Introduction

The Resource Evaluation and Assessment Division of the Northeast Fisheries Science Center (NEFSC), National Marine Fisheries Service (NMFS), with headquarters in Woods Hole, Massachusetts, regularly updates assessments of finfish and shellfish resources off the northeastern coast of the United States and presents information as needed to administrators, managers, the fishing industry, and the general public. Some of these assessments are prepared exclusively by NEFSC scientists; many others are prepared jointly with researchers at other federal and state agencies and academic institutions. This report summarizes the status of selected finfish and shellfish resources off the northeastern coast of the United States from Cape Hatteras to Nova Scotia based on information available through Spring of 1998.

Night watch net mending, R/V *Albatross IV* NOAA Fisheries NEFSC Photo by Brenda Figuerido

This report includes review chapters on fishery landings and economic trends, aggregate resource trends, and the status of key fishery resources. The Fishery Landings Trends section provides summary overviews since publication of the last "Status of the Fishery Resources" document; specifically, final commercial and recreational landings data for 1994-1996 and preliminary data for 1997. The Fishery Economic Trends chapter provides information on fishing activity and fishery economics in the Northeast including fleet size and characteristics and economic returns. The Aggregate Resource Trends section provides an overview of trends in abundance for major finfish assemblages on the northeast shelf, together with an overview of resource status. A special topics chapter is added this year highlighting the groundfish fishery vessel buyout program in the northeast, which removed 79 vessels from the severely overcapitalized New England fleet. Finally, the Species Synopses section includes information about the status of 51 stocks of finfish and shellfish, and harbor porpoise.

The species and stocks described in the Species Synopses section can be logically grouped into eight categories: principal groundfish, flounders, other groundfish, principal pelagics, other finfish, invertebrates, anadromous fish, and marine mammals (harbor porpoise). The region occupied by these stocks (including areas in Canadian waters occupied by resources exploited by both the U.S. and Canada) is shown in Figure 1. Such "trans-boundary stocks" include stocks such as Georges Bank cod, which are found on both sides of the international boundary line on eastern Georges Bank, and highly migratory stocks such as Atlantic mackerel which move seasonally between U.S. and Canadian waters. There are several other species of commercial and recreational importance that are not included in this report, such as bluefin and yellowfin tuna, swordfish, red crab, sand lance, sea urchin, menhaden, pelagic sharks, and inshore shellfish (including softshell and hard

