reasoning against adopting approach suggested in that report. The minority report should explain reasoning against adopting approach suggested by the majority.**
9. **Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.**

credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments.

Stock assessments are performed according to guidelines known as terms of reference. These terms define the tasks to be completed in the stock assessment. Terms of reference are also used by a peer review panel when reviewing an assessment. Peer review panels are comprised of stock assessment experts who are not involved in the stock assessment or management of the species being assessed and can provide a critical assessment of the data, methods, and conclusions of a stock assessment.

If the peer review panel accepts a stock assessment, the results can be used by management to adjust harvest regulations based on the stock status determined by the assessment. If the assessment concludes the stock is healthy - the stock is not overfished and overfishing is not occurring - then management may find no changes to harvesting regulations are needed. If the stock is overfished or overfishing is occurring, management should take actions to reduce fishing levels so that no long-term damage is done to the stock, and to allow the stock to recover within a specified time period.

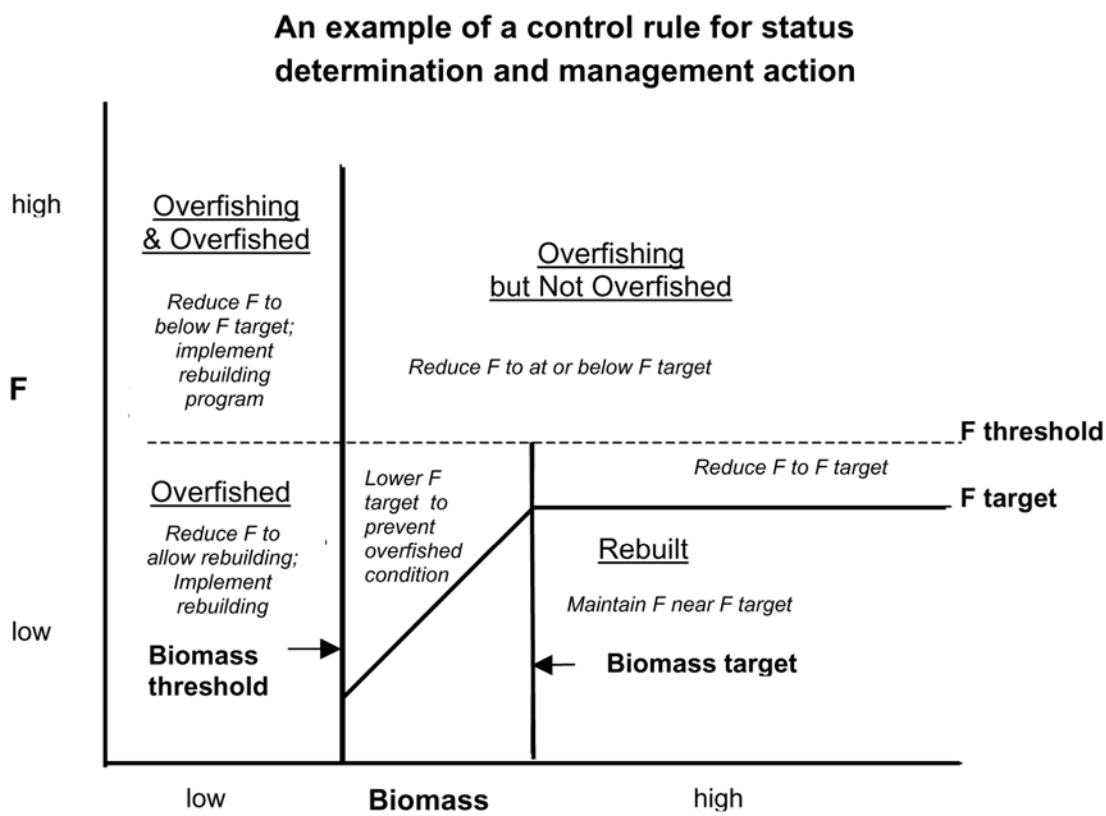
Data Limitations and Uncertainty

While the goal of science is to examine questions and provide advice, no underlying data are perfect. *Uncertainty* due to data limitations and analysis methods is inherent in all scientific undertakings and must be properly considered. With increasing uncertainty, the odds of finding absolutely true answers decrease and the risks associated with incorrect answers and subsequent advice must be considered. Uncertainty associated with fisheries data and methods must be adequately addressed in assessment results. Those involved in fisheries stock assessments should understand how uncertainty in data collection and analysis is addressed, and the risks associated with making different management decisions. The possible impacts of uncertainty must be conveyed to managers in a clear and understandable manner, allowing them to envision the possible outcomes of various alternative management decisions. Then they can make decisions based on the amount of risk they are willing to accept with respect to biological, economic, social, and political implications.

