



GUIDE TO FISHERIES SCIENCE & STOCK ASSESSMENTS

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This document significantly updates the first edition of the Guide to Fisheries Science and Stock Assessments, which was published in June 2009.

The 2026 revision is the result of the collaborative efforts of ASMFC staff members: Jainita Patel, Fisheries Science Coordinator; Katie Drew, Stock Assessment Team Lead; Madeline Musante, Fisheries Outreach Coordinator; and Tina Berger, Director of Communications.

All graphs in this document are created by Katie Drew.

All figures in this document are created by Madeline Musante unless stated otherwise.

We are grateful for the thoughtful review of this document by members of the Commission's Assessment Science Committee and various ASMFC staff.

Special thanks go to those who allowed us to use their photographs in this publication. Cover photograph is courtesy of the South Carolina Department of Natural Resources, Coastal Trawl Survey.

The Guide is also available in [StoryMap format](#).

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Management of coastal and marine resources is a complex process that balances what we know about the fish populations we are managing (like the size of a fish population, its habitat, and the food it relies on, and the factors that affect its growth, reproduction, and life span) and the people that use the resources. The tricky part is we can't easily count how many fish are in a population, so we have to use stock assessments to calculate these numbers. That's why we created this guide to show you what goes into a stock assessment, from what types of information are collected to how various models work to how the assessment results are considered for management.

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INTRODUCTION

Many countries use a census to determine the exact number of people that reside in that country. However, animals can be much more difficult to count. After all, it's not like we can send out a form for them to fill out and send back to us. This is especially true for fish, since they live in an environment that is hard for us to easily access.

But why count fish in the first place? We rely on fish for everything from sushi to summer fishing trips with the family to activities like whale watching and snorkeling. Fish populations are affected by fishing pressure and changing ocean conditions, so ensuring that there are enough of each species to go around is important to maintaining the longevity of marine or saltwater species and our enjoyment of them. Knowing the most accurate number possible for fish populations helps management agencies understand how and where to direct fishing efforts so that these species are around for current and future generations.



Crew from the Southeast Reef Fish Survey deploying equipment to sample fish. Photo by: South Carolina Department of Natural Resources.

Understanding the dynamics of populations of various fish species—where they are, their movement, their mortality, and how often and in what quantity they reproduce—is the job of [fisheries](#) scientists. Fisheries scientists use information on the biology of each species (how fast they grow, how long they live, and how old they are when they can first reproduce) and how many fish are caught every year to calculate how large the population is, how it has changed over time, and in some cases, how it may change in the future. Scientists are always working to improve the information and the mathematical tools used to do these calculations, but these [estimates](#) are not completely exact due to the complicated nature of collecting information on fish stocks and the inability to perfectly predict future events. The process of analyzing this information while accounting for gaps in our knowledge is what the fisheries world calls a stock assessment.

Words to Know

stock: a group of fish of the same species that behave (e.g., migrate or spawn) as a unit, are assessed and managed as a unit, and which may be genetically unique.

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.

estimate: (*verb*) the process of using mathematical tools to calculate a quantity of interest; (*noun*) a value calculated using mathematical tools.

DATA SOURCES

If stock assessments are the foundation upon which fisheries management decisions are made, then information, or [data](#), about these fish is cement that holds the foundation together. The better the evidence, the more reliable the stock assessment, and the more informed the management decisions.

The data we use in stock assessments come from many sources but can be broken down into two main categories: fishery-dependent datasets and fishery-independent datasets. Both types of data play a vital role in helping scientists determine the size of fish populations and the status of the fisheries that rely on them.

Fishery-Dependent Data

Fishery-dependent datasets are collected from commercial sources, where fish are sold to restaurants or markets (this can be shown in the form of vessel or dealer reports), and recreational sources, where people fish for food or pleasure, including individual anglers and party or charter boats. Using both sources, stock assessment scientists consider the [catch](#), [landings](#), and [effort](#). Information about the fishing trip itself is also useful – who, what (target species), when (season), where (location), how (gear type), and how much (the cost of fishing trips), as well as information on the fish's [life history](#).

The goal of these data collection programs is to obtain the most complete picture possible of the catch and effort of a fishery to help inform assessments.

Words to Know

data: information collected about real world phenomena used as a basis for analysis and decision-making.

catch: the total number or weight of fish captured, including fish that are retained, discarded dead, and released alive.

landings: the number or weight of fish brought to dock (commercial) or shore (recreational). Often used interchangeably with **harvest**.

effort: The amount of time and fishing power used to harvest fish. Effort can be measured in several different ways, including but not limited to: length (e.g., minutes, days), number of trips, number of trawl tows, or distance.

life history: the entire life cycle of a fish species, from fertilization to aging. It encompasses various characteristics that influence the growth, reproduction, and survival of fish, including diet, habitat, and predation.

Commercial Fishery Data

The first step in collecting commercial data is to define the number of commercial harvesters, the number and type of fishing vessels in a particular fishery, and the number of dealers. These make up the groups from which state and federal agency staff collect commercial data. For most fisheries, catch data are collected using mandatory 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. Although this method is more accurate, it can be difficult and expensive.

Catch Per Unit Effort (CPUE)

The ratio of catch to a standard unit of effort is known as the catch per unit effort, or CPUE. CPUE can be used 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 and in similar conditions, you would likely believe 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.



Commercial lobster fishing aboard Steve Train's F/V Hattie Rose. Photo by: ASMFC.

ACCSP

The Atlantic Coastal Cooperative Statistics Program (ACCSP) coordinates and helps standardize state and federal landings reporting on the Atlantic coast through a single integrated data management system. The ACCSP is intended to encompass commercial, recreational, party, and charter boat fishery-dependent statistics.



Commercial catch and effort data on the US Atlantic coast is collected for state fisheries (zero to three miles from shore) and federally permitted fisheries (three to 200 miles from shore). Permits are issued to vessels and dealers, and these permit holders may hold a state permit, a federal permit, or both. Commercial fisheries datasets are maintained by [NOAA Fisheries' Commercial Fishery Statistics Program](#) (for all US marine waters) and the [Atlantic Coastal Cooperative Statistics Program](#) (for the US Atlantic coast).

An important consideration when accessing and using data is confidentiality. Certain types of fishery-dependent data must be treated as confidential to protect an individual's economic information and may be presented as averages of groups in more general categories before being distributed to the public.

Recreational Fishery Data

Recreational fishery data for the US Atlantic coast are gathered by NOAA Fisheries and its state partners through the [Marine Recreational Information Program \(MRIP\)](#). This program uses voluntary surveys to estimate the number of trips saltwater anglers take (effort) and the number of fish they catch.



AP AIS being conducted in North Carolina. Photo by: NOAA Fisheries.

In the Atlantic region, MRIP administers three surveys to calculate estimates of recreational catch and effort:

1. The [Access Point Angler Intercept Survey](#) (APAIS) is an in-person survey conducted at marinas, boat ramps, beaches, fishing piers, and other public fishing sites. Trained samplers from state agencies interview anglers as they complete their fishing trips to collect information on fishing effort, time spent, area fished, demographic information, and number and species of fish caught (kept or released) and obtain length and weight measurements (biological data) on harvested fish. Surveys are completed in six-hour increments with interviewers collecting data on all fishing activity during that time, even if not every angler is interviewed. These surveys are conducted year-round, which allows MRIP to draw conclusions about the full recreational fishing community.
2. The Fishing Effort Survey (FES) is a mail survey that collects data on private boat and shore fishing effort from households in coastal states. To sample, NOAA Fisheries uses a US Postal Service list of residential addresses matched to the National Saltwater Angler Registry, which is a database of licensed anglers. This gives a better idea of which household anglers are licensed and unlicensed, allowing MRIP to sample more frequently from households likely to report fishing. That's why someone living in a land-locked state may not have heard of this mail survey, while those who live and fish along the coast may receive the FES in the mail.
3. The [For-Hire Survey](#) (FHS) is a telephone survey that collects effort information from for-hire (party/charter) vessel operators. Trained samplers from state agencies speak directly with vessel operators to determine all vessel-fishing activity for a specified one-week period, including number of trips with customers, number of anglers that fished on each trip, species targeted, hours, area fished, and, in some states, fishing method. Datasets from the FHS are used to calculate the number of angler fishing trips taken on for-hire vessels that hold state permits. State-permitted for-hire vessel trips are then added to the number of angler trips for the federally permitted vessels to calculate total MRIP for-hire effort.

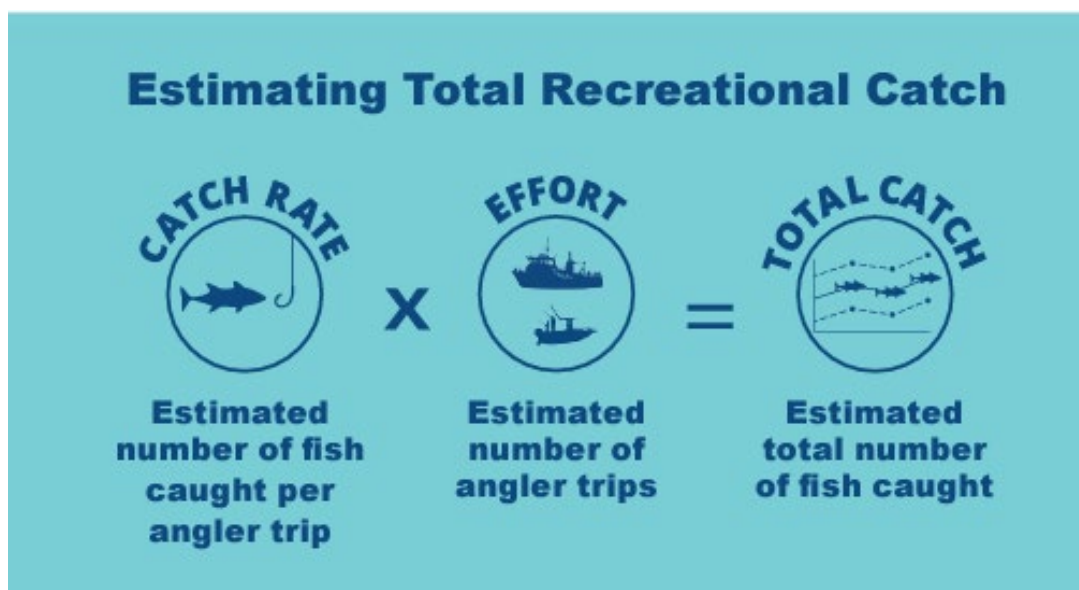


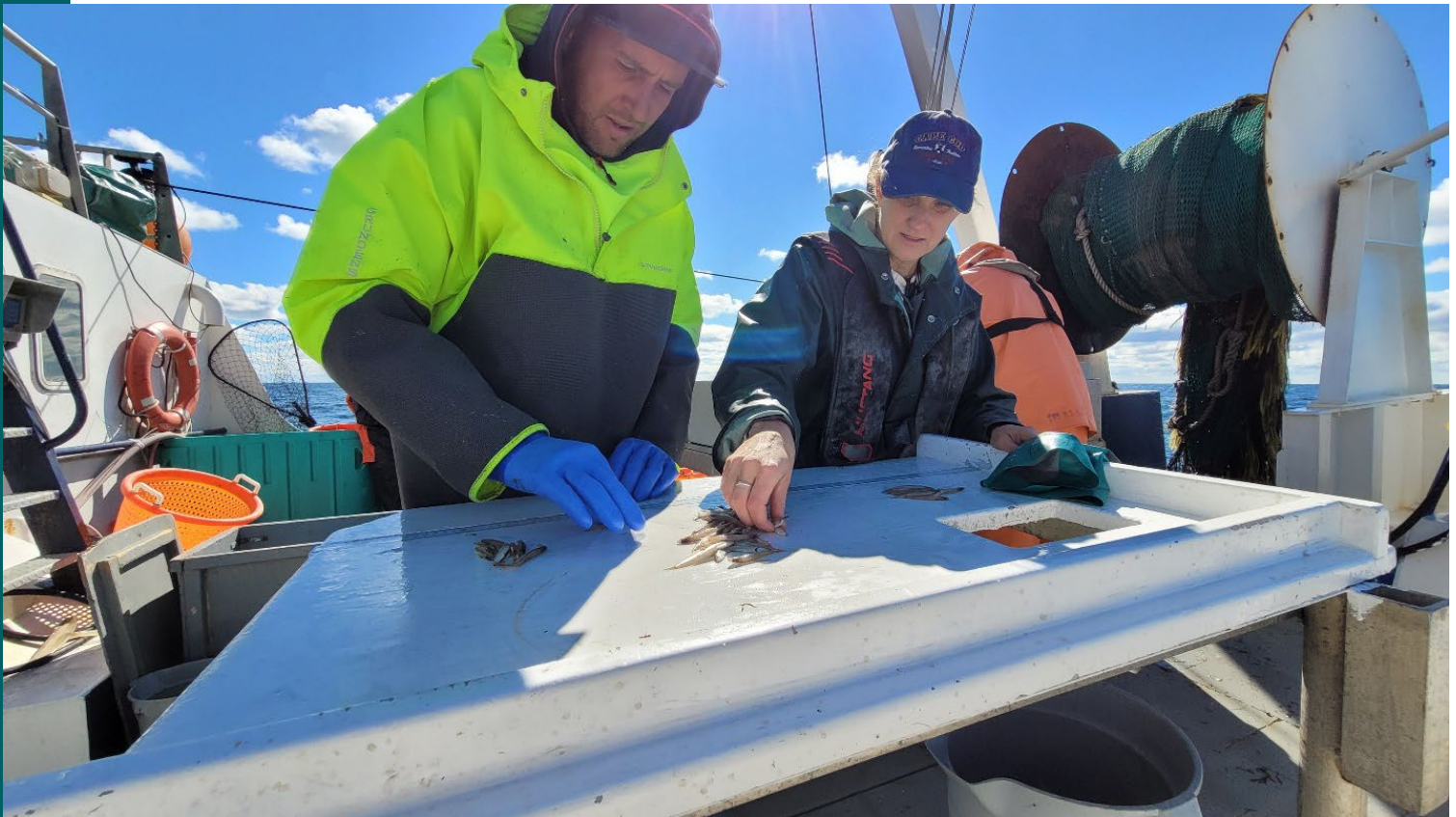
Figure by: National Marine Fisheries Service

In addition, MRIP administers the [Large Pelagics Survey](#) that calculates catch and effort for larger, open-ocean species that are highly migratory, such as tuna and sharks.

MRIP uses the catch data and effort from these surveys to calculate the total recreational catch. Additional state-run surveys allow anglers to play an important role in supplementing MRIP recreational data by voluntarily providing data from more specific fisheries or fishery events, like mini-seasons or fishing tournaments. There are also a number of [recreational tagging programs](#) that can be used to estimate the size of fish populations, fishing pressure on the stock, fish migration patterns, and stock structure.

There are several ways to access the information used to estimate recreational fishing activity:

- [Recreational Fishing Data and Statistics Queries Landing Page](#) or the [ACCSP Data Warehouse](#)—searchable databases of catch, effort, and fishing participation legacy data (from 1981 through the most recent year of available data) statistics.
- [Recreational Fishing Data Glossary](#)



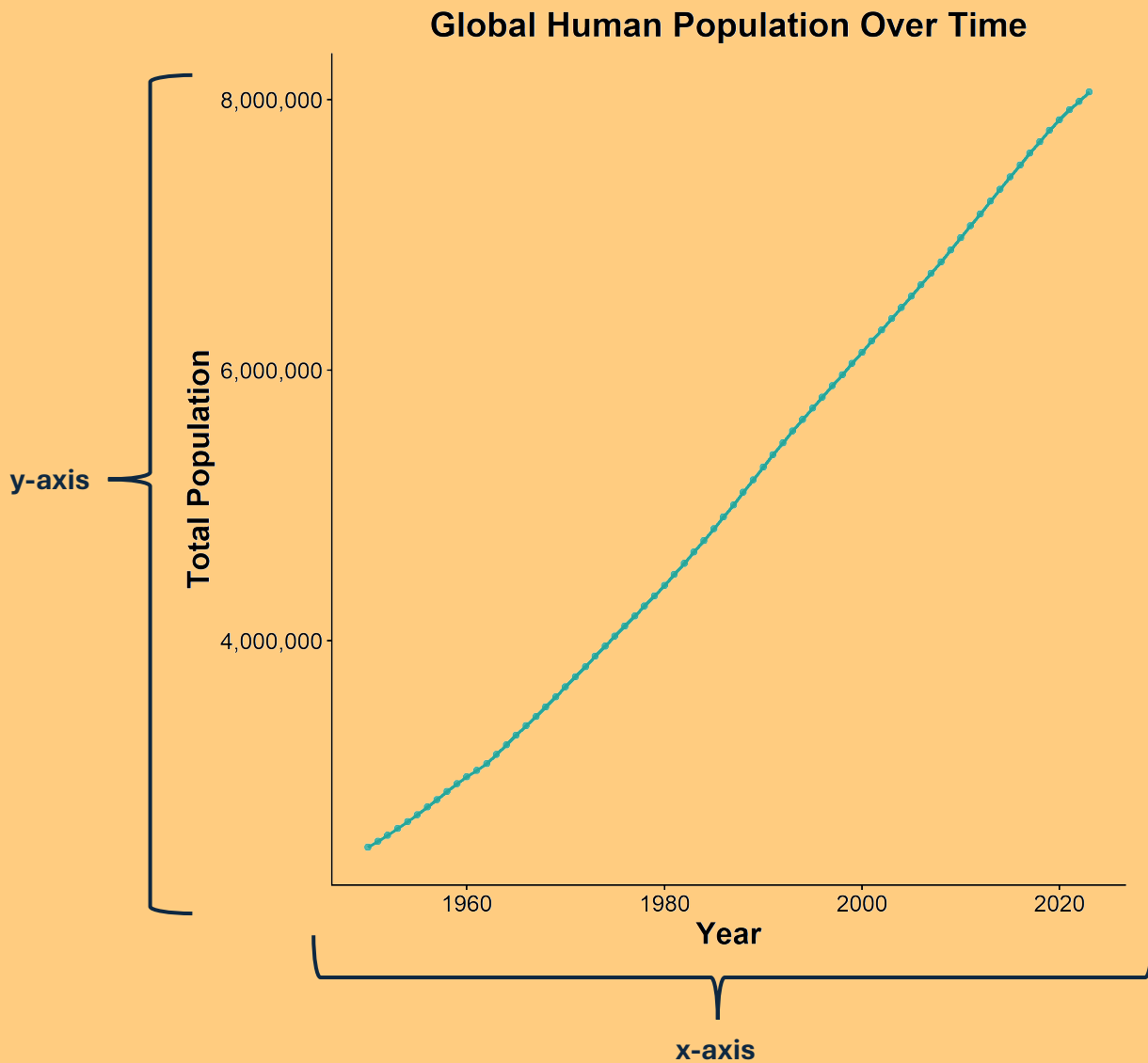
R/V Seawolf deckhand, John Holden, and NJDEP Assistant Commissioner, Katrina Angarone, measure anchovies in January 2023. Photo by: New Jersey Department of Environmental Protection.

How To Read a Graph

Graphs are a great way to convey a lot of information in a way that is often easier to understand than a long table of numbers.

Most graphs have two sides to them that are labeled and have numerical scales. The x-axis is on the bottom of the graph, and usually represents what is *causing* the phenomenon you are investigating. The y-axis is vertical on the left side and usually represents the *effect*.

The graph below is a time-series or a graph where the x-axis is time and the y-axis is the effect of time passing. This graph shows the growth of the global human population from 1950 to 2023.



Fishery-Independent Data

Fishery-independent data provide an important counterbalance to fishery-dependent data by providing information that is not influenced by fishing behavior or regulatory restrictions. These long-term surveys are run by scientists using consistent methods (the same gear at the same time of year in the same general area) to collect unbiased and independent data and see trends in fish populations. These data, when combined with fishery-dependent data, provide a fuller, more accurate picture of a fish population's [stock status](#).

Fishery-independent surveys are carefully designed to obtain an [abundance index](#). 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 collected data 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 or recreational fishery, like 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 methods.