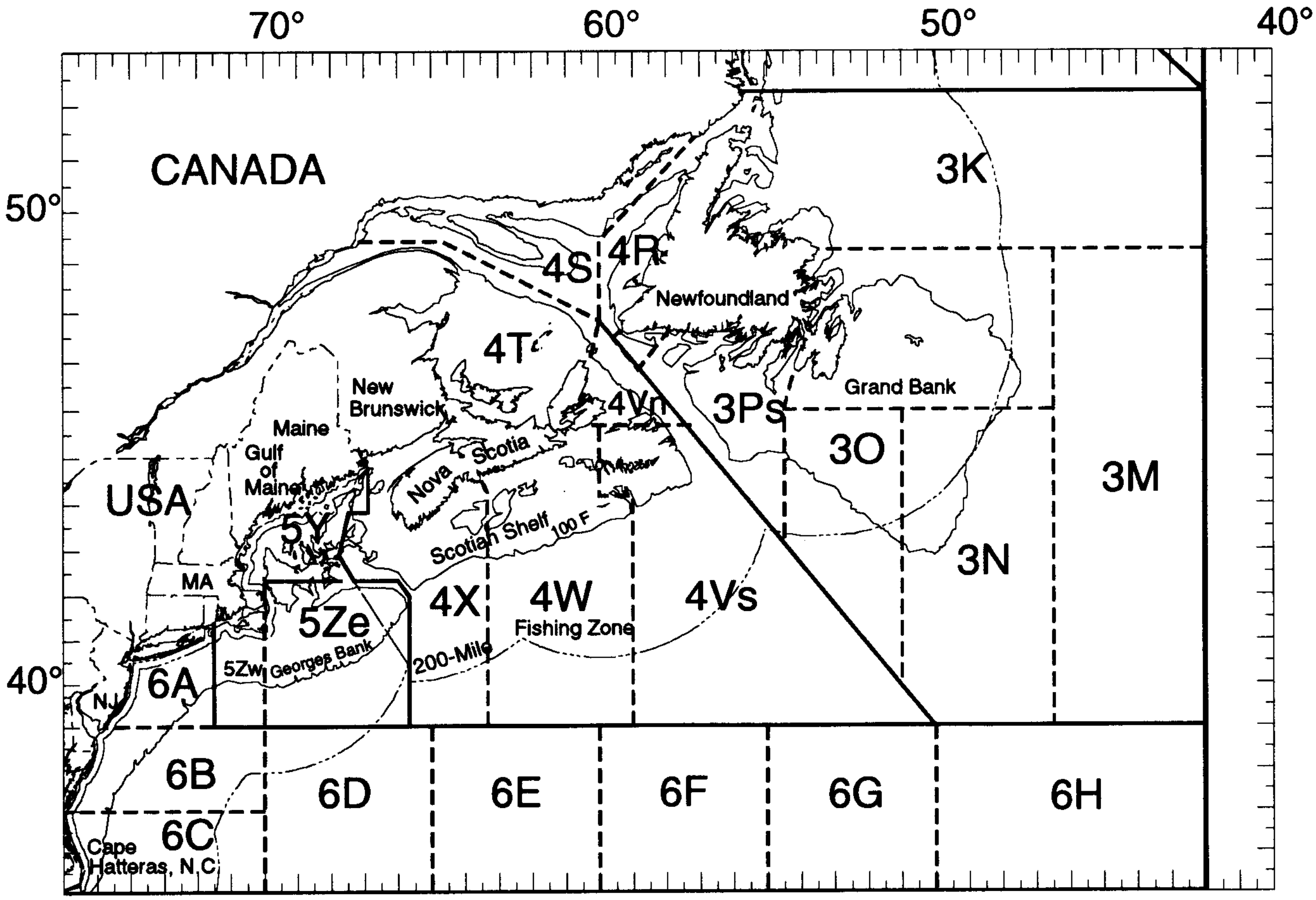

Figure 1. The Northwest Atlantic, including Northwest Atlantic Fisheries Organization (NAFO) subareas and divisions and other features mentioned in this report.

clams, oysters, and blue mussels). Some of these are migratory species that are present off the northeastern U.S. only seasonally, while others are resident primarily or exclusively within state waters and are routinely assessed and managed by state agencies.

OVERVIEW OF ASSESSMENT APPROACHES

Depending on the nature of the fishery, the type and amount of data available, and the information required for management, assessments may be generated in several different ways. The simplest approach involves use of commercial landings and fishing effort data and/or research vessel survey data to generate indices of abundance. (As research vessel surveys are performed using small mesh gear to sample juvenile fish and invertebrates, survey data are also used to develop indices of incoming recruitment.) A second approach is to utilize commercial landings and effort data and/or information on population size and productivity to determine relationships between effort and yield; this is referred to as a surplus-production or surplus-yield model (Figure 2A). Yield and spawning stock biomass-per-recruit curves may also be developed based on biological parameters (growth and natural mortality rates, maturation, etc.) generated from biological sampling or other sources of information (Figure 2B). The most complex (and useful) assessments can be performed when size and age composition of the catch and the population can be determined reliably through sampling of commercial and recreational catches at sea and at dockside and through sampling of research vessel survey catches at sea. This allows development of more detailed analytic (size or age structured) assessments such as virtual population analysis or VPA which provide information on stock size, recruitment and fishing mortality and exploitation patterns over time. Such assessments may incorporate relationships between spawning stock size and recruitment (stock-recruitment models) which provide a basis for benchmark advice on management options. These models may account for changes in environmental conditions.