> "Acknowledging our level of uncertainty permits managers to make a more informed decision regarding the risks of overfishing likely with alternative management policies."
>
> -- AFS Uncertainty

A reality in fisheries science is that there are not enough resources – both fiscal and human – to meet the growing demand to collect data and conduct species stock assessments. Adequate data collection programs are in place for some well-known species of high commercial or recreational value. However, for many species the data availability and quality are too limited to perform a proper quantitative stock assessment. An additional point of caution is the disconnect between biologists collecting the data and the stock assessment scientists analyzing the data. Assessment scientists may be unaware of discrepancies in a data set unless they are properly advised by biologists responsible for data collection.

Uncertainty includes both elements of natural random variation, and observation and error. For carefully designed experiments, there are relatively simple statistically valid methods for determining variance (i.e. uncertainty). However, incorporating uncertainty in stock assessments is typically a much more daunting task. Another source of error common to stock assessments is process error, or the uncertainty arising from a model's failure to capture the processes driving the fishery. However, assessment scientists have several different tools available to incorporate these known sources of uncertainty into assessments and for conveying uncertainty to managers. Control rules are tools used to explain possible outcomes of alternative management decisions on stock status (see figure on next page).



Elements of a control rule. Bold indicates thresholds and targets. Underlined is stock status. Italics describe management actions agreed upon by managers that are triggered by changes in stock status.

Another factor affecting the utility of stock assessments when faced with uncertainty is that when estimates of variance have been presented to managers in the past they may have been ignored or used inappropriately. Point estimates for fisheries average values (such as spawning stock biomass or MSY) are impossible to calculate with complete certainty. In order to understand the confidence of these estimates, one needs to consider the variance and sources of error associated with all data and estimates.

Management Implications

The information above describes the scientific basis for management – essentially, the information that is provided by scientists - and addresses the first goal of fisheries management, to protect the resource. The second goal, providing the greatest good to resource users, is where managers have to make tough choices, balancing scientific information against the various desires of stakeholders, whether they are commercial harvesters, recreational fishermen, or environmentalists.

Most successful management programs are designed by first establishing the limits – the biological boundaries or thresholds that define the harvest level – of what the population can support while sustaining long-term viability. This may include examining factors such as size limits that further maximize productivity (landings) within allowable population limits. Scientists are charged with providing these biological limits to managers.

The next step is defining management targets – essentially the population and productivity characteristics managers hope to achieve. Targets are chosen to achieve various management objectives. A recurring theme in modern fisheries management is to follow a precautionary approach with respect to population viability. In other words, management targets for key population parameters such as harvest levels should be conservative. Harvest rate targets should be set below levels identified by scientists as limits (i.e., the maximum the population can support). This acknowledges that fisheries data are seldom ideal, all estimates of biological parameters have considerable uncertainty, and the fishery is more efficient when the rate of removals is less than the maximum possible. That is to say, it requires less effort to harvest fish when a species is at higher levels of abundance.

In setting targets, managers consider the desires of stakeholders and the overall reliability of the scientific information. For instance, in a large-scale, predominantly commercial fishery with adequate sampling and reliable scientific advice, managers may choose to establish targets fairly close to the biological limits, thus allowing the greatest overall yield. Reliable data and scientific advice can give managers confidence that limits will not be exceeded and that a strong, active management program will ensure target harvest values are not exceeded. Conversely, users of some fisheries may have different desires, which managers may accommodate by selecting targets with greater separation from the limits. For example, in the case of recreational fisheries, users may desire a single trophy fish, or alternatively, to catch a large number of fish of smaller sizes. Managers may set harvest targets well below limits to allow the population to reach greater abundance, which will increase fishermen's success rates. Managers may combine a lower harvest target with size limits to prevent harvest until fish become larger, thus increasing the opportunities for anglers to catch a trophy. Other fisheries may be characterized by less than adequate data, because they are difficult to sample reliably and do not have good measures of abundance, or lack the biological sampling necessary to develop age distributions. This may compel managers to take a more conservative approach, and set targets below estimated limits. Or perhaps be forced to set targets based on general 'rules of thumb' or analogies with other species. In practice, most fisheries are a mixture of these situations, and managers must set targets balancing the needs of various user groups who may have conflicting desires with the biological realities represented by the limits.