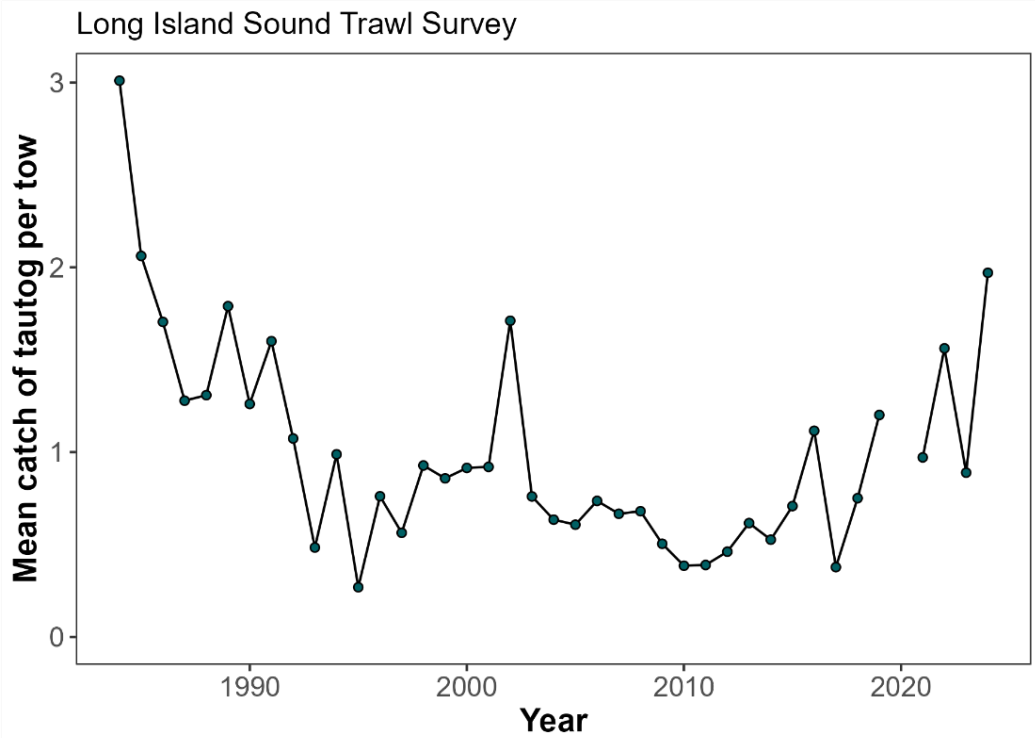
Principal Biologist and trawl survey lead Chris Parkins at the measuring table on board the R/V John H. Chafee on a Rhode Island Trawl Survey. Photo by: AndyMoranPhoto.com.

Words to Know

stock status: the condition of a stock of fish that is determined through a stock assessment. (i.e., whether a stock is overfished, experiencing overfishing, or depleted).

abundance: the total number of fish in a stock.

abundance index: a scientific measure of abundance which can be used to monitor trends in abundance and distribution of a fish stock over time and over the entire range of the species.



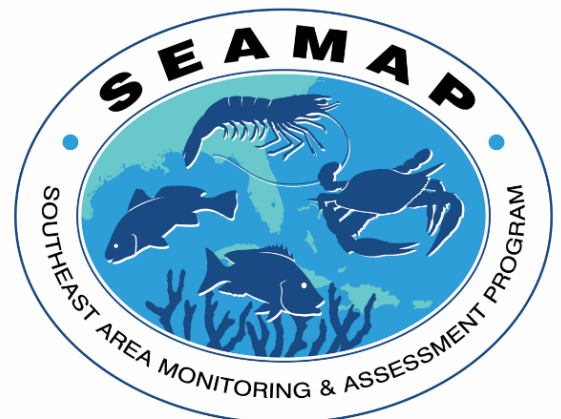
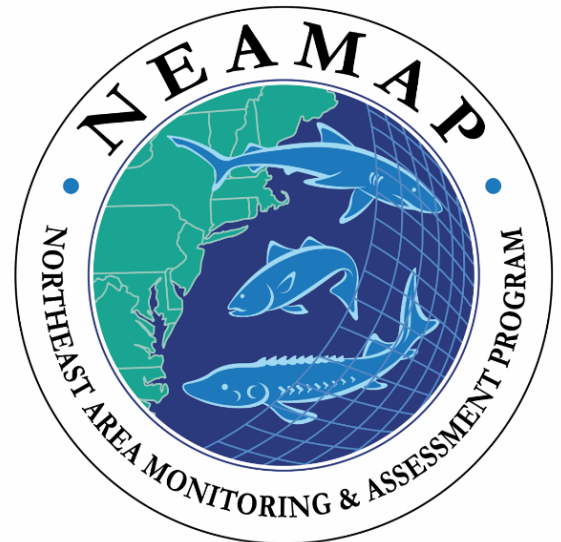
An index of abundance for tautog derived from the fishery-independent Long Island Sound Trawl Survey.

State/Federal Cooperative Resource Surveys

Along the Atlantic coast, fishery-independent surveys are conducted by state, regional, and federal fishery management agencies. Each of these fishery-independent surveys plays a vital role in stock assessments for the specific species or group of species that they target. However, these types of surveys can also be costly to run and maintain. To minimize or overcome the problems associated with funding and other limitations, agencies often combine resources and share responsibilities to gather information they could not gather independently.

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 [Northeast Area Monitoring and Assessment Program](#) (NEAMAP)—which are composed of several state-run surveys.

SEAMAP's coverage stretches from the Gulf to the Caribbean and up the Atlantic coast through North Carolina. SEAMAP is composed of several state-run surveys that collect long-term, standardized fishery-independent data and provides a platform for the development and implementation of research programs. Datasets from SEAMAP's South Atlantic component, which include time series that extend back to the 1980s, are used in the stock assessments for many South Atlantic species, such as red drum, gag grouper, and Spanish mackerel.



Based on the success of SEAMAP, state, interstate, regional, and federal management bodies from Maine to North Carolina established NEAMAP, a collaborative state-federal initiative dedicated to the collection, analysis, and dissemination of fishery-independent data from the Gulf of Maine to Cape Hatteras, NC. NEAMAP is run by individual state agencies and institutions that also have time series that extend back to the 1980s. These are frequently used in stock assessments for species like American lobster, tautog, summer flounder, and black sea bass.

Equally important to SEAMAP and NEAMAP are fishery-independent surveys run by individual states, federal agencies, and academic institutions. These surveys, many of which are decades old, provide critical information for ages of fish not frequently caught in these cooperative programs, species not encountered by these programs, and regions that these programs cannot sample.

Biological Data

Both fishery-dependent and fishery-independent surveys are important sources of biological data on fish stocks, especially in determining the size and age composition of both the catch and the stock. Standardized data collection methods by species for information like length and age give scientists the important biological data that can help them determine the age structure of the population. 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 undulatus*) on NJ Department of Environmental Protection's Delaware River Seine Survey.

Let's Do a Mini-Assessment!

Now that you know a bit more about how the data is collected, let's do a mini assessment!

Let's pretend we do a survey every year: we go out and count how many purple leopardfish we catch every time we tow the net. This year, on average, we caught 20 purple leopardfish per tow. Then, we open the fishing season, and we catch one million purple leopardfish this year. Next year, when we do the survey, we only catch 10 purple leopardfish per tow.

How big was the population last year?

We know that when we caught one million fish, the survey catch rate went down 50%, which means that the overall population size went down 50%. That means there were two million fish in the population last year.



Photo by: Maryland Department of Natural Resources, Coastal Bays Survey.

Some species of fish only live a few years, while others can live 50+ years. Some species never grow larger than six inches long, while others can grow to over six feet. Some species filter tiny plants out of the water to eat, while others eat smaller fish. Different species live in different parts of the ocean: some species live in seagrass beds or mudflats in bays and estuaries, some in coral reefs, some in the ocean within sight of the shore, and some in deep water far out to sea—and other species live in many other places! All of these factors—how long a fish lives, how big it grows, where it lives, where it spawns, and what it eats—are part of its life history and biology. In this section, we'll touch on the different life history factors used to inform stock assessments.

Age & Growth

Different fish species grow at different rates and have varying life spans. For example, Atlantic sturgeon have an average life span of 60 years and can grow up to six feet in length, while bay anchovies live for only about a year and grow to about four inches. Not all small fish are short-lived, and not all large fish are old: blackbelly rosefish, which only reach ten to twelve inches in maximum length, can live for over 80 years, while cobia, which can get well over three feet long, only live for a few years. A small fish will generally be younger than a large fish of the same species, but there is a lot of variability in how large a fish is at a given age both within species and across species. There are a few important factors to consider when trying to determine when and how fast an individual fish is growing:

Seasons. Many fish species live in places that experience seasonal changes. In the spring and summer, warm coastal waters encourage large blooms of plankton, which are the base of most marine food webs. Because of this, these months are often ideal for fish growth. In colder months, food availability decreases, and growth rates slow down.

Words to Know

otoliths: inner 'ear stones' (commonly referred to as ear bones) that can be used to age fish.

opercula: hard plate-like flaps that cover the gills of a bony fish.

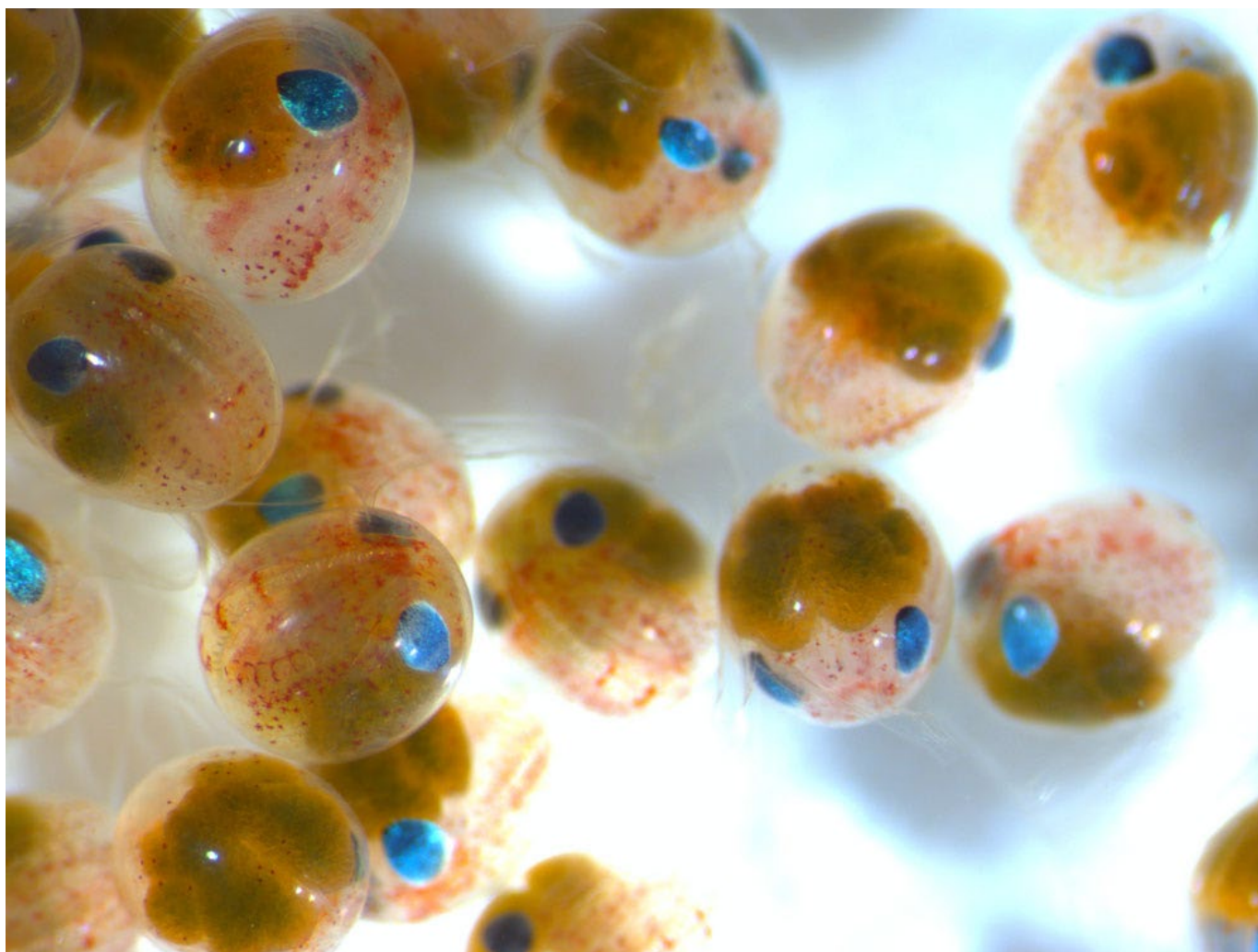
larvae: an early life stage of a fish after hatching from the egg and before the juvenile stage.

juveniles: a young fish, usually resembling an adult in appearance, that has not yet become sexually mature.

Competition. Fish look for habitat that will give them prime access to their preferred food sources. Because of this, competition also impacts growth. Individuals that live in a resource-rich habitat or are faster at catching prey usually grow faster than those who cannot secure productive habitat or aren't as fast at obtaining food.

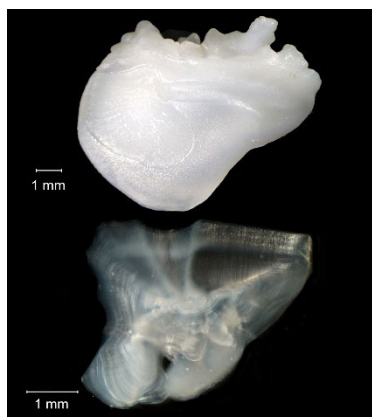
Age. Typically, young fish begin life so small that you often need a microscope to see them. This often means that many young fish are usually eaten before they can make it to adulthood. To give them a shot at survival, younger fish grow at a much more rapid rate than adults. For example, in its first year, a red drum can grow up to approximately 14 inches! Once a fish reaches adulthood, it will divert its energy from growth to reproduction.

But how exactly do you determine the age of a fish? Most commonly, fisheries scientists determine this by examining hard structures on or in their bodies, like [otoliths](#), [opercula](#), fin spines, and vertebrae. Similar to rings in tree stumps, counting the rings on these structures helps scientists determine an individual's age. Also like a tree, these structures grow slower during cold seasons and faster during warmer seasons. This

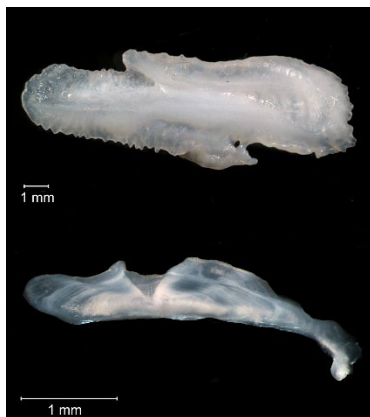


Late-stage American lobster (*Homarus americanus*) eggs photographed with digital dissecting microscope. Photo by: Alicia Miller, NEFSC/NOAA.

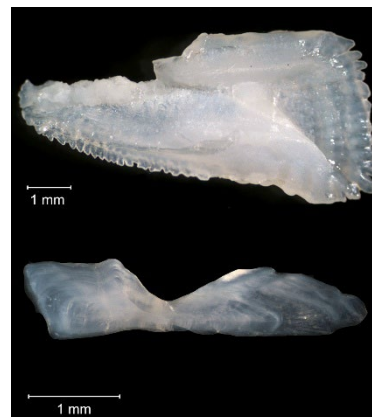
The gallery below shows scales, otoliths, and opercula from various species. Scientists use these marks to age fish.



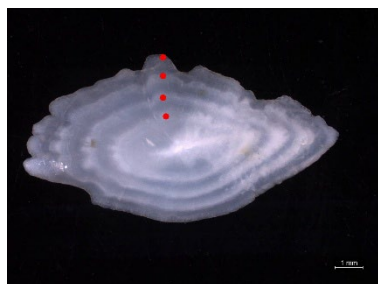
Atlantic croaker otolith (Credit: FL FWC)



Bluefish otolith (Credit: FL FWC)



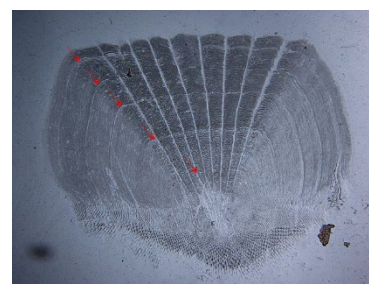
Spanish mackerel otolith (Credit: FL FWC)



Black sea bass otolith (Credit: FL FWC)



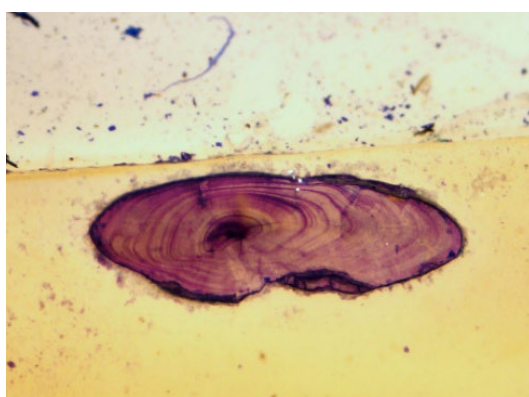
American shad otolith (Credit: MA DMF)



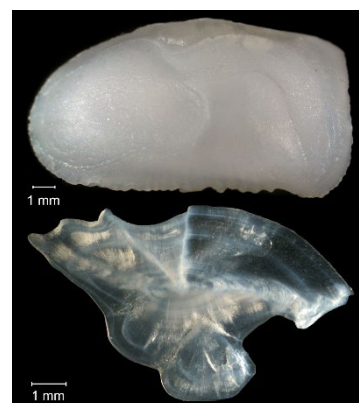
Black sea bass scale (Credit: VIMS)



American shad scale (Credit: MA DMF)



American eel otolith (Credit: ASMFC Ageing Workshop 2018)



Red drum otolith (Credit: FL FWC)

Predator & Prey

To know where to find a fish species, your best bet is to look for its food, but not all species feed the same way, and most fish feed differently at different stages of their lives.

When they're first born, newly hatched fish (or [larvae](#)) are about 1/16 of an inch or even smaller—for finfish, at least. Some sharks and rays lay eggs that are much larger, and others give birth to live young that are several inches long. These larvae are born with a yolk supply that lasts a few days to a few weeks to help them survive while they become large enough to capture their own food. During this stage, they grow organs and muscles and turn into a very small version of their adult forms. Once this is complete, they are considered [juveniles](#). It's here that they start to feed like adults.

Different species use different strategies to capture food. For example, flatfish like flounders blend into the bottom to ambush prey while fish like tautog use their strong jaws and large molars to crush crabs and other invertebrates. Most large fish-eating species have sharp teeth while filter feeders (like Atlantic menhaden) have gills that they use as a sieve to filter out algae as they swim.

Understanding what a fish eats helps us understand the relationships between different species in the ecosystem: who is being eaten by whom, and who relies on whom for food.

Habitat & Migration

Habitat is where species live and all of the living and non-living things in that area that an individual needs to survive. For most people, their habitat is their home, and more broadly, their cities and communities. Similarly, for fish, habitat can be broad, encompassing temperature ranges, specific bottom types, and the communities of other fish they're surrounded by. Based on their life stages, habitat requirements can look different. Some species will spend their whole lives in bays and estuaries close to shore, but others will live there only as juveniles and move to deeper waters or



Photo by: ASMFC, Striped Bass Tagging Cruise (2010).



Photo by: Stephen Badger, Maryland Department of Natural Resources, Striped Bass Young-of-Year Survey.



Photo by: Carl LoBue, The Nature Conservancy.



A rocky intertidal habitat found in coastal Maine. Photo by: Simen Kaalstad, ASMFC.

the open ocean as they grow older. For some species, like Atlantic salmon, American shad, or river herring, this can even mean a complete change from fresh to salt water or vice versa.

Fish will move around in their habitat every day to avoid predators or find prey, but some species will also travel long distances over the course of the year. This long-distance movement is called migration. Fish migrate for a number of different reasons. Some species move north in the summer as the water warms to their preferred temperature and prey becomes more abundant. They then will move south in the winter as the water gets colder. Some species migrate from the ocean into estuaries or rivers during certain times of the year to lay eggs and then return to the ocean. This means that species often occupy several different types of habitats over the course of a year or over their entire lifetime.

Fish habitat can also be directly impacted by human development, leading to loss and degradation. For example, wetlands that serve as nurseries for juvenile fish often

experience poor water quality because of agricultural runoff from fertilizers. Fishing gear like bottom trawls can disrupt bottom habitat through direct disturbance of vegetation, coral, and other structures. Dams and other impediments to free-flowing streams and rivers can prevent spawning fish from getting to upstream spawning habitats.

Fisheries scientists work to better understand exactly what habitat looks like for each fish species at each life stage to better see how these factors can impact the decline or recovery of fish populations and determine which habitats should be protected to support healthy populations.