The type of assessment performed depends on the complexity of the information needed. For intensively fished stocks requiring detailed information on trends in stock size, recruitment and fishing mortality, analytic assessments are generally required. For moderately exploited fisheries where management

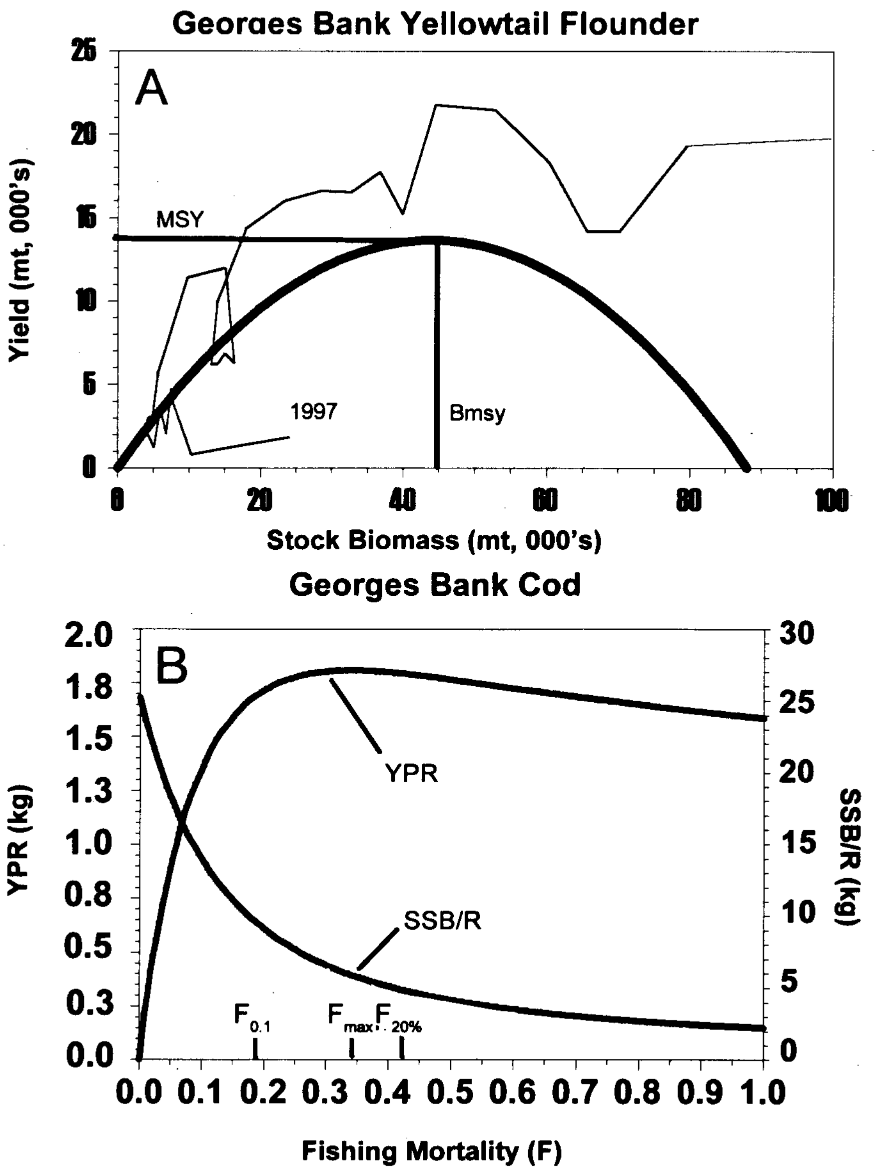

Figure 2. (A) Surplus production model yield curve for Georges Bank yellowtail flounder, and (B) yield-per-recruit and spawning stock biomass-per-recruit curves for Georges Bank cod, including biological reference points.

is less intensive, surplus-production or index-based methods may be adequate. In any case, the process obviously depends upon the type and amount of data available; while analytic assessments are the most useful and informative, adequate supporting information is available only for a relatively few northeast stocks. The improvement of "fishery-dependent" data collection programs (landings and effort data by area, and biological sampling of commercial and recreational catches at sea and at dockside) and "fishery-independent" data collection in research vessel surveys has been and continues to be a high priority of the National Marine Fisheries Service. Also, much remains to be learned about the biology of many species; the biological information which is available (*e.g.*, growth and maturation rates) requires continual updating in many cases since biological parameters may vary significantly with exploitation and environmental changes. For the present, there are great differences in availability of different types of information for the many species of interest in this region, and thus assessment work for different species will follow different pathways. As management needs continue to intensify, so will the need for improved fishery-dependent and fishery-independent data collection.