Chapter 7: "Using Stock Assessments" Summary

- The Commission convenes Data Workshops to compile and review available data, and Assessment Workshops to conduct stock assessments.
- To ensure quality and accuracy, stock assessments are peer reviewed using evaluations by independent teams of scientific experts.
- A key point to remember in considering this process is that it is not perfect – the true accuracy of stock assessments is limited by incomplete or uncertain data, changing conditions, and limited resources.

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Definitions have been taken from a number of sources, including Sea Grant, the Chesapeake Bay Fishery Ecosystem Plan, ASMFC Stock Assessment Users Manual (Special Report #69), Hilborn and Walters, Haddon, Nielson, Fishbase, and the NOAA Fisheries Glossary.

Abundance – The total number of fish in a population.

Abundance Index – Information obtained from samples or observations and used as a measure of the weight or number of fish in a stock.

Age class – All of the individuals in a given stock spawned or hatched in the same year; also known as 'year class' or 'cohort'.

Age-structure – The separation of a fish population into distinct age groups

Allocation – Distribution of the opportunity to fish among user groups or individuals. The share a user group is allocated may be based on the group or individual's historical harvest levels.

Allowable biological catch (ABC) – Catch that can be taken in a specific year to achieve the biological objectives, or stay within the biological constraints, of fisheries management. Such objectives and constraints are usually set in terms of a stock size to be maintained and/or a fishing mortality rate not to be exceeded. Estimates of allowable biological catch should be based on the best scientific advice available.

Anadromous – Species inhabiting brackish and marine waters for most of their lives, but returning to freshwater to spawn.

Annulus (or Annuli, *plural*) - A growth ring laid down on the scale or otolith of a fish. If these marks are formed once a year, they can be used to estimate age.

Anoxic Zone – An area of oxygen deficiency or absence of oxygen. Anoxic sediments and anoxic bottom waters are commonly produced when there is very high organic productivity, subsequent consumption of oxygen by bacteria feeding on organic matter, and a lack of oxygen replenishment to the water or sediment, possibly due to stagnation or stratification of a water body.

Assessment Science Committee – An ASMFC committee that coordinates the scheduling of species-specific stock assessments and assists the ISFMP Policy Board in setting priorities and timelines in relation to current workloads of assessment scientists.

Asymptotic - A line whose slope approaches zero. Fish growth in length is often described as asymptotic. As fish grow toward their maximize length, the change in length over time (or growth rate) slows and approaches zero.

Atlantic Coastal Cooperative Statistics Program (ACCSP) – A cooperative state-federal program to design, implement, and conduct marine fisheries statistics data collection programs and to integrate those data into a single data management system that will meet the needs of fishery managers, scientists, and fishermen.

Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) – Federal legislation, passed in December 1993, that provides a mechanism to ensure Atlantic coastal state compliance with mandated conservation measures in Commission-approved fishery management plans.

Atlantic States Marine Fisheries Commission (ASMFC) – An interstate compact of the 15 Atlantic coastal states with the vision of "working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015."

Availability – Describes the distribution of fish of different ages or sizes that can be caught by a specific gear type in an area.

Biological reference point (BRP) – A particular value of stock size, catch, fishing effort, or fishing mortality that may be used as a measure of stock status or management plan effectiveness. BRP's can be categorized as limits, targets, or thresholds depending on their intended use.

> $\mathbf{B_{MSY}}$ – The long-term average biomass that would be achieved if fishing at a constant fishing mortality rate equal to F_{MSY}.
>
> $\mathbf{F_{0.1}}$ – The rate of fishing mortality at which an increase in catch for a given increase in effort is only 10% of what it would be from an unfished stock.
>
> $\mathbf{F_{X\%}}$ – The rate of fishing mortality that maintains the egg production or spawning stock biomass per recruit at X% of the unfished EPR or SSBR. Commonly selected %SPR levels are 20% and 40%.
>
> $\mathbf{F_{COLL}}$ – The fishing mortality rate that would cause the stock to collapse if continued over time.
>
> $\mathbf{F_{HIGH}}$ – The fishing mortality rate corresponding to an equilibrium spawning potential ratio equal to the inverse of the 90^{th} percentile observed survival ratio.
>
> $\mathbf{F_{LOW}}$ – The fishing mortality rate corresponding to an equilibrium spawning potential ratio equal to the inverse of the 10^{th} percentile observed survival ratio.
>
> $\mathbf{F_{MAX}}$ – The fishing mortality rate that maximizes the weight taken from a single cohort over its entire life.
>
> $\mathbf{F_{MSY}}$ – The fishing mortality rate that will result in the stock biomass producing the maximum greatest yield over time, or weight of harvest within a year.
>
> $\mathbf{F_{MED}}$ – The fishing mortality rate corresponding to an equilibrium Spawning Potential Ratio equal to the inverse of the median observed survival ratio.
>
> $\mathbf{F_{REP}}$ – The fishing mortality rate that produces the replacement %SPR, which represents the spawning biomass level necessary to maintain the stock given the history of recruitment and exploitation.