Reproduction

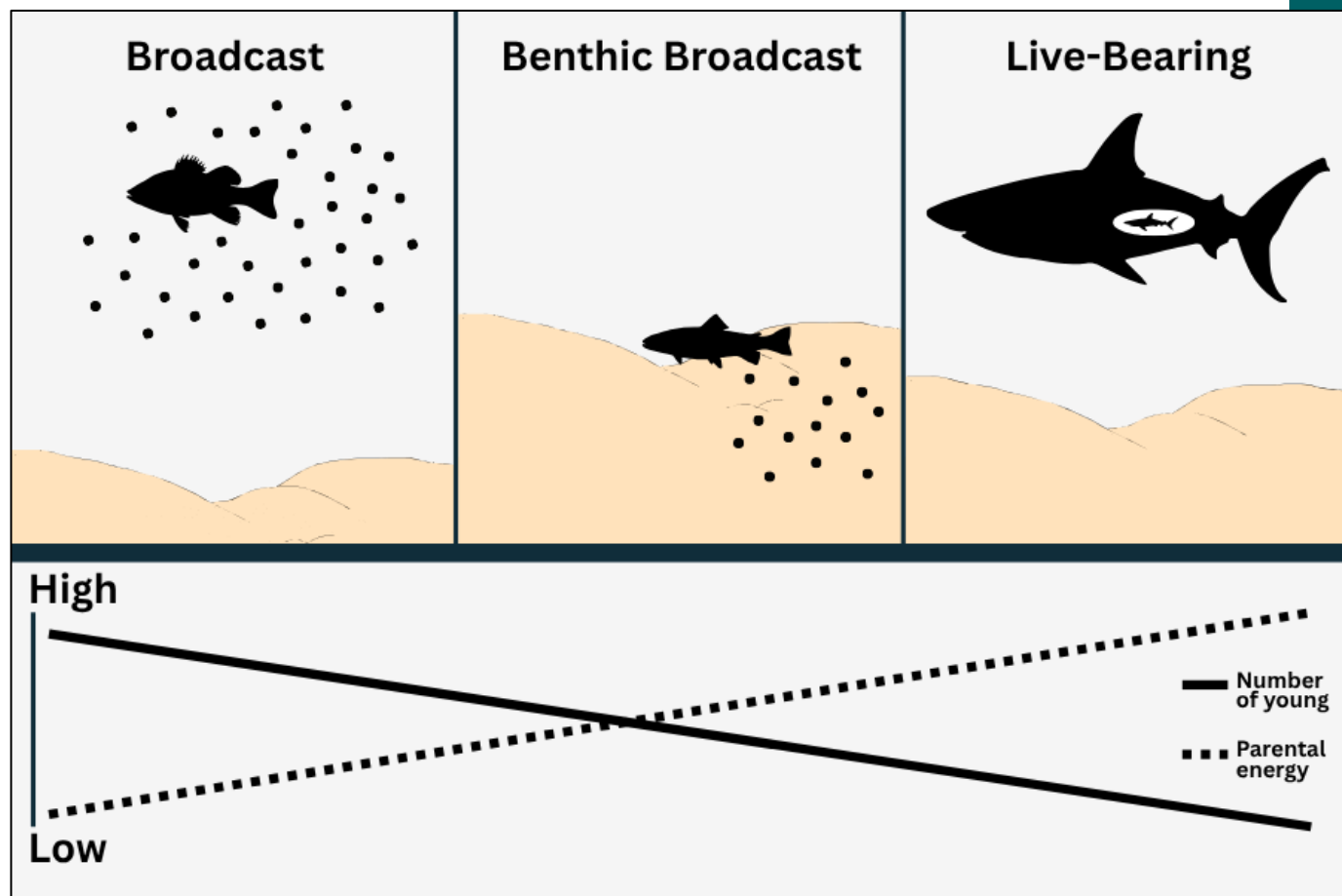
Equally as important as knowing where fish live is where they reproduce. Fish reproduce through spawning events, where eggs are released into the water by females and gametes (sperm or milt) are released by males. To ensure that the eggs and gametes meet, males and females of a species often become ready to mate at the same time of year and may exhibit a variety of courting behaviors.

Most fish have two sexes—male and female—but some function as both male and female during parts of their life cycle. Some are both sexes at the same time (synchronous hermaphrodites), and some switch over the

the course of time (sequential hermaphrodites). For example, black sea bass start life as a female before becoming a male, whereas northern shrimp mature as males before becoming female.

To reduce competition and make sure their offspring have the best chance of survival, fish have evolved a wide range of strategies around when and where they spawn. Many species use the nutrient-rich environments of estuaries as nursery grounds—a place where larvae and juveniles can settle and grow with plenty of access to food. Some of these species will spend their whole lives in bays and estuaries, and some will move out to deeper water once they are grown.

Some species, like red drum, form spawning aggregations where thousands of males and females gather at the same time and place in the estuaries or just offshore where the eggs can be carried into the nursery ground. Some species, like Atlantic menhaden, spawn almost all year round as they move up and down the coast, so that no matter what the environmental conditions are, some of their eggs will find a good nursery area. Some fish species, like Atlantic striped bass, will return to the rivers where they were born to lay their eggs in freshwater. Their young will then move down into the estuaries for several years while they grow and then move out to join the migratory ocean population for the rest of their life, returning once a year in the spring to spawn. These are known as anadromous species. There are also fish, like American eel, that function in the opposite way—spawning in marine waters and living out their lives in freshwater. These are catadromous species. Both of these types of fish are [diadromous](#) fishes, which generally encompass fish that migrate between salt and fresh water to mate.



Words to Know

diadromous fish: fish that spend part of their life cycle in saltwater and part in freshwater; a broader term for both anadromous and catadromous fish.

fecundity: the number of eggs produced per female in a set amount of time (e.g., per spawning season).

population dynamics: the study of how and why fish populations change over time.

natural mortality (M): the rate of death from natural causes such as being eaten by a predator, disease, starvation, extreme heat or cold, or other causes.

Fecundity changes with age, size, and environment. In general, larger, older fish have higher fecundity than smaller fish of the same species, but there is significant variability across species in how many eggs a female can produce, how much energy is invested in parental care, and how quickly individuals mature relative to their total lifespan. For example, spiny dogfish bear live young instead of laying eggs and have two to 15 pups once every two years, while red drum produce around two million eggs in a single spawning season, which hatch after about a day, leaving the newborns to fend for themselves. Usually, species that give greater parental care to their offspring and take longer to reach adulthood relative to their total lifespan are not as reproductive as species that give less parental care, are shorter-lived, and mature early in life.

Understanding fecundity can help determine how many mature fish should remain in the water to ensure they can produce enough eggs for the next year and what size limits managers should set to make sure fish can spawn before we catch them.

Natural Mortality

Natural mortality refers to the death of fish due to natural causes. This includes things like predation, disease, and environmental conditions (fish can die because the water is too hot or too cold or because there is not enough oxygen in it). Natural mortality is usually very high for larval fish and relatively low for adult fish, but this number is difficult to directly measure. However, there is a loose relationship between natural mortality and a fish's life history. Fish that reach adulthood faster, have a faster growth rate, and have a shorter life span generally have higher natural mortality. For example, anchovy would fall into this category. Fish that take longer to reach adulthood, have a slower growth rate, and live longer generally have a lower natural mortality—sturgeon and spiny dogfish fall into this category.

Now that we have gone over the basic life history concepts, let's explore in the next section how these concepts relate to a species' population dynamics.

POPULATION DYNAMICS

The size of a population is determined by the number of new individuals coming in, how much surviving individuals grow that year, and the number of individuals that die. As births occur, the population increases in abundance. With new growth, the population increases in **biomass**. As deaths occur, the population decreases, both in number and in weight.

Words to Know

biomass: the total weight of a stock of fish.

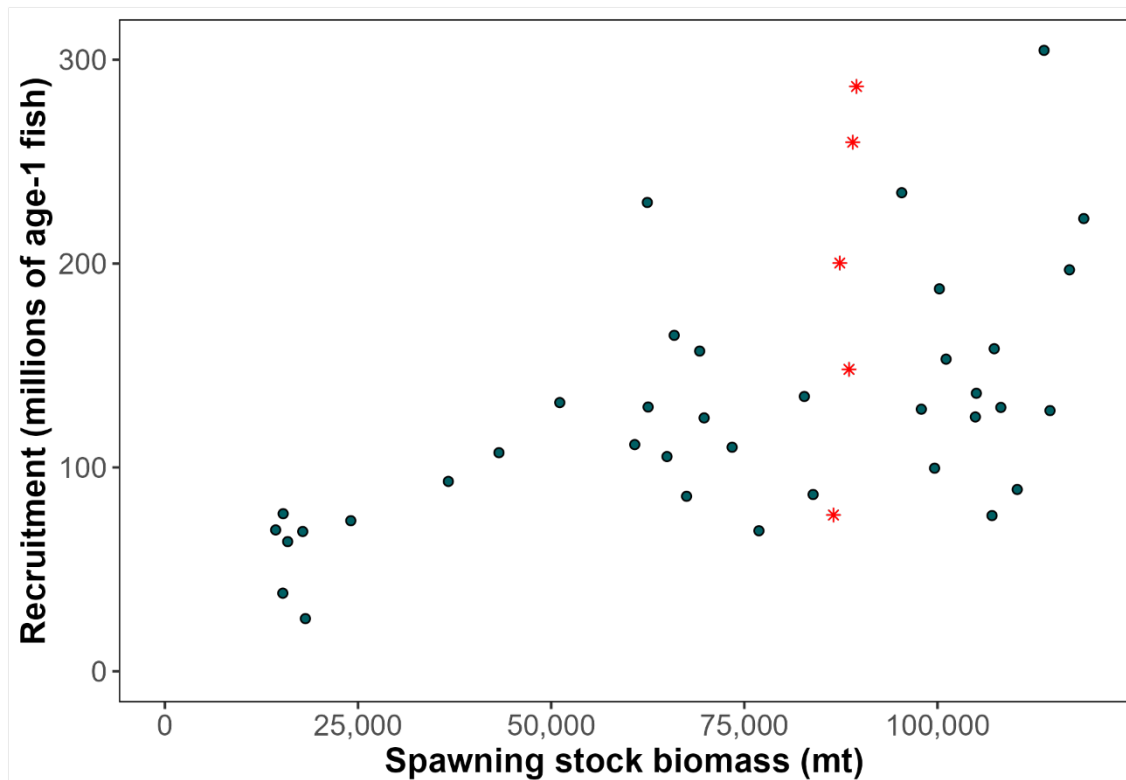
Since all three factors act in unison, population size is constantly changing, or dynamic. Therefore, the study of populations and factors affecting them is often called population dynamics. In this section, we'll define the key factors that influence population dynamics.

Recruitment

Recruitment has multiple meanings in fisheries science. There is recruitment to the population, which refers to births, and there is recruitment to the fishery, which means becoming vulnerable to being caught by fishing gear. In this section, we are mainly focused on the first definition, birth.

Recruitment is the mechanism by which populations increase in abundance. In the life cycle of fish, adults spawn and produce eggs that hatch into larvae that develop into juveniles, which then grow and mature into adults. Newly hatched fish are very vulnerable to environmental conditions like high water temperatures and low dissolved oxygen levels during the summer, or cold temperatures during the winter. In addition, most species are too small at this age to be affected by fisheries. As a result, most stock assessments evaluate recruitment as the number of fish that survive from hatching (age-0) to one year old (age-1).

How many new fish are produced every year depends on both how many adult fish there are to lay eggs and what the environmental conditions are like that year. All species have some kind of relationship between the spawning stock (the number or biomass of mature fish in the population in one year) and recruitment (the number of new fish that enter the population the next year). If there are no adults to produce eggs, then no recruitment will occur. If there are some adult fish, then



some level of recruitment can occur. However, for a lot of species, the size of the spawning stock is less important than environmental conditions. If conditions are good, then a lot of eggs and larvae will survive to age-1, and recruitment will be high. All the fish born in the same year are known as a year-class; e.g., all the Atlantic striped bass born in 2025 are part of the 2025 year-class. If recruitment is high in one year, we say that it was a strong year-class. If environmental conditions are poor and very few fish survive to age-1 that year, we would say that was a weak year-class.

As a result, when we plot the relationship between the spawning stock and recruitment, we often see a lot of variability. For example, in the graph shown here, the red stars indicate years where spawning stock biomass was approximately 90,000 mt; even though the size of the spawning stock was very similar in those years, the level of recruitment produced varied widely. This variability makes it hard to predict just from the size of the adult population how many new fish will enter the population next year.

This is why good young-of-year surveys are so valuable. These surveys go out every year and see whether very young fish (i.e., fish that are less than a year old) are more or less abundant than previous years. For some species, the trends in the young-of-year surveys match trends we see in the fishery and in surveys of older fish a few years later, so these surveys can give us a better idea of whether a strong year-class, a weak-year class, or an average year-class will be entering the population. However, for other species, the relationship between the young-of-year survey and the size of the year-class that enters the fishery is weaker, making the survey less informative.

Growth

The mechanism by which populations increase in biomass is growth. Individual fish grow in both length and weight, so a population with older (and larger) fish is a population with higher biomass. Bigger, heavier fish produce more and/or higher-quality eggs, so it's important to understand not just how many fish are in the

population but how much total biomass is out there and how much mature biomass (i.e., spawning stock biomass) is out there to know how productive the population can be.

Mortality

Mortality is death, and it's what makes a population smaller, balancing out the increases from recruitment and growth.

We separate the total mortality a population experiences into two sources: natural mortality (also referred to as M) and fishing mortality (also referred to as F). Natural mortality, which we discussed in Section 3 above, is death from natural causes, like being eaten by a predator, disease, starvation, extreme heat or cold, or other causes. Fishing mortality is death that results from fishing activity. Fishing mortality includes fish that are caught and kept for sale or personal consumption, as well as fish that are caught accidentally and discarded or released at sea for other reasons, and fish that are released alive but die from the stress and injury of being caught. Both of these are considered discard mortality.

Selectivity

The size and age of the fish that are captured in a fishery depend on the selectivity of fishing gear and how the fishery operates. If the holes in your net are large, smaller fish can slip through, but if your trawl vessel is moving slowly, larger, faster fish can outswim it and avoid being caught. Similarly, if you are fishing in a species' nursery ground, you may catch more small fish than if you are fishing in a more offshore area where the older fish live.

The selectivity of the gear matters. If the fishery catches mainly small, immature fish, that will have a bigger impact on the population than a fishery that catches mainly large, mature fish. Managers set limits on things like the size of the mesh you can use in trawl nets or gillnets and the size of the fish you can keep to help ensure that the fishery is not catching too many immature fish.

We've collected a bunch of data: information on how many fish we catch every year, their biology, and trends with the population and in the fishery. But none of that tells us how many fish are out there or what proportion we are killing (catching and landing) every year due to fishing.

We use [stock assessment models](#) to synthesize all of the fishery-dependent and fishery-independent data we've collected into estimates of the size of the population as well as the fishing mortality rate the population has experienced over time.

In this section, we'll explain what a model is, describe the common types of models we use to assess Commission-managed species, the kinds of data they require, their strengths and weaknesses, and talk about how we evaluate uncertainty in stock assessments.

Just like we are constantly striving to collect more and better data, fisheries biologists are always working to improve stock assessment models to make them more accurate and reliable. The types of models we use have changed over time as our data collection, statistical techniques, and understanding of species' population dynamics have improved.

Words to Know

stock assessment models: mathematical and statistical techniques used to estimate abundance, population dynamics, and stock status.

fitting a model: the practice of finding a combination of parameters or variables that bring predicted values as close as possible to observed values.

What is a model?

A model is a way to describe something that's happening in the real world using math. They work to turn our qualitative understanding of fish dynamics into something quantitative. For example, we know that fish keep growing throughout their lives, but they grow quickly when younger and more slowly as they age. But how fast is "quickly"? How big will a bluefish be when it's two years old? How big will it be when it's five?

The von Bertalanffy growth model is an equation that describes this process. It predicts how long a fish will be at any age.

The von Bertalanffy Growth Model

$$\text{Length at Age } a = L_{\infty}(1 - e^{-k(a-t_0)})$$

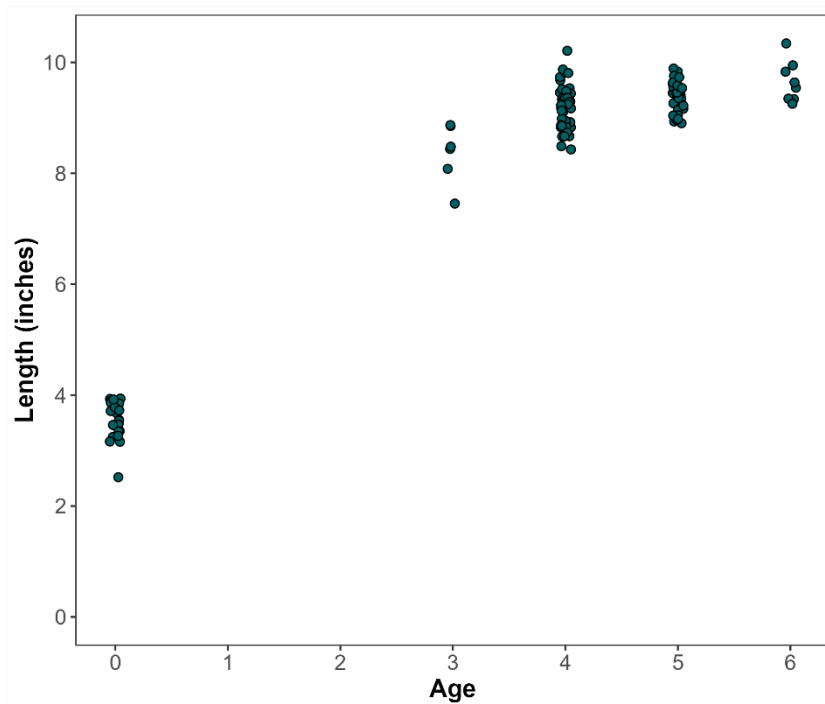
The equation says that the size of a fish at age a depends on:

- L_{∞} (L infinity) is the size the average fish would reach if it lived forever
- k is how fast the fish grows (growth rate)
- t_0 is the hypothetical age at which the length of the fish is zero

How do we know what L_{∞} or k or t_0 is? Those numbers are going to be different for every species. We figure those numbers out by fitting the model to the observed data.

Fitting a Model

To fit the von Bertalanffy growth model, scientists conduct fisheries-dependent and -independent surveys to collect thousands of fish length measurements (for growth data) and otolith or scale samples (for age data). For example, here is what some data for alewife from the Hudson River look like:



On this graph, each dot or data point represents one fish. Based on the placement of the dot, you can see each individual's age and size. In these data, you can see that there is a lot of variability in how big fish are for any given age. Just like humans, not all three-year-olds or six-year-olds are the same size. The youngest fish on average are three to four inches long, while the oldest fish are about 10 inches long on average. Based on this, we can make some guesses about what L_{∞} , k , or t_0 are. Let's say L_{∞} is equal to the largest size we measured in our data, $k=0.45$ because we know other species that are biologically similar to alewife grow that fast, and t_0 , because the length of age-0 fish should be close to zero (fish are very small when they first hatch!).

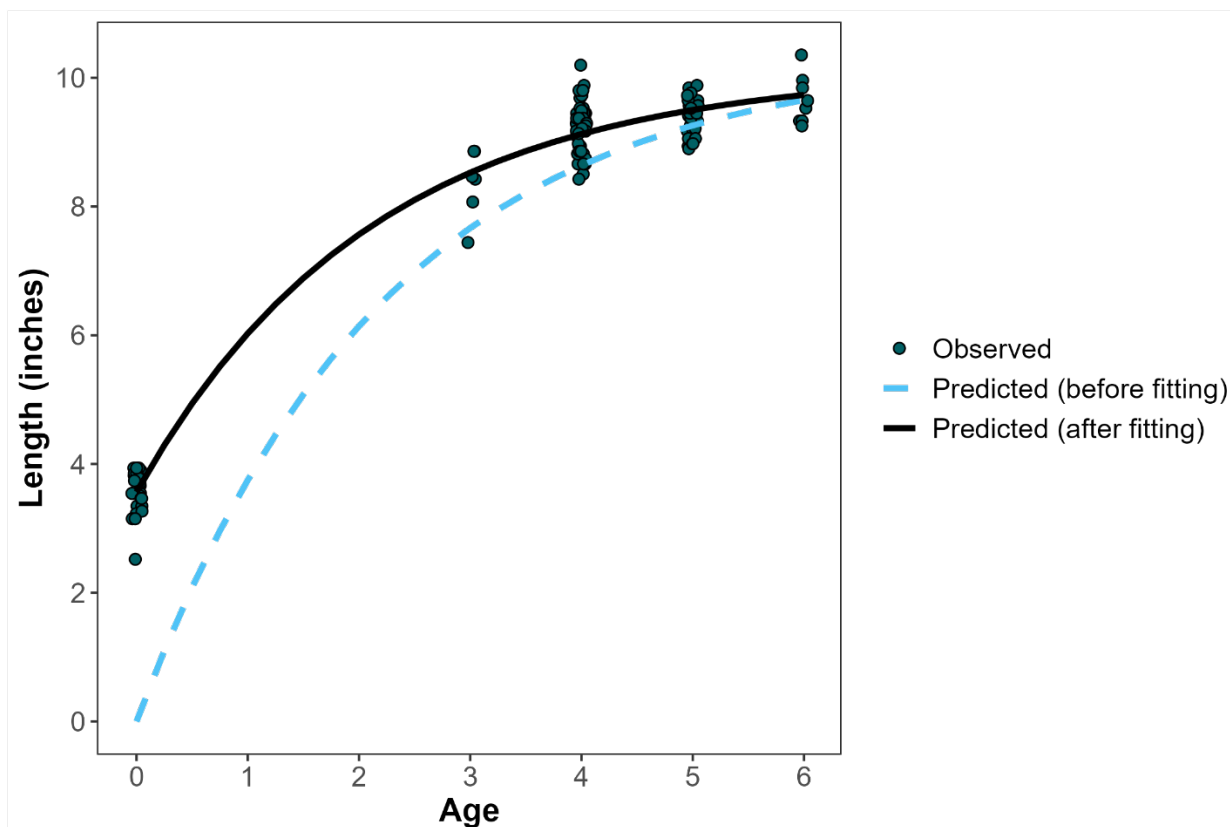
Now we can predict what the average size of an alewife should be at each age using the von Bertalanffy growth model and compare how close we are to the actual observed data.