KINDS OF ASSESSMENTS

The assessments presented in this report can be roughly grouped in order of increasing complexity into the following categories, each one including features of simpler levels. Types are as follows:

INDEX: assessment involves development of an index of stock size from research vessel survey data (mean catch per tow) or from fishery catch-per-unit-of-effort (CPUE) data.

SURPLUS PRODUCTION: assessment models relationships between yield and fishing effort. Models are based on simple biological rules of increase and decrease and allow useful analyses with relatively little data, but cannot be readily adapted to account for detailed biological or fishery-related information.

YIELD PER RECRUIT: assessment provides evaluations of yield as a function of fishing mortality and age at entry to the fishery, incorporating information on biological parameters (growth and natural mortality rates). Spawning stock biomass per recruit calculations are analogous in that they use such information along with maturation data to model trends in spawning biomass.

AGE/SIZE STRUCTURED: assessment includes analysis of the observed size or age composition of the catch (*e.g.*, virtual population analysis, modified DeLury analysis) and biological information (size and weight at age, maturation rates) to provide estimates of fishing mortality and total and spawning stock size (numbers and weight) over time. Resulting estimates can be combined with estimates of incoming recruitment from research vessel surveys or other sources to make predictions of catch and stock size in upcoming years in relation to fishing mortality. They also provide data for a wide variety of more sophisticated analyses e.g. recruitment in relation to spawning stock size or multispecies modeling.

Figure 3 provides an outline of the sequence in which catch and survey data, in the lower right and left boxes respectively, can be used to provide assessment advice. For example, an INDEX level assessment involves information generated by following either the rightmost or leftmost vertical arrows, depending on whether commercial or survey data are available. A SURPLUS PRODUCTION type assessment would require landings and effort data from the fishery (lower right-hand box in the figure) while YIELD PER RECRUIT analyses are dependent on detailed biological information (biological data.) AGE/SIZE STRUCTURED assessments would require information represented in the middle column of boxes in Figure 3.

Increasing the level of complexity of an assessment requires a substantial additional commitment of resources to develop and maintain it at its more complex level. Conversely, the level and information content of an assessment can decrease relatively quickly if sufficient resources are not allocated to it.