Biomass – The total weight of a stock of fish or a defined stock subunit such as spawning females.

Biomass dynamic models – see definition of 'Surplus Production Models'.

$\mathbf{B_{MSY}}$ – see definition under biological reference points

Broadcast spawners – Fish that spawn by releasing their eggs and sperm into the water column (as opposed to depositing gametes on the bottom or attached to vegetation and other structure).

This spawning method is employed by many coastal and open ocean fishes. Fertilization occurs externally with successfully fertilized eggs typically hatching within 24 to 36 hours.

Bycatch – The portion of catch taken in addition to the catch of targeted species because of non-selectivity of gear to either species or size differences; may include non-directed, threatened, endangered, or protected species.

Bycatch reduction devices (BRDS) – An opening in the shrimp trawl net that allows finfish or other accidentally captured aquatic animals to escape while the target species is directed towards the tail bag or cod end of the net.

Carrying capacity – The maximum numbers or biomass of a given resource that an ecosystem can support.

Catadromous – Species inhabiting freshwater for most of their lives, but returning to the ocean to spawn.

Catch – The total number or weight of fish captured, including fish that are both retained and discarded. Note: catch, harvest, and landings are different terms with different definitions.

Catchability coefficient (q) – The portion of a stock caught by a single unit of fishing effort.

Catch and release mortality – Death of a fish from the practice of catch and release in the recreational fishery. The reasons for catching and releasing a fish can vary: the fish may not be of legal size, it may be out of season, or it may be caught and released simply as sport.

Catch-at-age – The number of fish at each age removed by all fishing activities.

Catch curve analysis – An age-based analysis of fishery catch data used to estimate total mortality of a fish stock. If an estimate of natural mortality is available, then fishing mortality can be calculated.

Catch per unit effort (CPUE) – The number or weight (biomass) of fish caught by an amount of effort. Effort is a combination of gear type, gear size, and length of time a gear is used. CPUE may be influenced by changes in abundance.

Closed population – A population with no emigration or immigration of individuals.

Cohort – A group of fish spawned during a given period, usually within a year; also known as a year-class or age-class.

Cohort analysis – see virtual population analysis.

Commercial fishery – The process of catching and marketing fish and shellfish for sale; also refers to fisheries resources, fishermen, and related businesses.

Confidence interval – A statistically-calculated probability that a given estimated number will be between an upper and lower limit.

Confidential data – Data whose source may be identified to the individual level. Confidential data may be aggregated into a more general category to protect individual economic information.

Control rule – A set of agreed upon management actions that may be triggered by changes in the status of the stock. For example, a control rule can specify how *F* or yield should vary with biomass. Control rules are also known as decision rules or harvest control laws.

Cooperative research – an arrangement made between scientists and fishermen where, most often, a commercial vessel and crew are employed by researchers to gather data for scientific purposes.

Dependent variable – The observed variable in an experiment or study whose changes are determined by the presence or degree of one or more independent variables.

Diadromy – Includes all reproductive strategies requiring migration between salt and fresh water to complete the reproductive cycle.

Directed fishery – Fishing by using gear or strategies intended to catch a given target species, group of species, or size class.

Discards – The portion of catch that is caught and returned to the sea unused. Discards may be either alive or dead. There are many types of discards: economic discards are the portion of catch that is not economically rational to land and is therefore discarded; regulatory discards occur because of restrictions on retaining certain sizes or amounts of fish; high-grade discards occur when a portion of the catch of low value is thrown back when higher quality fish are caught and retained later during a trip. High-grading is a form of regulatory discarding.

Ecosystem – A geographically specified system of organisms, their surrounding environment, and the processes controlling their dynamics.

Egg per recruit – The expected egg production from a female in her lifetime, usually expressed as a percentage of the egg production that would otherwise occur in an unfished stock.

Effort – The amount of time and fishing power used to harvest fish. Fishing power includes gear size, boat size, and horsepower.

Emigration – The geographical movement of fish out of a population.

Equilibrium – A state of system stability where all inputs and outputs balance equally. In fisheries, the concept of equilibrium refers to a population's ability to adapt instantly to changes in fishing effort (for every fish removed, a new fish is produced). In reality, equilibrium is difficult to achieve for most fish stocks.