Age	Observed Average Length	Predicted Average Length (based on initial starting guesses)
0	3.56	0.00
3	8.35	7.67
4	9.21	8.64
5	9.39	9.26
6	9.66	9.65

Pretty close, especially for the older ages! But can we do better? If we tweak our values for L_{∞} , k , and t_0 , we can find the values where our predicted values are as close as possible to our observed values. To do this, there are statistical algorithms that search over a bunch of different combinations of parameters (i.e., L_{∞} , k , and t_0 for this model) and find the combination that makes our predicted values as close as possible to our observed values. This process is referred to as [fitting a model](#) to the data.

For this data set, the final fitted values are $L_{\infty}= 10.1$ inches, $k=0.47$, and $t_0= -0.92$. You can see that the predictions are much closer to the real, observed average values now.

Age	Observed Average Length	Predicted Average Length (based on initial starting guesses)	Predicted Average Length (after fitting the model)
0	3.56	0.00	3.56
3	8.35	7.67	8.53
4	9.21	8.64	9.13
5	9.39	9.26	9.50
6	9.66	9.65	9.73



Why do we need models?

Models allow us to make inferences about things we can't observe based on things we can observe.

In our growth model example, you might be wondering, if we wanted to know the average size-at-age for alewife, couldn't we just use the actual average length that we measure for each age? Sure! And we do for some species, especially ones that don't exactly follow the von Bertalanffy growth model. But look at our data: we don't have any observations for age-1 or age-2. That's because alewife return to the rivers where they were born to spawn and then go back to the ocean. The newly hatched alewife move out into the ocean by the time they turn one year old, and they won't come back until they are mature and ready to spawn themselves, which is between ages three and five. That means we can measure them a few months after they've hatched and are still in the river (age-0), and we can measure the ones that come back to spawn (age-3 and above), but the age-1 and age-2 fish are all in the ocean, where they mix together with other alewife from up and down the Atlantic coast. Alewife from northern rivers grow at a different rate than alewife from more southern rivers, so if we want to know what size age-1 and age-2 Hudson River alewife are, we have to use our von Bertalanffy growth model to predict that.

This is the real strength of models: we can create models to predict things that we can't measure based on the things we can observe. We can't measure how fast alewife grow in the wild, but we can observe the average size-at-age of alewife, and estimate k , the growth rate, from those data.

We do the same thing with our stock assessment models. These models describe how populations grow over time and how the population is affected by fishing. We can observe things like total catch, catch-at-age,

trends in surveys, and much more based on the type of data collected. While we can't observe the size of the whole population each year or observe what would happen if we increase or decrease catch in future years, we can predict those things using our models. We fit our models to the data we do observe to make sure our models are as accurate and realistic as possible.

Model Assumptions

All models make assumptions about how the world works and how the data they use were collected. For example, for the von Bertalanffy growth model, we assume that fish grow quickly when they are young but more slowly as they get older. We also assume that the samples we collect are representative of the whole population.

It's important to understand what assumptions a model is based on, because if those assumptions are wrong, the model will be less reliable and the results we get from it will be less accurate. If fish growth doesn't slow down with age—that is, if fish growth is linear, with older fish growing at the same rate as younger fish—then we would overestimate the size of younger fish and underestimate the size of older fish with the von Bertalanffy growth model.

We can compare the results of the von Bertalanffy growth model to the results of a linear growth model fit to the same alewife dataset. We can see that the von Bertalanffy growth model matches the observed data better than the linear growth model, indicating that the assumption that fish growth slows down over time is valid. In this case, using a linear growth model would provide inaccurate results because it is based on a flawed assumption.

For all our models, we try to make our assumptions based on the data that we have observed and our understanding of the species' population dynamics. As we collect more data and see how the model performs over time, we can adjust our assumptions and make them more accurate and realistic so that the results of the model are more accurate and realistic.

Simple vs. Complex Models

The von Bertalanffy growth model is a relatively simple model: it is one equation with only three parameters that need to be estimated (L_{∞} , k , and t_0). However, we could make it more complex. Another assumption that this model makes is that L_{∞} and k are constant over time. But what if how fast a fish grows or how large that species could get depends on environmental conditions? Maybe alewife grow faster if there is a lot of food



A member of the NEAMAP Near Shore Trawl Survey holding a black sea bass caught during the survey. Photo by: the Virginia Institute of Marine Science (2008).

them, or in warmer water. Maybe they grow more slowly, or reach a smaller maximum size, if there are a lot of other alewife around to compete with them.

We could make a more complex version of the von Bertalanffy growth model that includes other factors so that the length of an alewife at a given age is a function not just of age but also temperature, food availability, or the size of the alewife population. But to do that, we would need to collect more data. The data in the figures above were collected over several years; we combined the data across all years because we are assuming that alewife are growing similarly in those years. To fit the more complex model, we need data not just on the age and length of each alewife but also on the other factors we want to include, like temperature, food availability, or population size. We'd have to make sure we collect enough ages and lengths under different levels of those factors so we know what the average length-at-age is when the water is warm vs when it is cool, during times of high food availability and low food availability, or when the population is very abundant and when it is very small.

Complex models make more detailed assumptions and have more moving parts than simple models. As a result, they are often more biologically realistic than simple models, but they require more data. It's not the case that a simpler model is always better than a more complex model, or vice versa—it depends on the species that we are working on and what kind of data we have. We could make the von Bertalanffy growth model more complex, but if we can't collect enough data to fit it, then the results of that complex model won't be reliable or accurate.

We want to use a model that is only as complex as it needs to be to make the best use of the available data. As we collect more data or change our assumptions, we can make our models more complex, but model complexity can't resolve missing or insufficient data.

Surplus Production Models

Surplus production models were one of the first types of assessment models ever developed. They're not widely used anymore, but the ideas behind them still provide the basis for how we manage most fisheries.

Surplus production models assume that every species has a [carrying capacity](#). In the absence of fishing, the

Words to Know

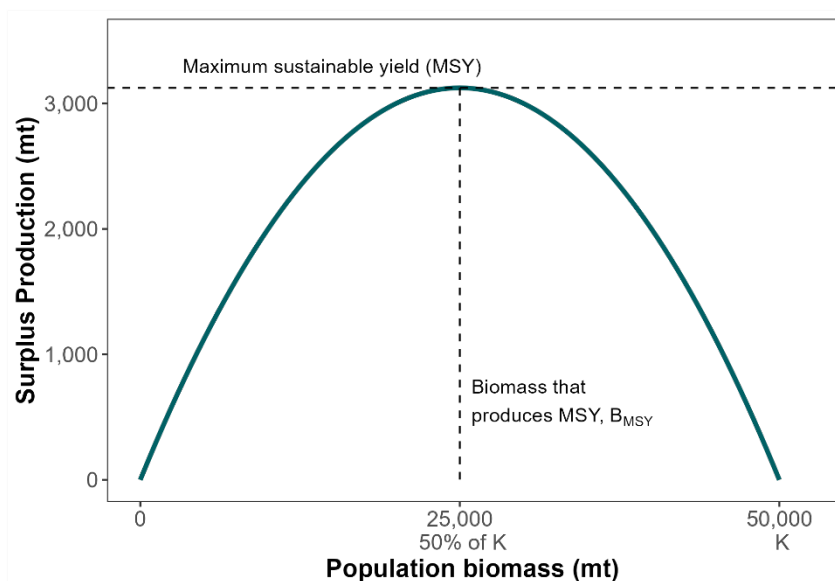
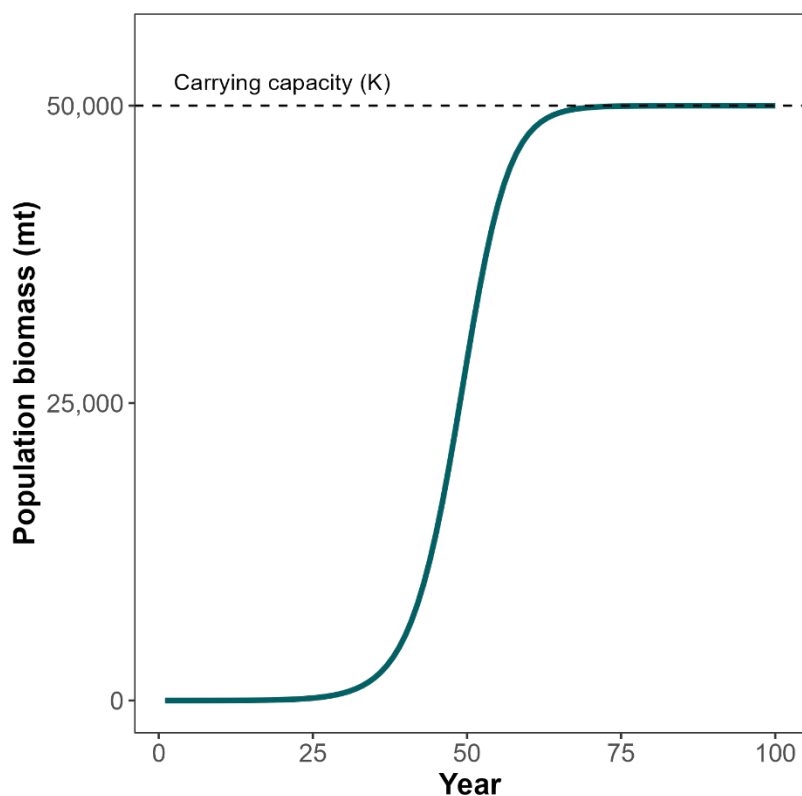
carrying capacity (K): the maximum size of a given population that an ecosystem can support.

surplus production: the total weight of fish that can be removed from a population by fishing without making the population smaller in the next year.

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.

B_{MSY} : long-term average population size that produces maximum sustainable yield.

F_{MSY} : the fishing mortality rate that produces the maximum sustainable yield when the population is at B_{MSY} .



population will grow to the carrying capacity and stabilize there, as competition for resources and habitat will prevent the population from getting larger.

Every year, the population produces enough new biomass to offset any losses from natural mortality and some extra biomass to get it closer to the carrying capacity. We call this extra biomass **surplus production**: the biomass the population produces beyond what is needed to keep the population at the same size as last year. If we harvest only the surplus production, the population will stay at the same level from one year to the next.

The extra biomass the population can produce depends on how close the population is to the carrying capacity. If the population is not close to the carrying capacity, then there are a lot of extra resources to go around, more fish can survive and grow, and there will be more surplus production. As the population gets closer to the carrying capacity, there is more competition for resources, and the amount of extra biomass the population can produce is lower. That means the population will grow more slowly, and the surplus production we can harvest without causing the population to decrease is lower. But if the population is too small, the amount of extra biomass that it can

produce is also lower. There are more resources to go around if the population is small, but there is an annual limit on how many eggs the adults can produce and how much weight each individual fish can gain.

For resource management, we want to catch the highest number of fish we can every year without causing the population to decline or its **maximum sustainable yield (MSY)**. The population size that produces the maximum sustainable yield is B_{MSY} , and the fishing mortality rate that catches the maximum sustainable yield is F_{MSY} .

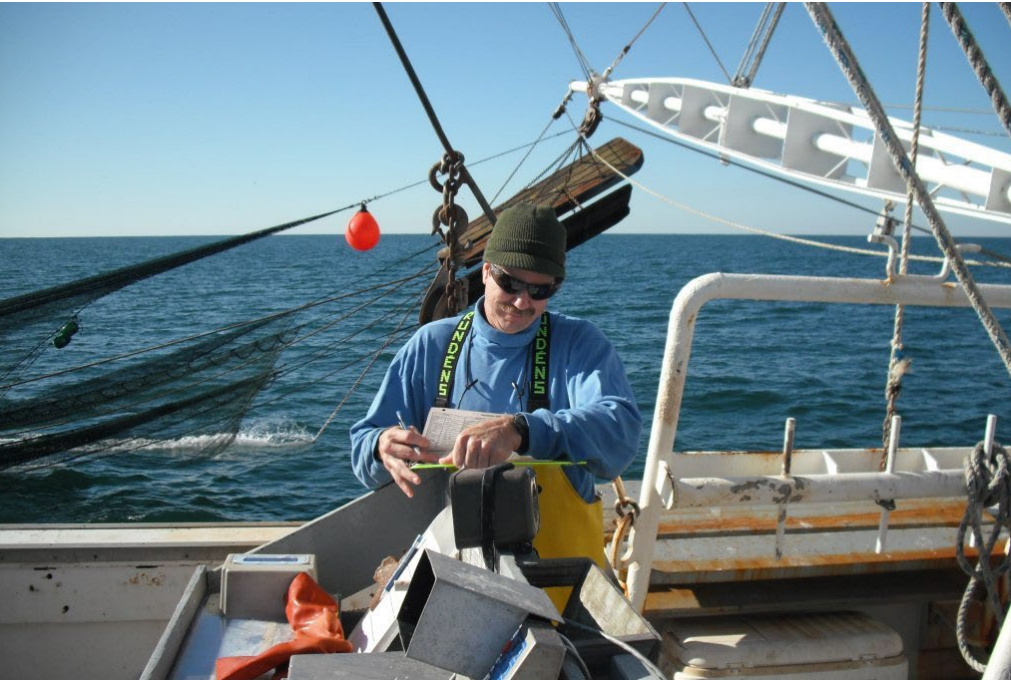


Photo by: South Carolina Department of Natural Resources, Coastal Trawl Survey.

Surplus Production Model Data Needs

To run a surplus production model, we need to know the total weight of fish removed by fishing each year, and we need an index of abundance for the whole population.

Pros and Cons of Surplus Production Models

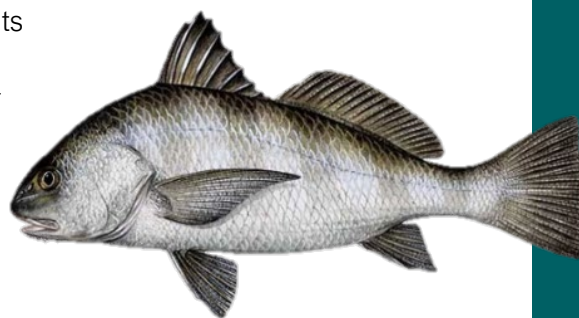
Surplus production models do not require age data, so they

are useful for species whose age data we haven't been collecting regularly, or for species that we can't age. However, surplus production models are not reliable in situations where the catch and the index have only declined over time. We call this a "one-way trip," and it's been common for many species. We have high catches at the beginning of the time series, but those catches are unsustainable, and over time, the population declines, which causes both the index and the catch to decline. In this situation, surplus production models have a hard time figuring out whether this is a population that grows slowly but has high carrying capacity or a population that grows quickly but has a low carrying capacity. In these cases, we would need to stop fishing and see how the population recovers (does it bounce back quickly or not?) to get reliable results from a surplus production model, but for many species, we are only assessing them after a long period of exploitation without a following recovery period.

As a result, surplus production models are not widely used anymore. However, we still use the concept of maximum sustainable yield to develop reference points to use with other models.

Commission Species Assessed with Surplus Production Models

None of the Commission's species are currently assessed with a traditional surplus production model. The [black drum](#) assessment uses an age-structured production model, which combines elements of a surplus production model with elements of age-structured models to take advantage of some of the strengths of both types of models.



Catch Curves

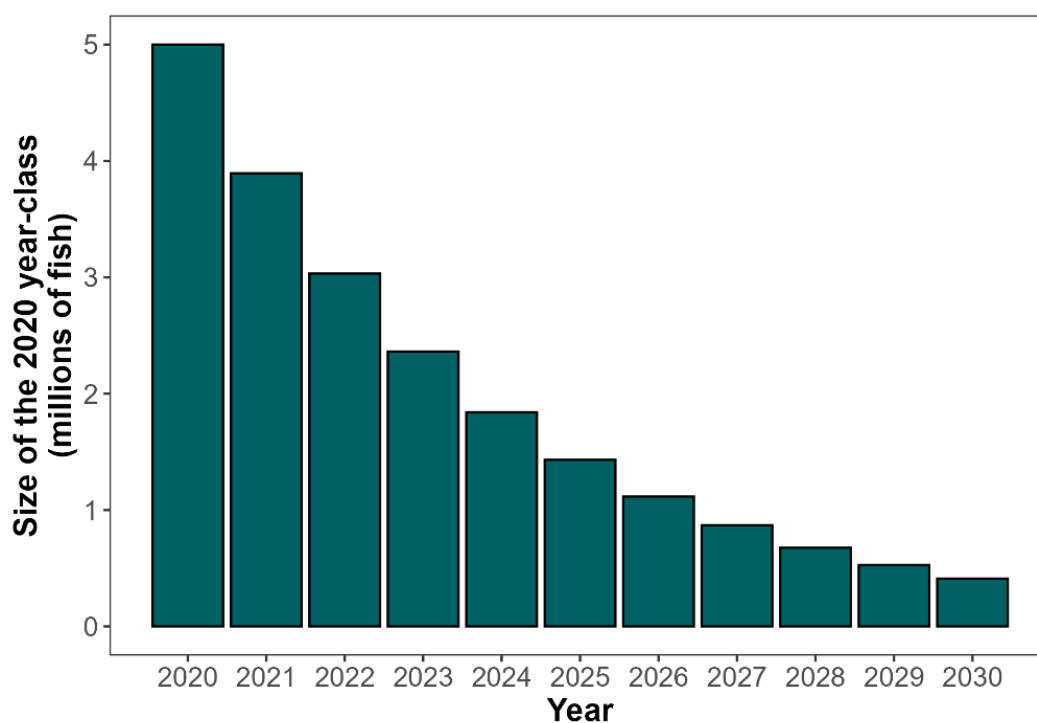
Words to Know

catch-at-age: the number of fish at each age removed by all fishing activities.

Surplus production models treat the population as one big blob of biomass that grows or shrinks over time, but we know that different ages in the population are experiencing different things. The number of fish that are born and enter the population varies from year to year based on how many eggs are produced and what environmental conditions are like. Young fish are more likely to be eaten by predators, but older fish are more likely to be caught in the fishery. If we break the population down into age classes, we can better understand what's causing the population to grow or decline. This allows us to ask questions like, has recruitment been poor for a number of years, or are we harvesting too many fish before they can mature?

Catch curves are the simplest form of an age-structured model and are another early example of stock assessment models.

As we discussed in the last section, every year, fish are born, creating a year-class. That year-class will get older: fish that hatched in 2020 make up the 2020 year-class (age 0). In 2021, they would be 1 year old (age 1), in 2022, they would be 2 years old, and so forth. Every year, some fish from that year-class die. The 2020 year-class was most abundant in 2020, and every year since it's gotten smaller as fish die. If we plot the abundance of that year-class over time, it would look something like the graph below.



We can go out and take samples from the catch and figure out how many fish of each age we catch every year. We call this catch-at-age.

For example, to the right, you can see what the catch-at-age looks like for tautog in 2022.

There are usually one or two ages which are most common in the catch, with younger and older fish being less common. The youngest fish are not fully vulnerable to the fishery yet because of size limits, the type

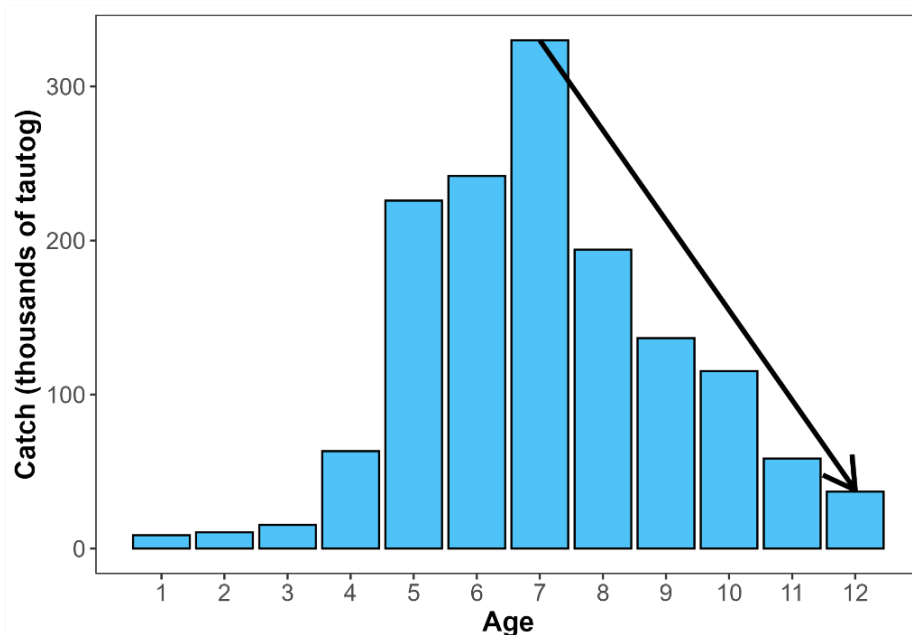


Photo by: Maryland Department of Natural Resources, Gillnet Survey (2018).

of gear used, and where the fishery takes place. As a result, the younger fish are less common in the catch.