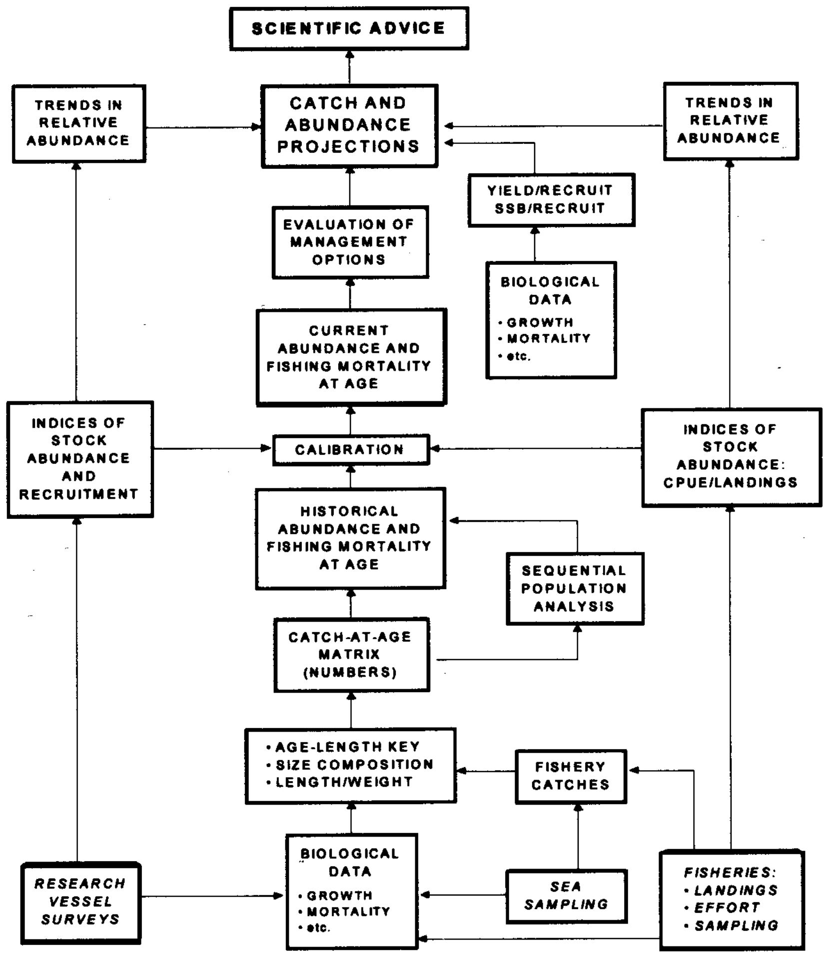

Figure 3. Diagram of alternative pathways by which fishery-dependent and fishery-independent data are used to provide assessment advice.

The assessments in this report consider each species as a separate entity, with no consideration of species interactions. However, there are significant biological (predator/prey) as well as technological (bycatch) interactions for northeastern U.S. fishery resources, and a large part of the Center's research program is dedicated to modeling the effects of these interactions. The results of these studies are not presented here. The significance of the mixed-species nature of the northeast trawl fisheries is illustrated in the section entitled Aggregate Resources Trends. There, aggregate research trawl survey and commercial trawl data are presented illustrating major trends in abundance and catches. The approaches used, however, are illustrative of overall trends and do not address species interactions and other complexities of multispecies fishery resources.

FISHERY MANAGEMENT

Fisheries occurring primarily in the Exclusive Economic Zone (EEZ) off the Northeastern U.S. are managed under Fishery Management Plans (FMPs) developed by the New England and the Mid-Atlantic Fishery Management Councils. Fisheries occurring primarily in state waters are managed by the individual states or through Interstate Agreements made under the auspices of the Atlantic States Marine Fisheries Commission (ASMFC). Current management plans are listed in Table 1.

PATHWAYS OF ASSESSMENT ADVICE

Stock assessments and related analyses and documentation are sometimes provided directly to the Councils through Scientific and Statistical Committee meetings or to ASMFC via section meetings. Increasingly, however, managers are depending upon the Northeast Regional Stock Assessment Workshop (SAW) process for assessment advice.

The SAW originated in 1985 as a vehicle for in-house or local peer review of stock assessments and related research. As the condition of fishery resources in the Northeast de-

Table 1. Federal, joint and interstate fishery management plans currently in place or under development for species-stocks mentioned in this report.

Plan	Jurisdiction	Organization Responsible	Year Implemented	Last Amendment	Amendment Number
1. Northeast Multispecies	Federal	NEFMC	1986	1997	8[1]
2. Atlantic Sea Scallop	Federal	NEFMC	1982	1997	6[1]
3. American Lobster	Interstate	ASMFC	1979	1997	3
	Federal	NEFMC	1983	1997	6[1]
4. Atlantic Surfclam and Ocean Quahog	Federal	MAFMC	1977	1996	10[1]
5. Atlantic Mackerel, Squid, and Butterfish	Federal	MAFMC	1978	1996	6[1]
6. Summer Flounder, Scup, and Black Sea Bass	Joint	MAFMC/ASMFC	1988	1997	10[1]
7. Bluefish	Joint	MAFMC/ASMFC	1989		
8. Atlantic Herring	Federal	US Dept of Commerce	1995		
	Interstate	ASMFC	1993		
	Federal	NEFMC		Under Development	
9. Northern Shrimp	Interstate	ASMFC	1986		
10. Striped Bass	Interstate	ASMFC	1981	1995	5
11. Tilefish	Federal	MAFMC		Under Development	
12. Atlantic Salmon	Federal	NEFMC	1987		
13. Winter Flounder	Interstate	ASMFC	1989	1992	1
14. Dogfish	Federal	MAFMC/NEFMC		Under Development	
15. Atlantic Sturgeon	Interstate	ASMFC	1990		
16. Shad and River Herring	Interstate	ASMFC	1985		
17. Goosefish	Federal	NEFMC/MAFMC		Under Development	