Exclusive economic zone (EEZ) – U.S. federal waters that extend from 3 to 200 miles from shore. The U.S. has sole management authority of the natural resources found therein.

Exploitation (u) – The percent of a fish population removed by fishing over the course of a year.

Fecundity – The number of eggs produced per female per unit time (e.g., per spawning season).

Fishery – (1) One or more stocks of fish that are treated as a unit for conservation and management purposes and identified on the basis of geographical, biological, technical, commercial, recreational, or economic characteristics; and (2) any fishing for such stocks.

Fishery-dependent data – Data provided by recreational and commercial fishermen and dealers; typically includes catch, landings, and effort information.

Fishery-independent data – Data collected by research surveys; typically includes abundance and recruitment information.

Fishery-independent survey – Data collection methods specifically designed to follow consistent procedures and develop unbiased and independent estimates of relative abundance of the species sampled.

Fisheries management – The process by which decisions are made to determine the status and either the exploitation or conservation of a fishery resource. Fisheries management decisions require input on fisheries biology and stock status information, the socioeconomic needs of recreational and commercial fishermen, food web and predator/prey relationships, habitat needs, and law enforcement considerations.

Fishery management plan – A plan to achieve specified management goals for a fishery, including data, analysis, and management measures for a fishery. ASMFC, Regional Management Councils, and NMFS have the authority to develop FMPs for Atlantic coast fish stocks.

Fishing mortality – see definition under Mortality.

Fishing power – The catch which a particular gear or vessel takes from a given density of fish for a certain time interval.

Fork length - A measurement of fish length from the tip of the snout to the fork of the tail.

Gamete – The reproductive cells (i.e. sperm and eggs) of a fish or shellfish.

Gear – Any device used to capture fish or shellfish.

Groundfish Assessment Review Committee (GARM) – The federal stock assessment review committee that evaluates groundfish assessements, such as winter flounder.

Growth – The process through which individuals in the population increase their length and weight.

Growth overfishing – see definition under overfishing.

Habitat – All of the living and non-living components in a localized area necessary for the reproduction and survival of fish.

Harvest – The total number or poundage of fish caught and kept from an area over a period of time. Note that catch, harvest and landings are different.

Hermaphrodite – A fish possessing both male and female reproductive organs at some point during life.

> **Synchronous hermaphrodites** – Function as both male and female simultaneously and have the capacity to produce both milt and eggs simultaneously.
>
> **Sequential hermaphrodites** – Switch sexes during their lives.
>
> **Protogynous hermaphrodites** – Mature as females and then transform into males.

Protandrous hermaphrodites – Mature as males and then transform into females.

Immigration – The geographical movement of fish into a population.

Independent variable – A variable in an experiment or study whose presence or degree determines changes in the dependent variable.

Intercept Interviews – An interview conducted dockside as an angler returns from a fishing trip. Interviews collect (1) the number, weights, and lengths of fish caught by species; (2) the state and county of residence; (3) the frequency of fishing trips per year; (4) the type of fishing (i.e., from shore vs. boat, private vs. charter vessel); and (5) the location of fishing. These data provide information about the recreational catch and are also used to develop an estimate of catch per trip.

Interstate Fisheries Management Program (ISFMP) – An ASMFC program dedicated to the development and maintenance of interstate fisheries management plans for 22 species groups.

Juvenile – A young fish, usually resembling an adult in appearance, that has not yet become sexually mature.

Juvenile abundance index (JAI) – A measure of the relative abundance of juveniles in a stock that may serve as an indication of reproductive success. For some species, the JAI may predict future adult abundance.

Landings – The number or weight of fish brought to dock (commercial) or shore (recreational). Landings are reported at the points at which fish are brought to shore

Larvae – Newly hatched fish or shellfish of a distinctly different form than juvenile or adults of the same species.

Length frequency – A summary of the different lengths of fish in a stock used to describe the size-composition of that stock.

Length-weight relationship – A mathematical formula describing the relationship between the length and weight of a fish. L-W relationships are used by fishery scientists to derive either the length or weight of a fish when only one is known.

Linear regression – A model relating a dependent variable to one or more independent variables, so that the relationship between variables is a straight line (i.e., "linear"), plus or minus any random variation. This is a common method used to describe the relationship between observed and predicted data points. Linear regression minimizes the "sum of squares" of the residuals. Residuals (residual errors) are the difference between a single observation (point) and the predicted outcome (line). The object of the regression is to find a line minimizing these residual errors for all data points. Positive and negative values can cancel each other out. A better approach is to minimize the "absolute" value of the residuals. The absolute value refers to the magnitude of a value independent of whether the value is positive or negative (e.g. both 8 and –8 have an absolute value of 8 units). An efficient way to get rid of troublesome negative residuals is to square each residual. This tends to put more weight onto larger residuals than smaller residuals. The regression takes each residual of a data set into consideration, minimizing the collective sum of the residuals.