Once fish reach a certain age, they're fully vulnerable to the fishery and caught more frequently. After that age, the number of older fish in the catch decreases, because each year-class can only get smaller over time, meaning there are fewer older fish available to be caught.

In the early 1900s, fisheries scientists realized that they could estimate the total mortality the population is experiencing from the rate at which older fish disappear from the catch.

If we know what natural mortality is for this species, we can calculate fishing mortality by subtracting natural mortality from the total mortality—what's left over is fishing mortality.

Catch curves can't tell us anything about the total size of the population, or whether it's getting bigger or smaller over time, but they can tell us the mortality rate that the population is experiencing.

Catch Curve Data Needs

To run a catch curve, we need at least one year of catch-at-age data. This can come from the fishery (fishery-dependent data) or from a survey (fishery-independent data).

Pros and Cons of Catch Curves

Catch curves are useful for scenarios where we don't have an index of abundance, where we don't know what the total catch is, or where we don't have a long enough time-series of catch-at-age data to run a more complex age-structured model.

Catch curves are less reliable in situations where recruitment varies a lot from year to year or where older fish are less vulnerable to the fishery (for example, in fisheries with both a minimum and a maximum size). Catch curves assume that total mortality is constant over the years or ages that you include in the analysis. They essentially estimate an average mortality over several years, not a year-specific value.

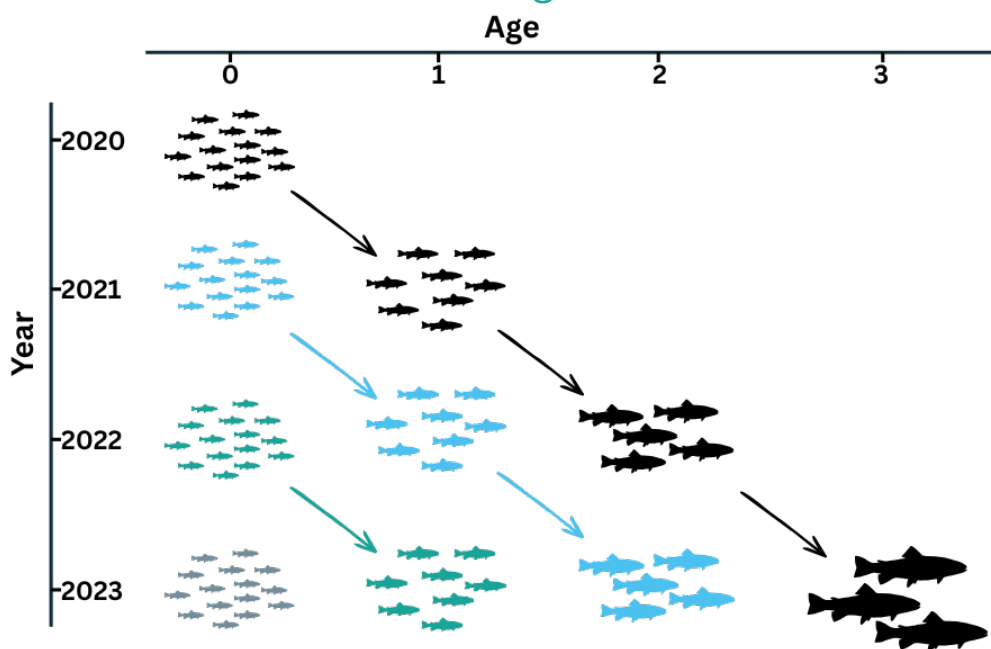
Commission Species Assessed with Catch Curves

The Commission uses catch curves to assess [American shad](#) and [river herring stocks](#). For American shad and river herring, each river represents a single stock. All the stocks along the Atlantic coast mix in the ocean where they are caught as bycatch in other fisheries. That means we don't know how many fish are

killed from each river every year. In addition, many of the rivers do not have surveys to track adult abundance from one year to the next. But many rivers have data on the ages of fish coming back to spawn, either from in-river fisheries or from samples of fish crossing dams to move upstream. We can use catch curves to calculate total mortality to evaluate whether mortality levels are too high.



Statistical Catch-at-Age Models



Catch curves are based on the idea that the age structure of the catch and how it changes over time tells us something about the total mortality the population is experiencing. Statistical catch-at-age models take this idea and combine it with more information on total catch, fishery-independent surveys, and life history information to create a model that can estimate fishing mortality, recruitment, and total population size.

Statistical catch-at-age models track each age-class through the population from year to year. This lets the model account for differences in what happens to each age over time. For example, younger ages are less vulnerable to the fishery than older ages, so they experience a lower fishing mortality rate, but they also usually experience a higher natural mortality rate because they are more vulnerable to predators. In fisheries that are managed with a minimum size limit, all of the age classes that are larger than that minimum size will experience the same fishing mortality, while in fisheries that have both a minimum and a maximum size limit (also known as a slot limit), the older fish that are larger than the maximum size will experience a lower fishing mortality than the younger fish that are within the slot limit.

Statistical catch-at-age models estimate what fishing mortality was and how many new fish entered the population every year by predicting how many fish from each age class were caught each year, what the total catch was, and whether the population increased or decreased.

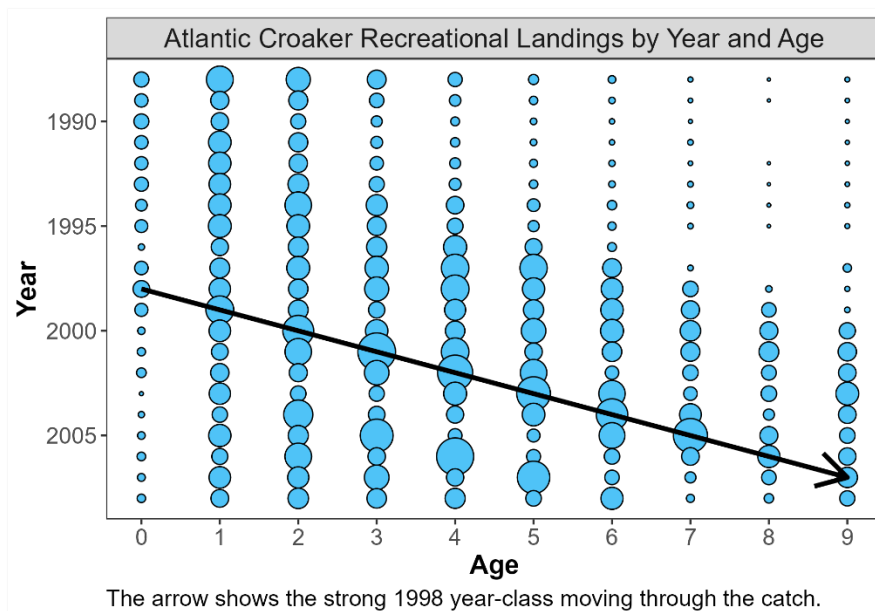


Photo by: Kate Taylor, Striped Bass Tagging Survey (2011).

These predictions can be compared to observed data to find the estimates of fishing mortality and recruitment that match the observed data most closely.

Some statistical catch-at-age models can incorporate information on environmental factors such as water temperature or river flow to help explain patterns in recruitment or trends in population size and provide better predictions about the future productivity of the stock.

Statistical Catch-at-Age Model Data Needs

Statistical catch-at-age models require catch-at-age information. They also need information on the number of fish killed by fishing every year, an index of abundance with age-structure information (i.e., how many fish

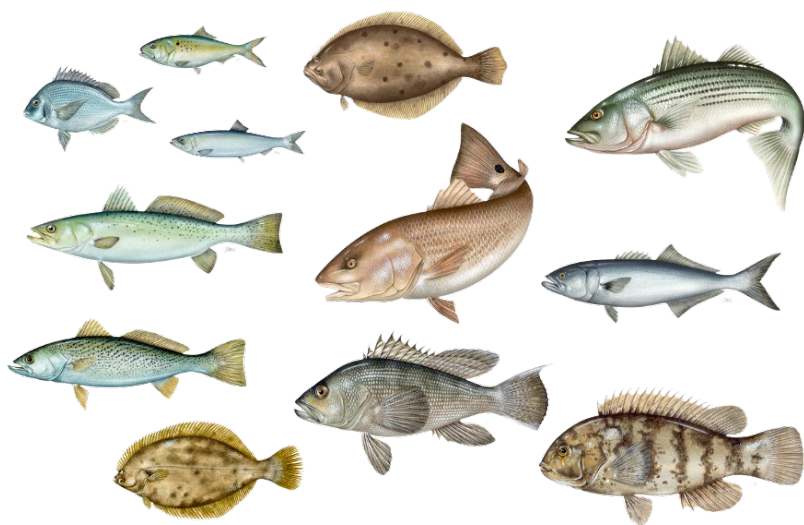
of each age do we see in the index data each year), an estimate of natural mortality, and information on growth and maturity.

Pros and Cons of Statistical Catch-at-Age Models

Statistical catch-at-age models provide the most detailed information on the population and can handle populations where recruitment is highly variable better than surplus production models and catch curves. However, they require a lot of data collected over at least ten years to produce reliable results.

Bayesian State-Space Models

You may hear some stock assessments use a Bayesian or a state-space model—these terms describe the statistical techniques used to fit the assessment model, not what kind of population model it is. You can have a Bayesian surplus production model or a Bayesian statistical catch-at-age model. The Woods Hole Assessment Model (WHAM), which is used to assess many species in the Northeast region, including bluefish and black sea bass, is a state-space catch-at-age model. Just Another Bayesian Biomass Assessment (JABBA), which is used to assess black drum, is a Bayesian state-space surplus production model.



Commission Species Assessed with Statistical Catch-at-Age Models

Statistical catch-at-age models are used for a number of Commission-managed species, including [red drum](#), [Atlantic menhaden](#), [Atlantic striped bass](#), [tautog](#), [weakfish](#), [spotted seatrout](#), [Atlantic herring](#), [black sea bass](#), [bluefish](#), [scup](#), [summer flounder](#), and [winter flounder](#).

Ecosystem Model Approaches

The models described above—surplus production models, catch curves, catch-at-age models—are single-species models. They are applied to one species at a time and only take into account the catch and population trends for that species alone. However, we know that each individual species is part of the larger ecosystem and that what happens to one species can affect other species in the ecosystem. For example, if there is not enough prey, like Atlantic menhaden and herring, the population of predators, like Atlantic striped bass and bluefish, can be negatively impacted. This reduction in prey availability could be due to environmental conditions, fishing pressure on the prey species, or competition by other species, which become too abundant and feed on the same prey species.

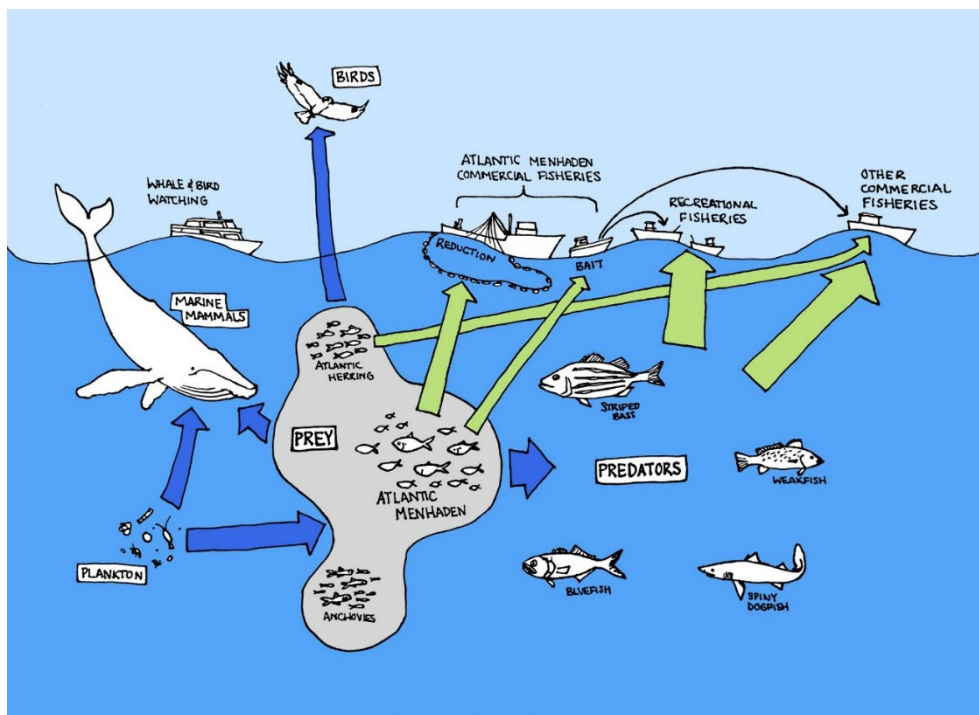


Figure by: Sarah Murray.

Ecosystem models analyze data for multiple species at once to understand how they interact and how fishing for each species affects not just each individual species but also the other species in the ecosystem.

Ecosystem Model Data Needs

Ecosystem models are our most data-intensive models. They not only require the same kinds of information we need to do a single-species stock assessment (e.g., catch and index data) but also information on diet and consumption rates. They need this for all the species in the model, so not just the high-profile species like Atlantic striped bass that are well-monitored and have their own stock assessments and extensive diet data studies, but also the species that form the basis of the food chain, like zooplankton and tiny invertebrates that live on the seafloor, as well as species that don't have traditional stock assessments or diet studies like birds and marine mammals.



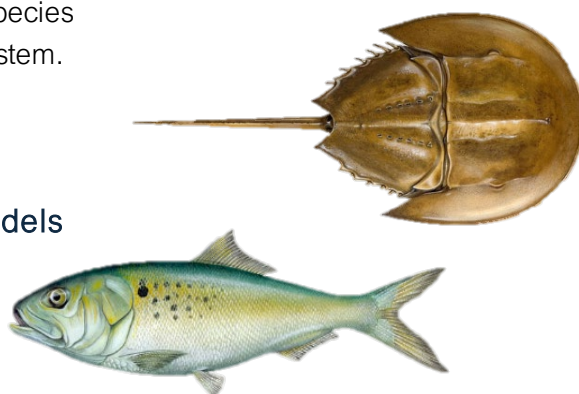
Photo by: ASMFC, Horseshoe Crab Tagging Survey (2005).

Pros and Cons of Ecosystem Models

Ecosystem models can help us manage species in a more holistic, comprehensive way to ensure that the management of one species doesn't have a negative impact on other species in the ecosystem. However, they require a lot of data.

Commission Species Assessed with Ecosystem Models

The Commission uses ecosystem models to set quotas for [horseshoe crabs](#) and [Atlantic menhaden](#).



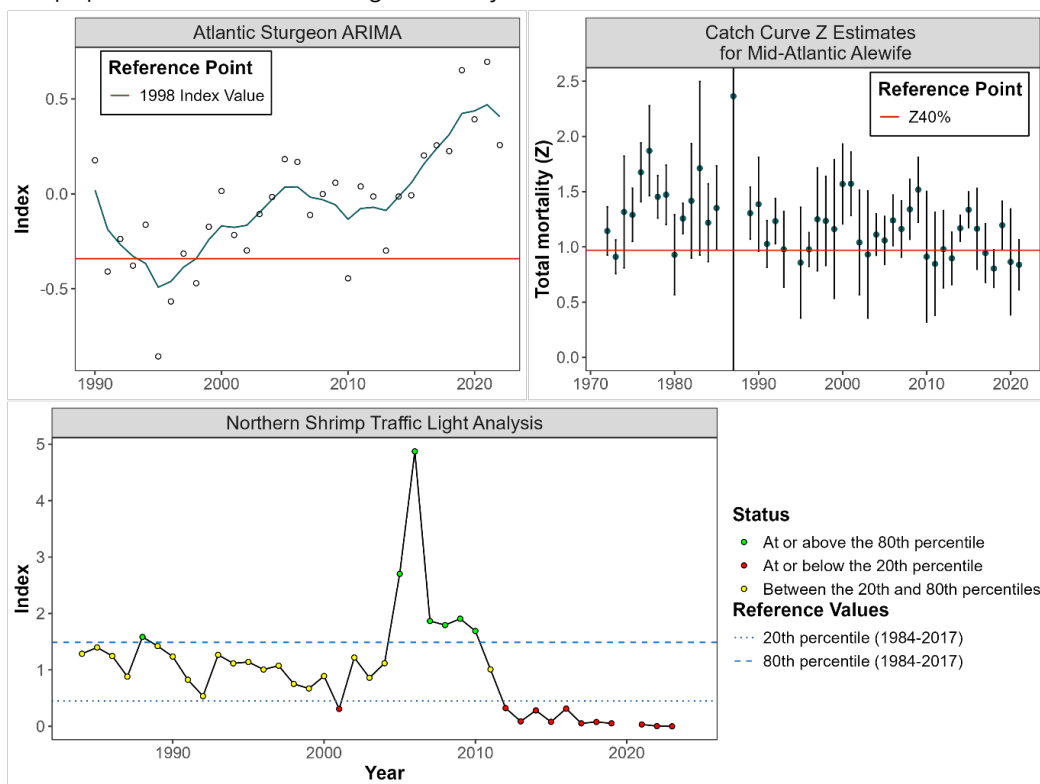
Data-Limited Approaches

Stock assessment models need data on total catch (what's landed and what's discarded or released at sea) and catch-at-age, population trends (indices of abundance), and biological information (e.g., length, weight, maturity, natural mortality). But for some species, we only have one or two of these types of data.

Maybe we don't have reliable estimates of catch because it's a species that's hard to tell apart from other similar species, like some snapper or grouper species. Maybe we don't have reliable indices of abundance because it's a species that's hard to catch in our surveys, like cobia, or it's a species that's difficult to age, like American eel. Or maybe we have catch and index data, but our assessment models fail and can't provide reliable estimates of population size and fishing mortality.

In these cases, we still need some way to provide management advice for these species, and that's where data-limited approaches come in. There are a wide range of different data-limited approaches that have been used, and what we use depends on what kind of data are available.

Catch curves are an example of a data-



Three examples of data-limited approaches: trend-based (top left), catch curve, (top right), and traffic light (bottom).



Photo by: South Carolina Department of Natural Resources, Coastal Longline Survey.

limited approach: they are useful in situations where we only have information on the age structure of the catch.

There are catch-based methods that can provide advice about what level to set catch for the future and trend analyses that evaluate whether the population is increasing or decreasing or is above a historical reference point. There are also methods that scale current catch levels based on whether an index is trending up or down so that future catch will be lower if the

population is trending down and higher if the population is trending up.

Data-Limited Approaches Data Needs

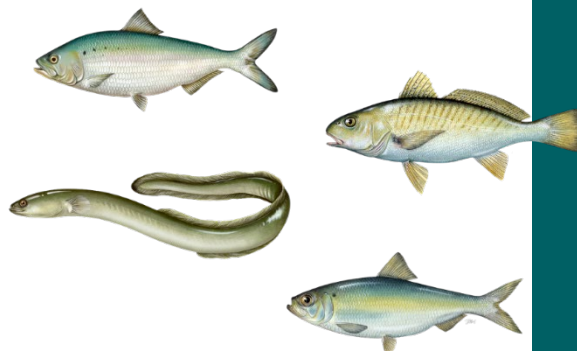
These methods are designed to work with the data that you have. There are methods that need only catch or catch and some information on life history, like growth rates, natural mortality, etc.; some that require only indices; and others that use a combination of catch and indices.

Pros and Cons of Data-Limited Approaches

These methods can provide managers with information on population trends or recommended catch advice for the future even in situations where very little data are available, so that managers can make science-based decisions that aim to keep those fisheries sustainable. However, these approaches don't give us the same understanding of stock dynamics that a more data-rich model does, so we can't predict the effects of management action as reliably. These approaches are better than doing nothing, but we still work to improve our data collection and models so that we can move away from them for as many species as possible.

Commission Species Assessed with Data-Limited Approaches

The Commission uses data-limited approaches for [American shad](#) and [river herring](#), [American eel](#), and [Atlantic croaker](#).



That's a lot of different ways to assess a stock. For a quick reference for all of the different types of modeling approaches, check out the table below!