[1] New Amendment in process

teriorated and pressure for assessment and management advice intensified, the SAW evolved into an intensive biannual review process involving four components: a Steering Committee to oversee the process and determine priorities; working groups responsible for completion of stock assessments and working papers; a Stock Assessment Review Committee (SARC) that reviews assessments and prepares management advice; and a Public Review Workshop that presents SARC reports and advice at fishery management council meetings. SARC membership is structured to include experts from the NEFSC and other NMFS Centers, the Councils and ASMFC, state agencies and academic institutions, and Canada; and all SAW-related meetings and workshops are open to participation by industry representatives and other interested parties. The SAW has been very effective in generating high quality assessment advice while enhancing the credibility of this advice through intensive peer review and participation by fisheries scientists, industry and the general public.

DEFINITION OF TECHNICAL TERMS

Assessment terms used throughout this document may not be familiar to all. A brief explanation of some of these terms follows, organized alphabetically.

Assessment level: Categories of the level of complexity of each assessment included in this document are as given above (INDEX, SURPLUS-PRODUCTION, YIELD PER RECRUIT, and AGE/SIZE STRUCTURED). The latter may include projections of future catch and stock sizes or modeling of relationships between recruitment and spawning stock size.

Biological reference points: Benchmarks such as fishing mortality rates that may provide acceptable protection against growth overfishing and/or recruitment overfishing for a particular stock. They are usually calculated from yield-per-recruit curves, spawning stock biomass-per-recruit curves and stock-recruitment data. Examples are $F_{0.1}$, F_{max} and $F_{20\%}$.

Exploitation pattern: The distribution of fishing mortality over the age composition of the fish population, determined by the type of fishing gear, areal and seasonal distribution of fishing, and the growth and migration of the fish. The pattern can be changed by modifications to fishing gear, for example, increasing mesh or hook size, or by changing the ratio of harvest by gears exploiting the fish (*e.g.*, gill net, trawl, hook and line, *etc.*).

Exploitation rate: The proportion of a population at the beginning of a given time period that is caught during that time period (usually expressed on a yearly basis). For example, if 720,000 fish were caught during the year from a population of 1 million fish alive at the beginning of the year, the annual exploitation rate (or annual fishing mortality rate) would be 0.72. Note that this rate cannot exceed unity; obviously, more fish cannot die than were originally present.

Fishing mortality rate (F): That part of the total mortality rate applying to a fish population that is caused by fishing. Fishing mortality is usually expressed as an instantaneous rate, as discussed under **Mortality rates**, and can range to values exceeding unity, such as 2.0 or higher.

F_{max}: The fishing mortality rate that results in the maximum level of yield-per-recruit. This is the point that defines growth overfishing.

F_{med}: The fishing mortality rate at which recruitment balances removals over time, as estimated from stock-recruitment data.

$F_{0.1}$: The fishing mortality rate at which the increase in yield per recruit in weight for an increase in a unit of effort is only 10 percent of the yield per recruit produced by the first unit of effort on the unexploited stock (*i.e.*, the slope of the yield-per-recruit curve for the $F_{0.1}$ rate is only one-tenth the slope of the curve at its origin).

$F_{20\%}$: The fishing mortality rate at which spawning per recruit (usually using spawning biomass per recruit as a proxy) is reduced to 20% of the unfished level. Other levels may be used depending on biological characteristics of the target species and/or management objectives.

Growth overfishing: The rate of fishing, as indicated by a yield-per-recruit curve, greater than that at which the loss in weight from total mortality equals the gain in weight due to growth. This point is defined as F_{max}.

Long-term potential catch: The largest annual harvest in weight that could be removed from a fish stock year after year, under existing environmental conditions. This can be estimated in various ways, such as maximum yield from surplus production models or average observed catches over a period of years.

Maturation: Reported in this document wherever possible as median length or age at maturity (L_{50} or A_{50}) as determined from length and age-specific maturation ogives.

Mortality rates: The rates at which fish die from fishing and/or natural causes. Mortality rates can be described in several ways.