Logbook – Records maintained by captains of fishing vessels for their own information or for license or permit-mandated purposes.

Marine Recreational Fisheries Statistics Survey (MRFSS) – A program of the National Marine Fisheries Service for collecting and compiling data and statistics on recreational fisheries executed in the marine waters of the United States.

Maturity – The age or size at which a species is able to reproduce.

Mass-Balance – The production of biomass for a system is maintained over time following the principle of conservation of matter. Thus, the available resources in a system are allocated to species groups based on trophic interactions within the ecosystem (i.e., the transfer of prey biomass to predator biomass). New predator biomass cannot exceed old prey biomass, but must balance new and old.

Maximum likelihood estimation – A statistical method for estimating parameters from measured variable data that maximizes the probability of obtaining the observed data.

Maximum Spawning Potential (MSP) – The estimated egg production from female spawning stock biomass that would occur in the absence of fishing. A percentage of this value (%MSP) can be used as a measure of the health of a fish stock.

Maximum Sustainable Yield (MSY) – The largest average catch that can be taken from a stock over time under existing environmental conditions without negatively impacting the reproductive capacity of the stock.

Mid-Atlantic Fishery Management Council (MAFMC) – One of eight regional fishery management councils established by the Magnuson Act that are responsible for management of fisheries in federal waters (3-200 miles from shore).

Model – an equation or set of equations and their parameters used to describe something that cannot be directly observed. For example, we cannot count every single fish in a population, so we develop models to estimate total abundance. Typically, several equations are needed to describe the complex relationships within a stock or fishery.

Mortality – The rate at which fish die, expressed either as an annual percentage or instantaneous rate (the portion of the stock dying within each small amount of time). Instantaneous rates are used in most stock assessment modeling equations. Fishery scientists estimate several different types of mortality to evaluate the status of fish stocks, and some mortality rates serve as biological reference points.

> **Fishing mortality (F)** – The instantaneous rate at which fish in a stock die because of fishing.
>
> **Natural mortality (M or M1)** – The instantaneous rate at which fish die from all causes other than harvest. This rate has traditionally included unmeasured bycatch mortality. As research has improved our understanding and estimation of bycatch, bycatch is increasingly included in F. Usually, the value of M is assumed or estimated using maximum age data, or the value used for other species with a similar life history strategy. Natural mortality is difficult to measure directly.

> **Predation mortality (M2)** – The component of natural mortality attributed to being the prey of one or more predators. When M2 is estimated, M1 includes only mortality due to starvation, disease, or other factors not associated with fishing or predation.
>
> **Total mortality (Z)** – The rate of removal of fish from a population due to both fishing and natural causes.

Multispecies model – A fisheries stock assessment model linking individual single-species assessments of predator and prey species through the addition of trophic interactions (feeding).

Multispecies virtual population analysis (MSVPA) – A series of single-species age-structured stock assessment models (VPAs) linked by a simple feeding model and used to calculate natural mortality rates. The goal of the MSVPA is to evaluate fisheries management decisions at the ecosystem level.

MSVPA-X – Expanded multispecies virtual population analysis – An enhanced version of the MSVPA that includes more complex predator-prey interactions and more flexible options for building single-species VPAs.

National Marine Fisheries Service (NMFS) – The service within NOAA dedicated to the stewardship of living marine resources through science-based conservation and management, and the promotion of healthy ecosystems; also known as NOAA Fisheries Service.

National Oceanic and Atmospheric Administration (NOAA) – A federal agency within the Department of Commerce focused on the condition of the oceans and the atmosphere.

Natural mortality (M) – see definition under mortality.

New England Fishery Management Council (NEFMC) – One of eight regional fishery management councils established by the Magnuson Act that are responsible for management of fisheries in federal waters (3-200 miles from shore).

Northeast Area Monitoring and Assessment Program (NEAMAP) – A cooperative state/federal fisheries-independent research and data collection program covering nearshore waters from the Gulf of Maine to Cape Hatteras, NC. The program is intended to maximize the effective capability of fishery-independent survey activities and maximize the usefulness of data collected by such surveys, through cooperative planning, innovative uses of statistical theory and design, and consolidation of appropriate data into a useful data management system.