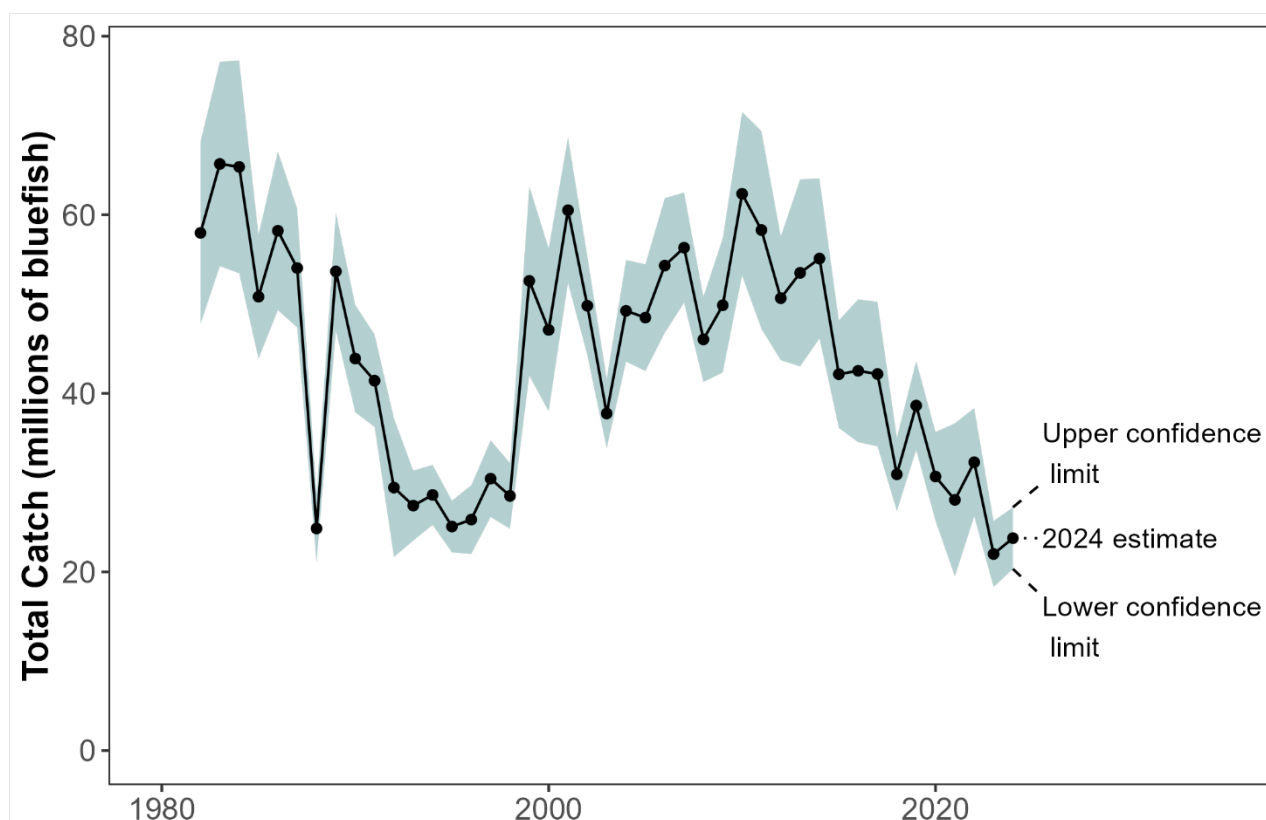
Modeling Approach	Description	Data Needs	Pros and Cons	Commission Species Assessed with This Approach
Surplus Production	Assumes every species has a carrying capacity and is focused on the surplus production of the population. Aims to measure the maximum sustainable yield of a fishery.	Total weight of fish killed by fishing each year, index of abundance for the whole population	Pros: don't require age data. Cons: they are unreliable when catch and abundance only decline because they can't distinguish between slow-growing populations with high carrying capacity and fast-growing ones with low capacity.	None, but the black drum assessment uses an age-structured production model
Catch Curve	Breaks the population into age classes to help us understand growth and decline. A simple age-structured model that tracks how each year-class declines over time using catch-at-age data.	One year of catch-at-age data	Pros: don't require an index of abundance, total catch or a long time-series. Cons: less reliable when recruitment varies a lot from year to year or when older fish are less vulnerable to the fishery because it assumes that total mortality is constant over time and age.	American shad and river herring
Statistical Catch-at-Age	Tracks each age-class through the population from year to year, accounting for differences in what happens to each age over time	Catch-at-age data, total number of fish killed by fishing every year, an index of abundance with age-structure information, an estimate of natural mortality, and information on growth and maturity	Pros: provides the most detailed information on the population and can handle variability in recruitment. Cons: require at least ten years of data.	Atlantic striped bass, red drum, Atlantic menhaden, tautog, weakfish, spotted seatrout, Atlantic herring, black sea bass, bluefish, scup, summer flounder, winter flounder
Ecosystem	Analyze data for multiple species at once to understand how they interact and how fishing for each species affects not just each individual species, but also the other species in the ecosystem	All of the above data needs, diet and consumption rates for all the species in the model and for those impacted by species in the model	Pros: help us manage species in a more holistic way to ensure that management of one species doesn't negatively impact another. Cons: require a lot of data.	Horseshoe crab, Atlantic menhaden
Data-Limited	Includes a wide range of approaches that work off of limit data	Works with whatever data you have available	Pros: can provide managers with population trends or recommended catch advice even when there is limited data available. Cons: cannot predict the effects of management actions as reliably as we can with other modeling approaches	American shad and river herring, American eel, Atlantic croaker

Uncertainty in Stock Assessments

No dataset or model is perfect. So, there is always some degree of uncertainty in the results of a stock assessment. Following are some of the ways that fisheries scientists describe and present uncertainty in stock assessments.

Confidence Intervals

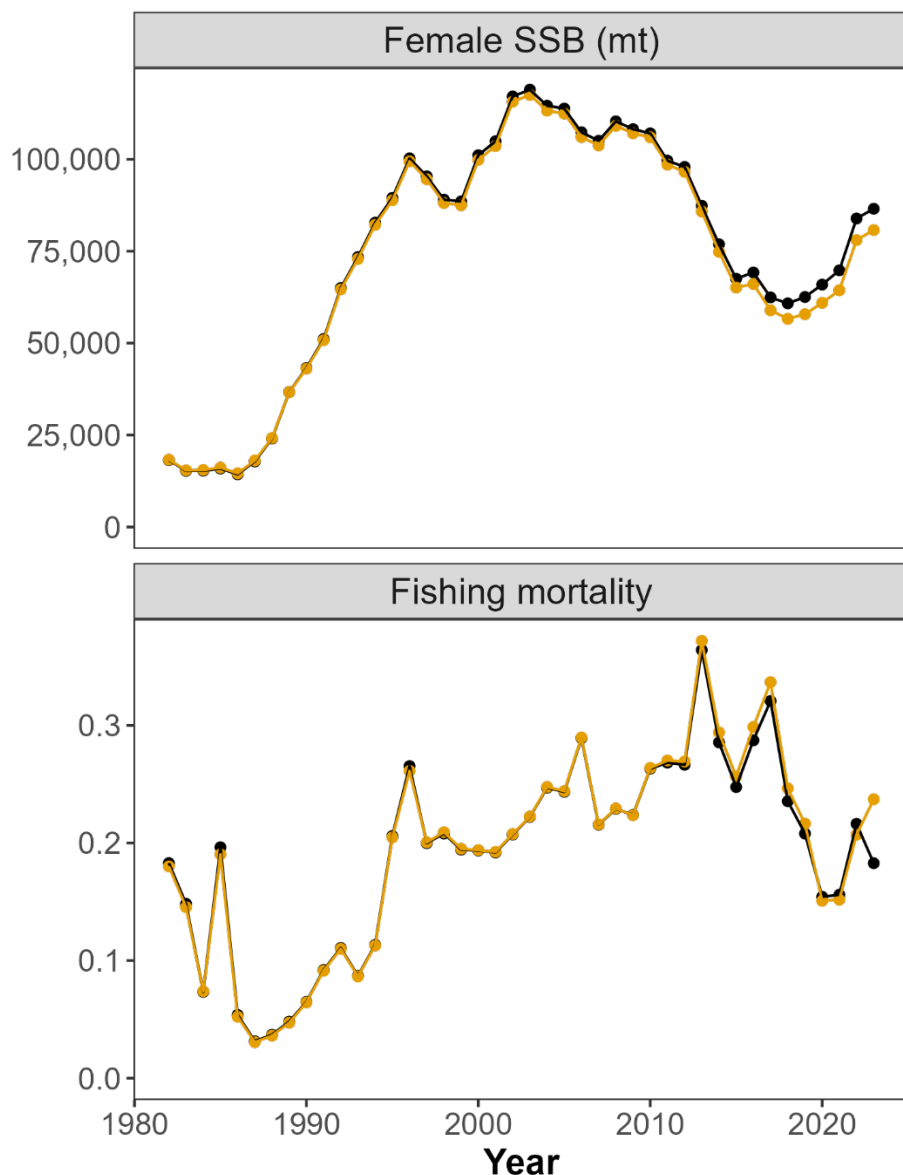
Real data are messy. To estimate how many fish are caught by recreational anglers on the Atlantic coast every year, state biologists go out and interview people returning from fishing trips to see how many fish of each species they caught on their trips. They can't interview everyone, so they interview a sample of those anglers and calculate the average number of fish from each species that were caught on that trip. To get an estimate of how many bluefish were caught by recreational anglers in that year, MRIP takes the estimate of how many bluefish are caught on every trip and multiplies it by the estimate of how many recreational angler trips were taken on the Atlantic coast that year. But not every trip catches the same number of bluefish, so there is



The shaded area indicates the confidence interval around the best estimate of catch for each year. The confidence interval is the range between the upper confidence limit and the lower confidence limit.

variability in the estimate of how many bluefish are caught on every trip. MRIP takes that variability into account when it estimates the number of fish that are caught and reports [confidence intervals](#) on the estimate. For 2024, MRIP estimated 23.8 million bluefish were caught on the Atlantic coast, with 95% confidence intervals ranging from 20.3 million to 27.3 million bluefish. This means 23.8 million fish is our best estimate of how many bluefish were caught, and, if our survey methods and assumptions are correct, it's likely that the true number of bluefish caught is between 20.3 million and 27.3 million.

Our stock assessment models can do something similar: we can take into account the variability in the survey data and the catch data and provide confidence intervals around our estimates of fishing mortality and population size, so we can show what we think the best estimate is as well as a range of likely estimates—assuming our models are capturing the population dynamics correctly.



Estimates of female spawning stock biomass and fishing mortality from the base run (black lines and circles) and a sensitivity run (yellow lines and circles) of the 2024 striped bass stock assessment update. The base run uses what we consider the most realistic and most defensible assumptions and data, while the sensitivity run makes a change to one of the assumptions to see what happens if we are wrong about that assumption. In this case, that change does not affect the results very much: female SSB is slightly lower in the sensitivity run, and the estimate of fishing mortality is higher in the last year. In this case, we would say that the model is not very sensitive to that assumption.

Sensitivity Runs

Confidence intervals are useful for understanding some of the uncertainty in stock assessment results, especially uncertainty from data that we can incorporate into the model itself. But they don't capture all of the potential sources of uncertainty. We use sensitivity runs to test the effect of assumptions that we make, including things like our estimate of natural mortality, the inclusion or exclusion of different surveys, whether we assume all older fish are equally vulnerable to the fishery, and so on. We compare the results of these runs to the results of our base run main model results (which includes all of the assumptions that we think are most defensible and likely to be correct, to see what the effect is on our estimates of fishing mortality, population size, and stock status.

In some cases, changing an assumption might result in a higher or lower population size (with the same increasing or decreasing trend), a change in the overall trend (with a similar estimate of population size at the end of the time series), or a similar stock status determination.

This helps us understand how well our models fit the data and assumptions that go into them.

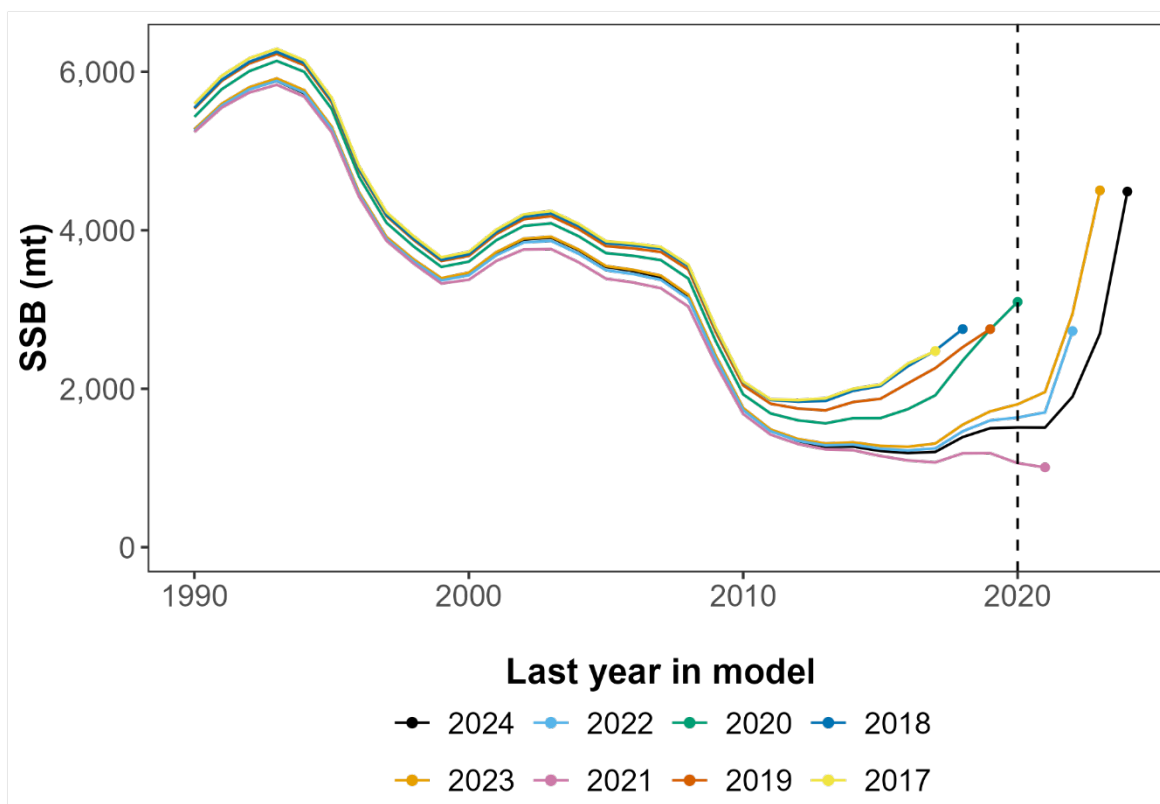
Retrospective Analysis

The most recent few years of the assessment are usually more uncertain. As a result, when we add more years of data (for example, during an assessment update), the estimates for those years can change. If our model ended in 2021 for the last assessment and we add data for 2022-2025 during this assessment, our estimate of what we thought fishing mortality and population size were in 2021 will be different, because the model has more data on what happens after 2021.

For example, the young-of-year index might be high in the last year or two of the assessment, so the model predicts that recruitment was high in those years. But as we add more years of data, if we don't see those young fish show up in the catch and the adult index doesn't increase very much, the newer assessment may say that, actually, recruitment wasn't very high in those years after all.

For some assessments, this difference will be small, but for other assessments, this difference could be significant. We can't know what will happen to our estimates in the future, once we add new data, but we can try to predict what will happen by exploring the impact of dropping years of data from our current assessment. This is called a [retrospective analysis](#).

Let's say the last year of data we have is 2024, so our model provides information on fishing mortality and population size through 2024. To do a retrospective analysis, we would drop all of the 2024 data and rerun the model, so the model stops in 2023. Then we'd drop the 2023 data and rerun the model so it stops in 2022. After doing this five to seven times, we'd compare the results of the model that stops in 2024 to the models that stop in 2023, 2022, and so on. This is what the results usually look like:



In this case, the estimate of spawning stock biomass in 2020 is the highest when the model ends in 2020 and lowest when the model ends in 2021. This means that if we had done the assessment in 2021 (with the last year of data being 2020), we would have thought the population was bigger in 2020 than it really was. If this pattern continues in future assessments, then our estimate of population size in 2024 would be too high.

There are a lot of things that can cause [retrospective patterns](#), including missing catch (e.g., lots of unknown discards), changes in natural mortality, or other factors that may prevent us from reducing or correcting a retrospective pattern during an assessment. In that case, if the pattern is significant, we may use the results of the retrospective analysis to adjust the estimate of population size and fishing mortality in the last year of the assessment and in the projections.

Words to Know

confidence intervals: the range of values (upper and lower limits) that an estimated value can be expected to fall between if the assumptions used to estimate it are correct.

retrospective analysis: an analysis used in stock assessments to examine a model's stability and precision by removing recent years of data one-by-one and re-running the model to see whether the results change in a consistent, predictable way.

retrospective pattern: the phenomenon in stock assessment models where estimates of parameters, like biomass and fishing mortality, change in a consistent direction (i.e., consistently increasing or decreasing from previous estimates) as new years of data are added to the model.

reference points: specific values of population metrics like fishing mortality and biomass that are used to evaluate a stock's status and the sustainability of the current catch.

Projections: From Stock Assessment Models to Management Advice

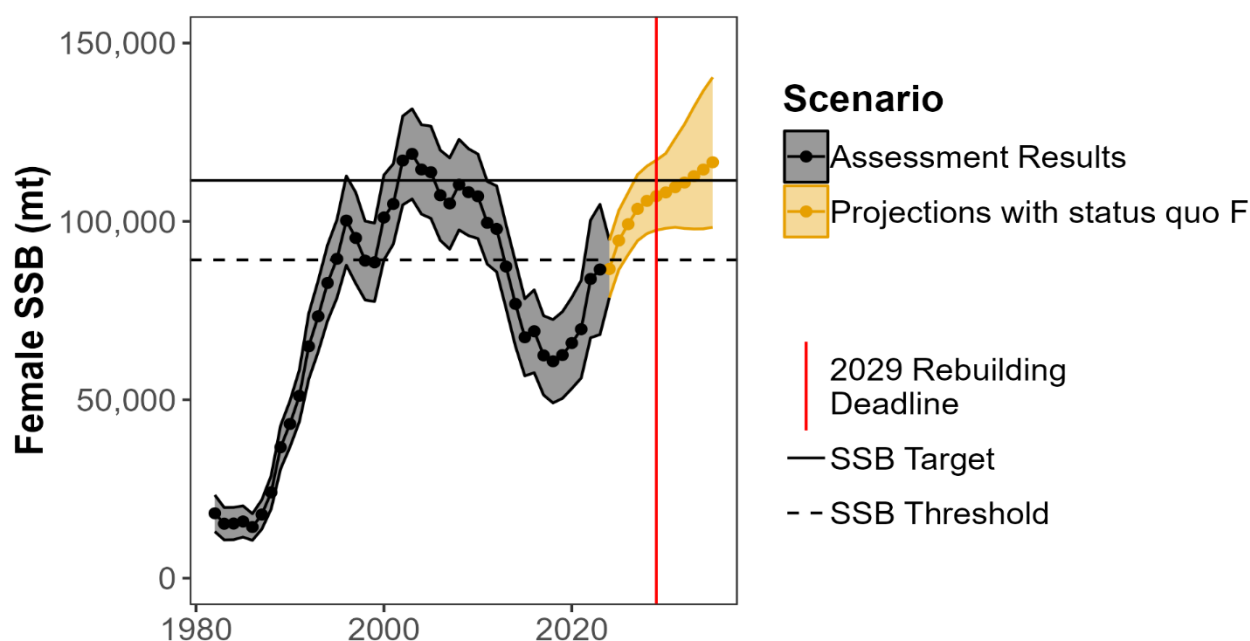
The stock assessment models discussed above provide information on what happened in the past (i.e., what the population size and fishing mortality were in the past). They do this by fitting to the observed data over those years. But just like we could use the von Bertalanffy growth model to predict the size of an age-7 fish from ages zero to six, we can use many of these models to predict what population size and fishing mortality will be in the future.

We have to make assumptions about future conditions for these projections, so we often explore different scenarios: what happens if the number of fish we catch stays the same as last year? What happens if it increases or decreases?

For our statistical catch-at-age models, we also have to think about things like what will recruitment and growth be in the future? Will the number of new fish being born each year be about average, or will it be higher or lower than recent years? Will the average size-at-age of the fish increase or decrease, or will it stay the same?

As a result, projections often show a range of results, or the probability of being above or below some level instead of a single value. This range includes uncertainty not just about future conditions but also the uncertainty in the results of the stock assessment. The further out the projections go, the more uncertain they become, because we have less certainty about what will happen in the future.

These projections help us understand how the population will respond to changes in management so that managers can set regulations to achieve their objectives for each species. Catch curves and other data-limited methods cannot provide these kinds of projections, which is one of the reasons they are less useful as assessment tools.