Northeast Fisheries Science Center (NEFSC) – One of NMFS' fisheries research and science arms, located in Woods Hole, Massachusetts**.**

Northeast Regional Stock Assessment Workshop (SAW) and Stock Assessment Review Committee (SARC) – The SAW is a formal scientific peer-review process for evaluating and presenting stock assessment results to managers for fish stocks of the Northwest Atlantic. Assessments are prepared by SAW working groups and reviewed by an independent panel of stock assessment experts called the SARC.

Observers – Trained biologists who monitor and record commercial catch data from fishing vessels and processing facilities.

Opercula – The bony part of a fish's gill cover or 'cheek' that can be used to age fish.

Otoliths – Inner 'ear bones' of fish that can be used to age fish.

Overfished – A stock exploited to a level of abundance considered too low to ensure safe reproduction.

Overfishing – Harvesting from a stock at a rate greater than the stock's reproductive capacity to replace fish removed through harvest.

> **Growth overfishing** – The excessive removal of smaller fish that inhibits the fishery's ability to produce its maximum yield. Growth overfishing does not affect the ability of a fish population to replace itself. The weight of fish removed is greater than the weight gained by fish remaining in the population.
>
> **Recruitment overfishing** – Levels of fishing mortality in which removals are so high the production of new recruits to the fishery is compromised. The number of fish removed is greater than the number gained from fish remaining and reproducing in the population.

Parameter – An estimated numerical quantity that characterizes a property of a population or system.

Peer review – The process of having experts provide an independent judgment of the value and appropriateness of the science and methods used to produce a stock assessment.

Population – All individuals of the same species occupying a defined area during a given time.

Population biomass – The total biomass of a population.

Population dynamics – The study of changes, and the mechanisms of change, in populations over time.

Predation mortality – see definition under mortality.

Predator – A fish or invertebrate of a higher trophic level that feeds upon prey from lower trophic levels.

Prey – A fish or invertebrate of a lower trophic level that is eaten by predators from higher trophic levels.

Projection – The forecasting of future stock conditions based on information from a stock assessment; used to establish future catch allowances, management restrictions, and time frames for rebuilding overfished stocks.

Protandrous hermaphrodites – see hermaphrodites.

Protected species – Species protected by the Endangered Species Act (ESA) or the Marine Mammal Protection Act (MMPA) that the National Marine Fisheries Service (NMFS) is responsible for conserving. These include all threatened, endangered, and candidate species, as well as all cetaceans (whales and dolphins) and pinnipeds (seals, sea lions).

Protogynous hermaphrodites – see hermaphrodites.

Recreational fishery – A fishery executed to catch (or attempt to catch) aquatic organisms for personal use, but not for sale, barter, or other compensation. The term refers to and includes the fishery resources, fishermen, and businesses providing recreational goods and services.

Recruit – An individual fish that has entered a defined group through spawning, growth, or migration. Fish recruit to the spawning stock when they become sexually mature. Fish recruit to the fishery when they reach the minimum legal size.

Recruitment – A measure of the weight or number of fish that enter a defined portion of the stock, such as the spawning stock or fishable stock.

Recruitment overfishing – see definition under overfishing.

Reference points – see biological reference points

Relative Abundance – An index of fish population abundance used to compare fish populations from year to year.

Reproductive biology – The strategy employed by a species to contribute (genetic material) to future generations.

Risk – The probability of something undesirable happening. In fisheries, risk refers to tradeoffs in conservative vs. relaxed management strategies in light of uncertainty associated with stock assessment results.

Robust – The resiliency of model results to changes in model input data and parameters.

Southeast Data, Assessment, and Review (SEDAR) – The stock assessment peer-review process used by the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils, and the ASMFC to improve the quality and reliability of fishery stock assessments in the US Southeast.

Southeast Area Monitoring and Assessment Program (SEAMAP) – A cooperative state, federal, and university program for the collection, management, and dissemination of fishery-independent data and information in the southeastern US and Caribbean.

Sequential hermaphrodites – see hermaphrodites

Selectivity – The ability of a fishing gear to catch fish of a certain size or species compared with its ability to catch fish of other sizes or species.

Simulation – An analysis showing the production and potential harvest of fish that can be used to predict changes in the fishery based on alterations of important factors included in models.

Size Distribution – The number or percentage of fish of different size groups in a stock or sample.

Slope – The measure of steepness of a line on a graph.

Spawning stock biomass per recruit – An expanded form of yield per recruit analysis that incorporates maturity and fecundity information. These models provide a group of reference points that define the amount of spawning biomass to preserve to ensure a population can replace itself.