Estimates of female spawning stock biomass from the 2024 striped bass stock assessment update, including projections. The black line and circles with the grey shading show the results from the 2024 assessment; this is what the model estimates for 1982-2023, based on the observed data. The yellow line and circles with the yellow shading show the projections; this is what the model predicts will happen in the future based on a specific set of assumptions. In this case, we are assuming status quo F , meaning we assume that fishing mortality in the future will be approximately what it was in 2023, the last year of the assessment.

Determining Stock Status

We've run our models and come up with estimates of population size and fishing mortality in the most recent years along with the uncertainty around those estimates. We can even project whether the population will increase or decrease in the next few years under the current catch levels. But what does that population size and fishing mortality rate mean? Is the population large enough to sustain itself? Can we increase our catches, or do we need to cut back?

To know that, we need [reference points](#) to compare our estimates against. We'll talk about what reference points are and how we develop them and use them to evaluate stock status in the next section.

REFERENCE POINTS & STOCK STATUS

We have run our stock assessment model and concluded that the spawning stock biomass in 2023 was 191 million pounds and fishing mortality was 0.18. Is that good or bad? Are we fishing sustainably, or do we need to reduce our catch?

To determine the answers to those questions, we need to establish reference points. Reference points are the yardsticks that we compare our stock assessment results against to evaluate the health of the stock and how sustainable our catches are. We want to make sure that we keep the population at a size where it can produce enough eggs every year to replace the fish lost to fishing and natural mortality; that population size is our biomass reference point. We also want to make sure that we are fishing at a rate that allows for a viable fishery but doesn't cause the population to collapse; that rate is our fishing mortality reference point.

There are several different approaches to calculating those reference points, depending on the model we use and the life history of the species. In this section, we'll talk about common types of reference points and how we use them to evaluate stock status.

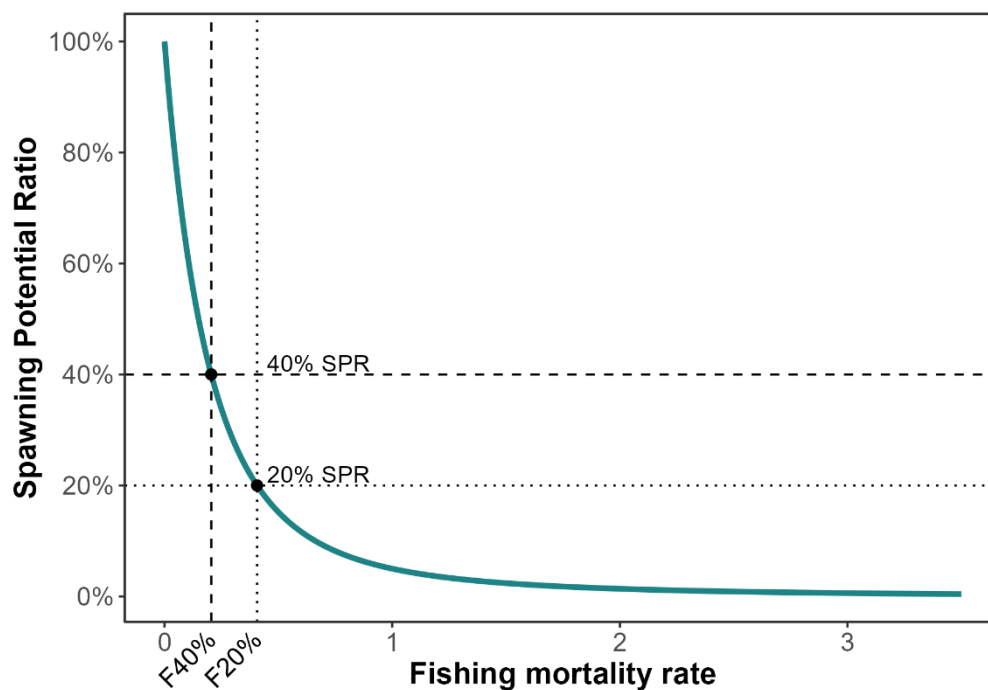
Model-Based References Points

We can use the same theoretical models we use for stock assessments to develop reference points that use the same assumptions and input data.

Spawning potential ratio (SPR) models are one of the most commonly used reference point models in stock assessments today. SPR models use information on how fast a species grows, when it matures, what its natural mortality rate is, and the selectivity of the fishery to determine how much spawning stock biomass the population could potentially produce under different levels of fishing. The SPR is calculated by dividing this estimate of spawning stock biomass under different levels of fishing mortality by the level of spawning stock biomass we expect if the population was not fished at all.

Words to Know

spawning potential ratio (SPR): A reference point that represents the reproductive potential (SSB or egg production per recruit) of a fished stock compared to its unfished condition.



This is what the SPR looks like for bluefish. The spawning potential ratio is 100% when fishing mortality is zero. As fishing mortality increases, the SPR decreases, as more fish die from fishing instead of living their full lifespan and contributing fully to the spawning stock. The spawning potential ratio is highest under no fishing mortality and declines to very low levels at the highest fishing mortality rates.

SPR models assume the same number of new fish will be entering the population every year regardless of the size of the adult population. We know that for many species, recruitment is driven more by environmental conditions and available resources than the adult population size, meaning they can produce relatively constant levels of recruitment over a range of adult population levels, so this is a reasonable assumption. However, once the adult population gets too small, recruitment will decline, and we run the risk that the population will collapse completely if it cannot replace itself. But how small is too small?

Fisheries scientists have looked at how different species have responded to different levels of fishing pressure and have found that fishing mortality rates that leave 30%-50% of the unfished spawning stock biomass (i.e., a 30%-50% SPR) in the water will allow us to maximize harvest without causing a major decline in recruitment. Species that grow quickly, mature at young ages, and live for many years, like red drum and bluefish, can sustain a higher fishing pressure and still be productive, so we might manage them at a lower SPR level, 30%-35%, while we manage other species at 40% or higher SPR. The fishing mortality rate that produces the SPR that we want is our fishing mortality reference point. We usually refer to the fishing mortality rate that produces an X% SPR level as $F_{X\%SPR}$ or $F_{X\%}$, so for example, if we want to set our fishing mortality reference point at the rate that results in an SPR of 40%, we would say our fishing mortality reference point is $F_{40\%SPR}$ or $F_{40\%}$.

SPR reference points are fishing mortality reference points. This means we can compare our current fishing mortality rates to those reference points, but they don't tell us anything about how large the population should be. To develop biomass reference points, we often use a projection-based approach. We project the population forward using our fishing mortality reference point (e.g., $F_{40\%SPR}$) while assuming that recruitment stays at average levels (either the long-term average over the whole assessment period or the average over a shorter time range). Eventually, the population will stabilize, and the level of spawning stock biomass that it stabilizes at is our biomass reference point.

Maximum Sustainable Yield Models

SPR reference points do not connect the number of new fish entering the population to the size of the adult population. MSY reference points are designed to take this relationship into account.

We can get MSY reference points from surplus production models; after all, that is where the entire concept of MSY came from. Surplus production models give us estimates of the fishing mortality rate and the biomass of the population that will produce the maximum sustainable yield (F_{MSY} and B_{MSY} , respectively).

But we can also develop MSY reference points for our statistical catch-at-age models by combining our SPR models with a spawner-recruit relationship. SPR models assume the same level of recruitment occurs every year, but if we have a spawner-recruit relationship, we know how much recruitment will occur under different levels of spawning stock biomass and we can plug those numbers into the model instead. From this, we can calculate the spawning stock biomass level and the fishing mortality rate that will produce MSY (SSB_{MSY} and F_{MSY} , respectively).

However, these kinds of reference points are very sensitive to the spawner-recruit relationship, so if we can't reliably estimate that relationship, we can't use MSY reference points. This is the case for most of our species. In this situation, we will usually use an SPR-based reference point as a proxy for the MSY-based reference points. Therefore, you will often see $F_{40\%}$ called the $F_{MSYproxy}$ and the long-term spawning stock biomass associated with that $F_{40\%}$ value called the $SSB_{MSYproxy}$.

Ecological Reference Points

For most species, we have historically based our reference points on the idea of maximizing yield—that is, getting the most catch we can out of the population without causing it to collapse. But for forage species like Atlantic menhaden, which are an important prey item for many predator species, we want to balance the needs of the fishery and the needs of the predators. The population level that produces enough eggs to sustain itself may not be large enough to sustain all the predators that depend on it as well. Therefore, we develop ecological reference points (ERPs) that take into



Photo by: ASMFCA

account the needs of the predators. For most species, we have historically based our reference points on the idea of maximizing yield—that is, getting the For Atlantic menhaden, $F_{40\%}$ would be 0.75, whereas the fishing mortality rate on Atlantic menhaden that would allow Atlantic striped bass to reach their biomass target when they are fished at their fishing mortality target is 0.19.

You can find more information about how the Atlantic States Marine Fisheries Commission uses ERPs to manage Atlantic menhaden via [this StoryMap](#).

Empirical Reference Points

For some species, instead of using a model-based reference point, we will use a reference point based on the past, observed performance of the fishery and the stock. Sometimes, this is done because we don't have a reliable assessment model. For example, for Atlantic sturgeon, we can calculate total mortality reference points using SPR models, but we don't have a model that produces estimates of recruitment or population size, so we can't set a biomass reference point. Instead, we compare our indices of abundance in the most recent year to the index in 1998, the year that all fisheries for Atlantic sturgeon were closed. This lets us evaluate whether the stock has increased since then.

For other species, we might have a stock assessment model but are concerned about the uncertainty or the assumptions in the model-based reference points. So, instead, we chose a reference point based on a period of time when managers and stakeholders were satisfied with the fishery performance and population size was stable. For example, Atlantic striped bass was declared rebuilt in 1995, based on the proportion of mature females on the spawning ground and levels of recruitment the stock was producing, and managers decided that we did not want the stock to go below that level in the future, so the level of spawning stock biomass in 1995 was set as the biomass reference point. The level of fishing mortality that keeps Atlantic striped bass at their biomass threshold under current recruitment levels is the fishing mortality reference point.

Stock Status

We compare our estimates of population size and fishing mortality from our stock assessment models to our reference points to determine stock status.

The Commission usually establishes both a [threshold](#) and a [target](#) reference point for population size and fishing mortality for each species. The threshold reference point is what determines stock status. If fishing mortality is above the fishing mortality threshold, then [overfishing](#) is occurring. This means the fishing mortality rate is too high and will cause the population to decline. If the population size (usually measured as spawning stock biomass) is below the biomass threshold reference point, then the stock is [overfished](#). This means that the population size is too low, putting it at risk of not being able to produce enough recruits to replace the individuals lost to fishing.

Going back to our question at the start of the section: we have run our stock assessment model and concluded that the spawning stock biomass of the stock in 2023 was 191 million pounds and fishing mortality was 0.18. Is that good or bad? The spawning stock biomass threshold is 197 million pounds, so biomass was below the biomass threshold, meaning the stock was overfished. The fishing mortality threshold is 0.21, so fishing mortality was below the fishing mortality threshold, meaning overfishing was not occurring in 2023.

Words to Know

target: A biological reference point (BRP) that represents management objectives for a desirable outcome (e.g., a sustainable stock). Not meeting a target does not mean the stock is in an unhealthy condition but consistently missing it may be a sign that management objectives are not being met.

threshold: A biological reference point (BRP) used to guide management objectives that represent critical levels not to be crossed. If crossed, the sustainability of the stock is threatened and management action is required.

overfishing: removing fish from a population at a rate that exceeds the fishing mortality threshold established in the fishery management plan, impacting the stock's reproductive capacity to replace fish removed through harvest.

overfished: a condition that occurs when stock biomass falls below the threshold established by the fishery management plan, impacting the stock's reproductive capacity to replace fish removed through harvest, and that decline is driven primarily by fishing mortality.

depleted: stock status that reflects low levels of abundance though it is unclear whether fishing mortality is the primary cause for reduced stock size.

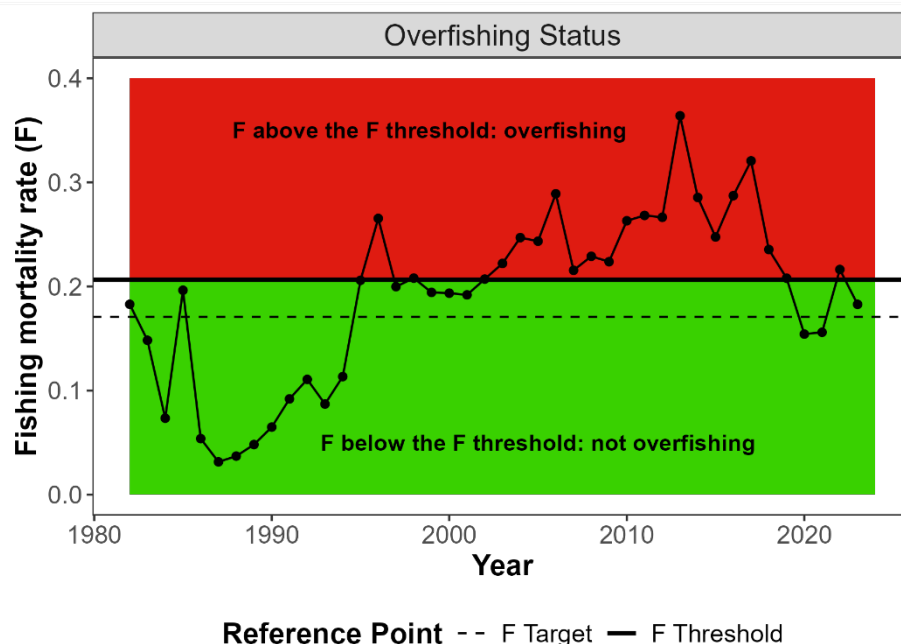
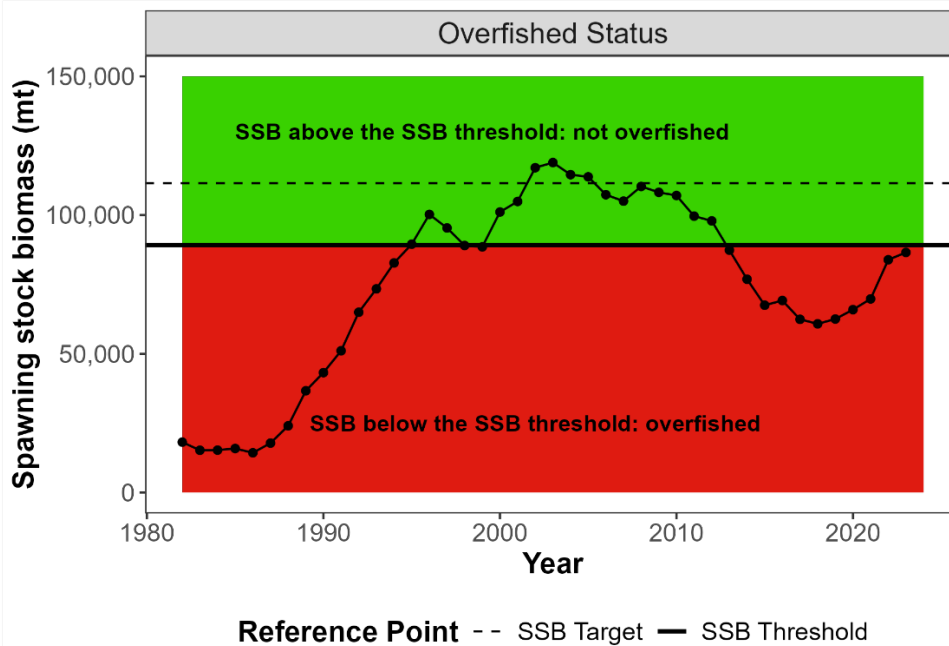
unknown status: stock status determination when there is no accepted stock assessment to estimate stock condition.

Sometimes this can be confusing because for biomass, we are aiming to achieve the target (higher value) and do not want to drop below the threshold (lower value). But with fishing mortality, the target that we are aiming to achieve is the lower value (i.e., less fishing) while we do not exceed the threshold (higher value).

A stock can be overfished and experiencing overfishing, which is the worst condition for the stock to be in. However, a population can be overfished but not experiencing overfishing. In this case, fishing mortality is at an acceptable level, but the population size is too low. Fishing mortality needs to be maintained at current levels or lower in order to allow the stock to rebuild. Conversely, the stock can be experiencing overfishing but not overfished yet. If fishing mortality is not reduced, it is likely that the stock will be driven below its biomass threshold and become overfished.

In addition to the threshold, which determines stock status, the Commission often sets a target to provide a buffer for uncertainty in the assessment and management actions. The fishing mortality target is lower than the fishing mortality threshold, and the biomass target is higher than the biomass threshold. Managers try to achieve the target with their actions, but if they don't get it quite right and fishing mortality or biomass is between the target and the threshold, the stock is not immediately overfished or experiencing overfishing. Being between the target and the threshold may also signal to managers that they may want to be more precautionary in the future if it is part of a trend towards the threshold.

REFERENCE POINTS & STOCK STATUS



The Commission has a special stock status for species that are at a low population size due to factors other than fishing: [depleted](#). For example, northern shrimp abundance has been at extremely low levels for over a decade, even though the fishery has been closed since 2014. Northern shrimp have been affected by the warming water temperatures in the Gulf of Maine, as they don't produce as many recruits when the water temperature is high, and by the increasing abundance of their predators in that region. As a result, even though fishing mortality is practically zero, the population has not rebounded to historical levels and instead remains very low; therefore, we say northern shrimp are depleted.

For some species, stock status is [unknown](#). This is usually the case when we don't have a reliable stock assessment model for that species.

So how is the science behind stock assessments implemented into management? This section covers how stock assessment information is used to provide fishery managers with the necessary information to make management decisions that balance conserving a fish stock with sustainable resource use. Stock assessments rely on high-quality data from fishery-dependent and fishery-independent sources to minimize risk and uncertainty. Robust stock assessment models that have passed peer review allow for projections to be made about how the stock will behave and respond to different management measures.

Assessments & the Peer Review Process

The Commission conducts two types of stock assessments: a benchmark stock assessment and a stock assessment update. A benchmark stock assessment is a full analysis and review of the stock condition, focusing on the consideration of new data sources and newer or improved assessment models. This type of assessment is generally conducted every five to ten years and undergoes a formal peer-review process by a panel of independent fisheries scientists that have expertise in that specific fish species or in the models that are used in the assessment. These are lengthier assessments that are prompted by potential new fisheries management actions, a major change in the models or datasets, or when a set number of years have passed since the last assessment. As these assessments require more time to complete, updates are needed to monitor stock status between benchmarks. A stock assessment update incorporates data from the most recent years into the peer-reviewed assessment model to determine current stock status (abundance and overfishing level) and is often conducted every two to five years.

Stock assessment development includes three types of workshops. To review the datasets that go into stock assessments for quality, stock assessment scientists and biologists conduct a data workshop. After a decision has been made about which datasets will be included, they conduct a methods assessment workshop to examine all available models and determine which models best suit the assessment. Following this, a final assessment workshop is conducted to refine the selected models for use. These workshops are open to the public and are guided by defining clear goals, products, and individual responsibilities for the participants involved. Participants include state and federal biologists and stock assessment scientists that make up the Commissions' species technical committees and stock assessment subcommittees and Commission staff.

Once a stock assessment has been completed, it is reviewed by a panel of independent fisheries science experts on the value and appropriateness of the science and methods. This panel also provides recommendations for future improvement. The panel uses guidelines known as terms of reference (TORs) to define the tasks needed to be completed in each assessment.

If the peer review panel endorses and the Management Board accepts the stock assessment for

management use, the results can then be used to adjust harvest regulations based on the stock status determined by the assessment.

The Commission's stock assessment process differs slightly from that of our federal partners; for more information about the federal process, you can visit [NOAA's website](#).



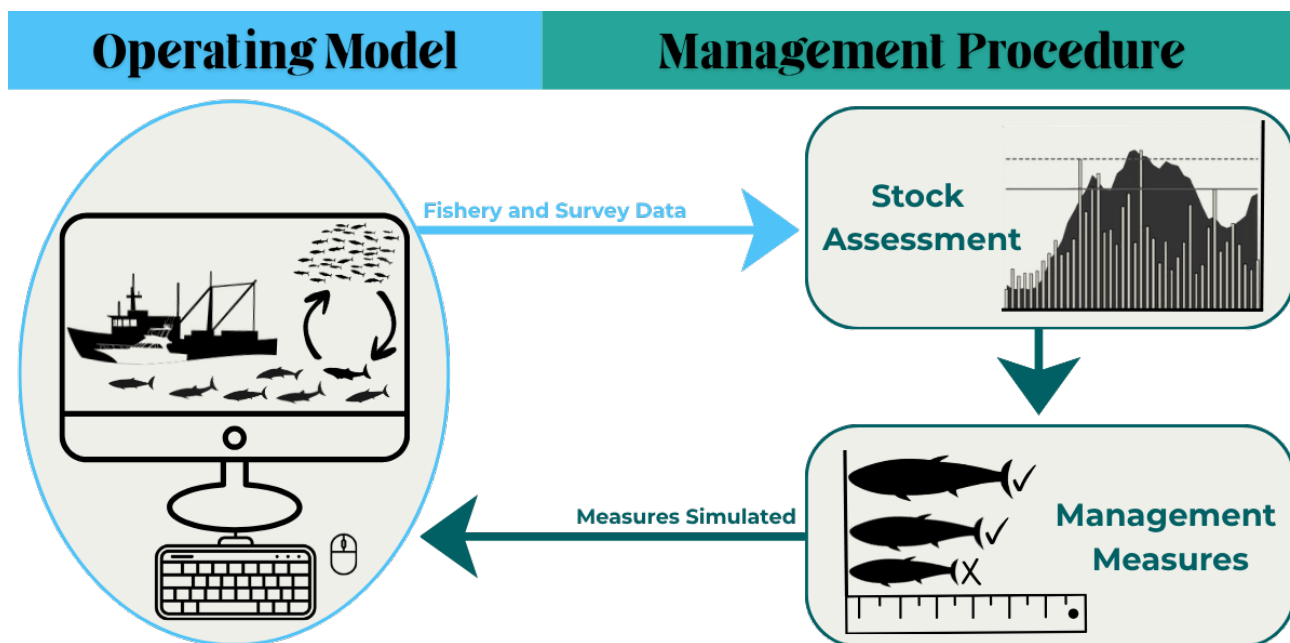
ASMFC staff running a public hearing for cobia management in June 2024. Photo by: ASMFC.

Other Stock Status Indicators

For some species, in the interim between benchmark stock assessments, annual data updates or traffic light analyses are conducted to monitor trends in fishery indices or metrics.

Management Strategy Evaluation (MSE)

A stock assessment uses observed data to understand what happened to the population in the past, and what is likely to happen in the future under different scenarios. However, sometimes managers have questions about the best action to take that can't be answered by a stock assessment alone. For example, if we want to reduce discards in the recreational fishery, what approach minimizes both the risk to the stock and the negative impacts on anglers? If we have a limited amount of money to spend on improved data collection, will it improve the stock assessment more if we invest in a fishery independent survey or get better data on catch? An MSE can help us answer these questions. An MSE is a simulation-based approach, where we create a virtual population based on the real species we're interested in, and then apply different strategies to see what happens to the population. A stock assessment model is often part of an MSE, because we are interested in comparing the results and management advice from the assessment to the known, simulated population, to understand how accurate they are. MSEs can be very useful tools, but they are also much more complex and resource-intensive than a stock assessment and often require input from socioeconomic researchers and stakeholders in addition to the traditional stock assessment data inputs. Recent examples of MSEs include the 2022 red drum simulation assessment and the 2022 MAFMC summer flounder MSE.



Risk and Uncertainty

A reality in fisheries science is that there are not enough resources (staffing, equipment, and funding) to meet the growing demand to collect data and conduct stock assessments. Adequate data collection programs are in place for some well-known, high-profile species of commercial or recreational importance. However, for many species, available data are too limited to perform a full stock assessment.

Although this process is rigorous and vetted at every stage, no underlying datasets—even the ones with large quantities of data available—are perfect. Uncertainty due to data and limitations in analytical methods are inherent in all scientific processes and must be considered. Stock assessment scientists and fisheries managers aim to take this uncertainty into consideration and better understand the risks associated with making different management decisions—whether that risk is biological, economic, or social.

Management Strategies

Management strategies are science-based and tailored to be species-specific; for example, scientists look at a variety of factors when giving advice to managers, including the size of the fish stock, how fast it reproduces, how it interacts with other species, and whether or not it needs to be rebuilt or receive additional protection. Stock assessments are the tools fisheries managers use to evaluate the current and projected health of the fish stocks and how much harvest they can sustain. Fisheries managers use this information and projections to devise management options for sustainable harvest. Stock assessments themselves do not provide the management options. To limit harvest to sustainable levels, managers employ a variety of management measures, including controlling the number and size of fish that are caught, the gears that may be used, and the areas and seasons that are open to fishing.

The Commission uses two main types of management strategies to limit the catch of the species it manages. Input controls limit the capacity of and effort in the fishery. These controls include fishing seasons, days out, and the number and size of fishing vessels in the fishery. For example, the measures managing the Atlantic herring fishery include days out of the fishery specifications for the inshore Gulf of Maine that allow permitted vessels to land herring four consecutive days a week from June 1 to September 30.

Output controls limit the amount of fish caught by the fishery. This includes measures such as total allowable catch (TAC) and bag limits. For example, the summer flounder commercial fishery is managed by an annual catch limit (ACL). The coastwide ACL is allocated to each state. When the state reaches its quota, the fishery is closed in that state, ensuring the coastwide ACL is not exceeded.

Managers must consider the pros and cons to each method and the benefits and costs to the stock they are managing, in addition to socioeconomic impacts, when making decisions about which management strategy to use.

Conclusion: Putting Science into Action

For fishery managers to make informed decisions, they must understand the fish and the fisheries they are managing, examine stock status, and have clear management objectives. The first step of which establishes the limits (biological reference points) that define the level of fishing the population can support while sustaining long-term viability. These reference points are developed as a result of the stock assessment.

In fisheries, determining stock status means estimating the size of the population, either in abundance or biomass, and the fishing mortality rate. Population size and fishing mortality rate are compared to reference points to determine whether the stock is overfished (the population size is too low) or overfishing is occurring (the fishing mortality rate is too high). On a routine basis, the Commission conducts stock assessments on Commission-managed species to determine the health and status of the fish stocks and to provide scientific advice to fisheries managers.

When setting management measures, managers consider the desires of the stakeholders and the overall quality of scientific information. Harvesters of some fisheries may have different needs, which can influence the outcome of management decisions. For example, in some recreational fisheries, anglers may want a single trophy fish, so managers may set harvest targets well below limits to allow the population to reach greater abundance, which will increase the angler's success rates for large fish. A lower harvest target and size limits may prevent the harvest of the fish until it grows to trophy size.

Once managers understand the needs of the fishery, they consider the latest science on the species, including stock assessment results, an analysis of fishery-independent indices, or other stock indicators to determine whether management action needs to be taken. This action can include a tightening of management measures when a stock is overfished or experiencing overfishing or a loosening of measures when a stock is considered fully restored. In making management decisions, managers strive to balance the needs of various groups with the biological requirements of the species using clear, agreed-upon management objectives to guide their decision-making.

We hope this guide has been useful in helping you understand how stock assessments are conducted, the data that are used, the assumptions that are made, and the assessment models that are used to inform management decisions. It's our intention to regularly update this guide. Please feel free to send your questions to info@asmfc.org.





Guide to Fisheries Science & Stock Assessments

Glossary

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[A](#)

Abundance: The total number of fish in a stock.

Abundance index: A scientific measure of abundance which can be used to monitor trends in abundance and distribution of a fish stock over time and over the entire range of the species.

Age-class: All fish in a given population or stock born in the same year (or cohort) and therefore assigned the same age.

Age-structure: The proportion or number of fish in each age-class in the population, stock, or catch.

Anadromous: Species inhabiting brackish and marine waters for most of their lives that return to freshwater to spawn (e.g., Atlantic striped bass, American shad, and river herring).

Annulus (or annuli, plural): A growth ring laid down on a fish's hard parts (like a scale or otolith) represented by a translucent and opaque zone that can be used to estimate age.

Atlantic Coastal Cooperative Statistics Program (ACCSP): A cooperative state/federal program that standardizes landings reporting on the Atlantic coast through a single integrated data management system. The ACCSP is intended to encompass commercial, recreational, and for-hire fishery-dependent statistics.

Atlantic States Marine Fisheries Commission (ASMFC): A cooperative interstate fisheries management organization dedicated to the conservation and sustainable use of Atlantic coastal fishery resources. Through collaboration among its member states, the Commission develops and implements management programs that balance ecological sustainability with the economic needs of coastal communities.

[B](#)

Benchmark stock assessment: A full analysis and review of stock condition, focusing on the consideration of new data sources and newer or improved assessment models. This assessment is generally conducted every 5-10 years and undergoes a peer review by a panel of independent scientists who evaluate whether the data and the methods used to produce the assessment are scientifically sound and appropriate for management use. In the federal system, this type of assessment is referred to as a research track in the Northeast Region and simply a stock assessment in the Southeast region.

Benthic: Inhabiting or occurring at the bottom of a body of water.

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 fishery management plan effectiveness. BRPs can be categorized as limits, targets, or thresholds depending on their intended use. Commonly used reference points in the Commission's assessment process are targets and thresholds for fishing mortality and spawning stock biomass, including:

- **B_{MSY} :** Long-term average population size that produces maximum sustainable yield.
- **F_{MSY} :** The fishing mortality rate that produces the maximum sustainable yield when the population is at B_{MSY} .
- **$F_{x\%SPR}$:** The fishing mortality rate that results in the spawning capacity of the population remaining at x% (e.g., 35% is commonly used) of the spawning capacity of an unfished population; often considered a proxy for F_{MSY} when F_{MSY} cannot be estimated reliably.

Biomass: The total weight of a fish stock or population.

Broadcast spawners: Fish that reproduce by releasing their eggs and sperm into the water column.

Bycatch: The non-targeted catch, including non-targeted species or individuals of the targeted species that are not of legal size and/or sex.

C

Carrying capacity (K): The maximum size of a given population that an ecosystem can support.

Catadromous fish: Species inhabiting freshwater for most of their lives that return to the ocean to reproduce (e.g., American eel).

Catch: The total number or weight of fish captured, including fish that are retained, discarded dead, or released alive. Note: catch, harvest, and removals are different terms with different definitions.

Catch and release mortality: The estimated proportion of fish that die as a result of catch and release. This may be referred to as discard mortality.

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 or population.

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 reflect changes in abundance.

Cohort: A group of fish born during a given period or spawning season, usually within a year; also known as a year-class.

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

Confidence interval: The range of values (upper and lower limits) that an estimated value can be expected to fall between if the assumptions used to estimate it are correct.

Confidential data: Sensitive information that requires protection from unauthorized access or disclosure, in this case, information about individuals' commercial fishing activity. Each state and federal agency is required by law to maintain the confidentiality of its data and is responsible for determining who is able to access those confidential data.

Control rule: A set of agreed upon management actions that determine fishing activity (e.g., harvest quote) based on a specified stock or population threshold. For example, a control rule can specify how fishing mortality 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, harvesters, and other stakeholders where, most often, a commercial vessel and crew are employed by researchers to gather data for scientific purposes.

D

Data: information collected about real world phenomena used as a basis for analysis and decision-making.

Depleted: Stock status determination that reflects low levels of abundance though it is unclear whether fishing mortality is the primary cause for reduced stock size.

Diadromous fish: Fish that spend part of their life cycle in saltwater and part in freshwater; a broader term for both anadromous and catadromous fish.

Discards: The portion of catch that is caught and returned to the water unused. Discards may be either alive or dead. Recreational fisheries often describe the portion discarded alive as "released alive."

E

Ecological reference points (ERPs): Biological reference points used to compare the status of an ecosystem, species or group of species, or ecological indicator to a desirable or undesirable state that account for the relationships between species and the ecological benefits they provide.

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

Ecosystem models: Models that analyze data for multiple species at once to understand how they interact and how fishing affects not just each individual species, but also the other species in the ecosystem.

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. Effort can be measured in several different ways, including but not limited to: length (e.g., minutes, days), number of trips, number of trawl tows, or distance.

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

Equilibrium: A state of system stability where all inputs (birth, immigration) and outputs (death, emigration) 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.

Estimate: (*verb*) the process of using mathematical tools to calculate a quantity of interest (*noun*) a value calculated using mathematical tools

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

Exploitation (*u*): The proportion of a fish population removed by fishing over a specified period, typically over a year.

F

F (Fishing mortality): the rate of death that results from fishing activity including harvest and discards.

Fecundity: The number of eggs produced per female in a set amount of time (e.g., per spawning season). Often used to represent the reproductive capability of an individual or population of fish.

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 collected about the fishery, provided by recreational anglers, for-hire captains, commercial harvesters and dealers, and port samplers; typically includes catch, landings, and effort information. Fishery-dependent data may also have some biological information (e.g., length, age, sex).

Fishery-independent data: Data collected about the population or stock independent from the fishery. This data is provided by fishery-independent surveys that are often conducted by government agencies or academic institutions; typically includes life history, abundance index, 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 over the long-term.

Fisheries management: All activities conducted by a government to improve, restore, rebuild, or maintain fish stocks and fisheries, including statutory action and rule-making, enforcement, research, monitoring, collection of statistics, enhancement, protection, development, and habitat conservation.

Fishery management plan (FMP): A plan to achieve specified management goals for a fishery, including data, analysis, and management measures for a fishery.

Fitting a model: The practice of finding a combination of parameters or variables that bring predicted values as close as possible to observed values.

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

G

Gamete: The reproductive cells (i.e., sperm and eggs) of any organism, including fish or shellfish.

Gear: Any device used to capture fish or shellfish (e.g., a trawl, a gillnet, or hook-and-line).

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

H

Habitat: All the living and non-living components in an area necessary for the reproduction and survival of a species.

Harvest: The total number or weight of fish caught and kept by the fishery. Often used interchangeably with **landings**. Note: catch, harvest, and removals are different terms with different definitions.

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

- **Synchronous hermaphrodites:** Fish that function as both male and female and have the capacity to produce both sperm and eggs simultaneously.
- **Sequential hermaphrodites:** Fish that switch sexes during their lives.
- **Protogynous hermaphrodites:** Fish that mature as females and then transform into males.
- **Protandrous hermaphrodites:** Fish that mature as males and then transform into females.

I

Immigration: The geographical movement of fish into a population.

Intercept interviews: An interview conducted dockside by state and federal biologists 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.

J

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 or population that may serve as an indication of reproductive success.

L

Landings: The number or weight of fish brought to dock (commercial) or shore (recreational). Often used interchangeably with “harvest.”

Larvae: An early life stage of a fish after hatching from the egg and before the juvenile stage. Larvae tend to be distinctly different in appearance from a juvenile or adult of the same species.

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

Length-weight relationship (L-W): 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 metric is known.

Life history: The entire life cycle of a fish species, from fertilization to aging. It encompasses various characteristics that influence the growth, reproduction, and survival of fish, including diet, habitat, and predation.

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

M

M (natural mortality): The rate of death from natural causes such as being eaten by a predator, disease, starvation, extreme heat or cold, or other causes.

Management strategy evaluation (MSE): Simulation-based process that is used to test how different management approaches might perform before applying them on the water. They can include an analysis of biological, economic, and/or social trade-offs.

Marine Recreational Information Program (MRIP): A state-regional-federal partnership that collects recreational fishing data and produces estimates of total recreational catch.

Maturity: The state of being capable of spawning or reproducing.

Maximum spawning potential (MSP): The maximum egg production from a population 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 fished 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.

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). 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):** Death that results from fishing activity.
- **Natural mortality (M):** Death from natural causes, such as being eaten by a predator, disease, starvation, extreme heat or cold, or other causes.

- **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).

N

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.

Northeast Area Monitoring and Assessment Program (NEAMAP): A collaborative state-federal initiative dedicated to the collection, analysis, and dissemination of fishery-independent data along the Atlantic coast, from the Gulf of Maine to Cape Hatteras, North Carolina.

O

Observers: Trained biologists who monitor and record commercial or recreational catch data, including bycatch, from fishing vessels.

Operculum (or opercula, plural): Hard plate-like flaps that cover the gills of a bony fish.

Otoliths: Inner ‘ear stones’ (commonly referred to as ear bones) that can be used to age fish.

Overfished: A condition that occurs when stock biomass falls below the threshold established by the fishery management plan, impacting the stock’s reproductive capacity to replace fish removed through harvest, and that decline is driven primarily by fishing mortality.

Overfishing: Removing fish from a population at a rate that exceeds the fishing mortality threshold established in the fishery management plan, impacting the stock’s reproductive capacity to replace fish removed through harvest.

P

Parameter: A variable in a model that describes a specific aspect of a fishery, its environment, or its biological components.

Peer review: The process of having external, independent experts provide a critical analysis of the science and methods used to produce a stock assessment and whether the assessment is suitable for management use.

Pelagic: Inhabiting or occurring throughout the water column.

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

Population dynamics: The study of how and why fish populations change over time.

Predator: Animals that feed or prey upon other animals.

Prey: An animal that is eaten by predators.

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

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

Q

Quota: The total amount of fish from a given stock that can be harvested each year as specified by a management authority. A quota can be set for the whole fishery, for sectors or gears within the fishery (commercial or recreational, gillnet, or trawl), for states or regions along the coast, or even for individual fishermen.

R

Recreational fishery: A fishery directed at catching (and/or releasing) fish for personal use, but not for sale, barter, or other compensation. Refers to and includes the fishery resources, anglers, and businesses providing recreational goods and services.

Recruit: An individual fish that has entered a defined population through hatching, 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 a specific age class (e.g., age-1), the spawning stock or fishable stock.

Reference points: Specific values of population metrics like fishing mortality and biomass that are used to evaluate a stock's status and the sustainability of the current catch.

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

Removals: The number or weight of fish that are killed (removed from the population) by the fishery. This includes fish that are harvested and discarded dead, as well as those that are released alive but die from the stress or injury of being caught but does not include those that are released alive and survive. Note: catch, harvest, and removals are different terms with different definitions.

Retrospective analysis: An analysis used in stock assessments to examine a model's stability and precision by removing recent years of data one-by-one and re-running the model to see whether the results change in a consistent, predictable way.

Retrospective pattern: The phenomenon in stock assessment models where estimates of parameters, like biomass and fishing mortality, change in a consistent direction (i.e., consistently increasing or decreasing from previous estimates) as new years of data are added to the model.

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.

S

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

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

Southeast Area Monitoring and Assessment Program (SEAMAP): A cooperative program to facilitate the collection, management, and dissemination of fishery-independent data from the waters of the southeastern US, Gulf, and Caribbean.

Spawning potential ratio (SPR): A reference point that represents the reproductive potential (SSB or egg production per recruit) of a fished stock compared to its unfished condition.

Spawning stock: The portion of a fish stock that is mature.

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

Standard length: The length of a fish as measured from the tip of the snout to the 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.

Stock: A group of fish of the same species that behave (e.g., migrate or spawn) as a unit, are assessed and managed as a unit, and which may be genetically unique.

Stock assessment: A quantitative evaluation of the health of a stock, which may include estimates of age and size composition, reproductive capacity, mortality rates, stock size, and recruitment. Estimated population size and fishing mortality rate are compared to reference points to determine whether the stock is overfished or overfishing is occurring.

Stock assessment models: Mathematical and statistical techniques used to estimate abundance, population dynamics, and stock status.

Stock assessment update: An evaluation of a stock that incorporates data from the most recent years into a peer-reviewed assessment model to determine current stock status (abundance and overfishing levels). Unlike a benchmark stock assessment, significant changes to the model or the datasets used are not considered during an assessment update. Assessment updates are generally conducted every 2-5 years. In the federal system, this type of assessment is called a management track assessment in the Northeast Region and simply a stock assessment in the Southeast Region.

Stock-recruitment relationship: The relationship between the size of the spawning stock and the amount of recruitment that is produced by that stock.

Stock status: The condition of a stock of fish that is determined through a stock assessment (i.e., whether a stock is overfished, experiencing overfishing, or depleted).

Surplus production: The total weight of fish that can be removed from a population by fishing without making the population smaller in the next year.

Surplus production model: One of the simplest stock assessment techniques to model population dynamics and track biomass. It is “simple” because it characterizes the dynamics of a stock in terms of changes in total biomass without regard to age or size structure.

T

Target: A biological reference point (BRP) that represents management objectives for a desirable outcome (e.g., a sustainable stock). Not meeting a target does not mean the stock is in an unhealthy condition but consistently missing it may be a sign that management objectives are not being met. Various levels of fishing mortality and spawning stock biomass are commonly defined targets.

Threshold: A biological reference point (BRP) used to guide management objectives that represent critical levels not to be crossed. If crossed, the sustainability of the stock is threatened and management action is required. Various levels of fishing mortality and spawning stock biomass 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 (e.g., several decades).

Total allowable catch (TAC): The total number or weight of fish from a given stock that can be caught each year, as specified by a management authority.

Total length: The length of a fish from the tip of the snout to the tip of the tail.

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, Atlantic menhaden is a primary consumer at a lower trophic level than bluefish, a secondary consumer at a higher trophic level that feeds on menhaden that is itself preyed upon by larger predators like sharks.

U

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.

Unknown status: Stock status determination when there is no accepted stock assessment to estimate stock condition.

US Fish and Wildlife Service (USFWS): A federal agency within the Department of Interior focused on managing fish and wildlife resources.

V

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

Y

Year-class: All the individuals in a given stock spawned or hatched in the same year; also known as a “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.

Z

Z (Total mortality): the rate of removal of fish from a population due to both fishing and natural causes.