Spawning potential ratio (SPR) – Most commonly calculated as the ratio of spawning stock biomass per recruit (SSBR) of a fished stock divided by SSBR of an unfished stock, SPR represents the reproductive potential (SSB or egg production per recruit) of a fished stock compared to its unfished condition.

Spawning stock – The female portion of a fish stock that is mature.

Spawning stock biomass – The total weight of the mature females within a stock of fish; frequently used instead of total biomass as a better measure of the ability of a stock to replenish itself.

South Atlantic Fishery Management Council – (SAFMC) – One of eight regional fishery management councils established by the Magnuson Act that are responsible for management of fisheries in federal waters (3-200 miles from shore).
Standard length - The length of a fish as measured from the tip of the snout to the hidden base of the tail fin rays.

Statistical catch-at-age models (SCA) – Age-based stock assessment methods utilizing catch-at-age data to derive estimates of population size and fishing mortality. However, unlike VPA, SCAA model parameters are estimated by working *forward* in time, rather than backwards as is done in VPA analysis.

Stock – A group of fish of the same species that behave (migrate, spawn) as a unit and are genetically unique.

Stock assessment – An evaluation of a stock, including age and size composition, reproductive capacity, mortality rates, stock size, and recruitment.

Stock-recruitment relationship – The number or weight of recruits is dependent upon the number or weight of the spawning stock.

Surplus production – The total weight of fish that can be removed from a population by fishing without changing the size of the population.

Surplus production model – Also known as 'Biomass Dynamic Models', these models are among the simplest stock assessment techniques commonly employed by fisheries scientists to model population dynamics and track biomass. They are "simple" because they characterize the dynamics of a stock in terms of changes in total biomass without regard to age or size structure."

Synchronous hermaphrodites – see hermaphrodites

Target (biological reference point) – Benchmarks used to guide management objectives that should not be exceeded on average in order to achieve a desirable outcome (e.g., a sustainable stock). Various levels of fishing mortality (*F*) and spawning stock biomass (SSB) are commonly defined targets.

Target species – A species or group of species that certain gear and strategies are designed to catch.

Threshold (Biological Reference Point) – Benchmarks used to guide management objectives that represent critical levels not to be crossed. If crossed, the sustainability of the stock is threatened. When on the safe side of a threshold, we expect to maintain a healthy, reproductive fishery. If on the other side of a threshold, the stock is at risk of collapse. Various levels of fishing mortality (*F*) and spawning stock biomass (SSB) are commonly defined thresholds.

Time series – a set of data collected sequentially over time. For example, fishery catch and effort data collected annually to estimate changes from one year to the next, preferably over a long time period (several decades).

Total allowable catch (TAC) – The annual catch recommended by a management authority for a species or group of species.

Total length - The length of a fish from the tip of the snout to the tip of the tail (caudal fin).

Total mortality – see definition under Mortality

Transboundary Resource Assessment Committee (TRAC) – A forum for U.S. and Canadian scientists to collaboratively recommend biological reference points and biomass levels based on updated stock assessment information.

Trophic levels - The classification of natural communities or organisms according to their place in the food chain. Green plants (producers) can be roughly distinguished from herbivores (primary consumers) and carnivores (secondary consumers). For example, menhaden is a primary consumer at a lower trophic level than bluefish, a secondary consumer at a higher trophic level that feeds on menhaden.

Uncertainty – The degree of imperfect knowledge in fisheries analyses due to several underlying factors that go into stock assessments, and in subsequent estimation of reference points provided to management. Managers should consider the degree of uncertainty when developing management strategies.

Unit stock – A population or populations grouped together for assessment purposes that may or may not include all the fish in a stock.

U.S. Fish and Wildlife Service (USFWS) – A bureau within the Department of the Interior with the mission of "working with others to conserve, protect and enhance fish, wildlife and plants and their habitats for the continuing benefit of the American people."

Virtual population analysis (VPA) – A method of estimating stock size through examination of sizes of individual age classes, growth, and mortality rates by "back calculating" the virtual population that must have existed to produce the current or past catches observed in a fishery.

Von Bertalanffy curve – A type of growth model commonly applied to describe fish growth in either length or weight with respect to fish age.

Year class – All of the individuals in a given stock spawned or hatched in the same year; also known as an 'age class' or 'cohort'.

Yield per recruit (YPR) – The expected yield in weight for a single fish or year class over the life of the fish or year class.

Young-of-the-year (YOY) – An individual fish in its first year of life; for most species, YOY are juveniles.

ASMFC Vision:

Healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by 2015

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