One conceptually simple approach is to express mortality on an annual basis, *i.e.*, A, the annual mortality rate, expressed as a proportion (5% or 0.05 per year). This is the fraction of the population alive at the beginning of the year which dies during the year. The survivors may be represented by (1-A) = S, the annual survival rate.

In exploited populations, however, it is important to account for both fishing and natural mortality. This can pose complex problems for three reasons: we generally have little information on natural mortality; population changes tend to be exponential; and also, different components tend to be multiplicative, that is, in any given period of time, individuals that die from natural causes would otherwise be killed by fishing and vice versa.

For these reasons, biologists tend to work with <u>instantaneous</u> rates, in which time intervals are sufficiently short so as to allow separation of the primary components as instantaneous fishing mortality (F) and instantaneous natural mortality (M). Together the two are equivalent to instantaneous total mortality (Z), *i.e.* Z = F+M.

The necessary mathematics are based on a logarithmic scale which relates well to biological processes (since they tend to be exponential); and effects which are multiplicative in nature become additive on a logarithmic scale.

The concept of instantaneous rates can be illustrated by a simple example. Imagine a year of a fish's life to be divided into a large number (n) of equal time intervals, and Z/n is the number dying within that interval. If n = 1,000 and Z =1.0, then during the first time interval 1/1000 = 0.1% of the population dies. For a population of 1,000,000 fish, 1000 would die, leaving 999,000 survivors. In the next time interval 0.1% of 999,000 fish, or 999 fish die, leaving 998,001 survivors, and so on. Repeated 1,000 times, we would have:

$$1{,}000{,}000\,(1-0.0010)^{1000}$$

$$= 367{,}695 \text{ survivors}$$

Or, we may use the relation:

$$S = e^{-Z} = 0.3679\,(1{,}000{,}000)$$

$$= 367{,}879 \text{ survivors}$$

where e is the base of natural logarithms (2.71828).

The calculation provides the same approximate result. Note that the annual mortality rate A = 1 - S, hence, 1-0.3679 or 0.6321 or 63% in our example. Again, A can never exceed unity, although F and Z can, for heavily exploited stocks.

Using instantanous rates to deal with different sources of mortality over time can be illustrated as follows. Assume a population at the beginning of a year consists of 1,000 fish, and that during the year it is subjected to an instantaneous fishing mortality rate of F=0.5, while instantaneous natural mortality (M) = 0.2. The instantaneous total mortality rate (Z) is equal to (F+M) = 0.7. Removals by fishing are calculated by applying the annual exploitation rate :

$$\frac{F}{Z}(1 - e^{-Z}) = \frac{0.5}{0.7}(1 - e^{-0.7}) = 0.3596$$

During the year, 0.3596(1000) = 360 fish are caught, and:

$$\begin{aligned} S &= e^{-0.7} \\ &= 0.4966(1000) \\ &= 497 \text{ fish survive} \end{aligned}$$

The difference from the original number of 1,000 fish (1,000-360-497), or 143 fish, is the number dying from natural causes. The additive property of instantaneous rates allows us to obtain approximately the same result for natural mortality, *i.e.*,

$$\begin{aligned} \frac{M}{Z}(1 - e^{-Z}) &= \frac{0.2}{0.7}(1 - e^{-0.7}) \\ &= 0.1438, \\ &\text{or, 144 fish} \end{aligned}$$

In the absence of fishing this number would be:

$$\begin{aligned} A &= (1 - e^{-0.2})\,1000 \\ &= 0.1813(1000) \\ &= 181 \text{ fish} \end{aligned}$$

with 819 fish surviving to the beginning of the following year. If the process is continued for another year, the catch in the exploited population would be 179 fish, 71 fish would die from natural causes, and 247 fish would survive, while in the unfished population 149 fish would die, leaving 670 survivors. Continued for 10 years the exploited population would be essentially eliminated (1 surviving fish) whereas 14% of the unfished population (135 fish) would survive.

This example uses an annual exploitation rate (36%) for the exploited population that is somewhat high but was sustained historically by some Northeast stocks. For some heavily fished stocks (scallops, yellowtail flounder) exploitation rates have in some years exceeded 80 percent. The corresponding instantaneous fishing and total mortality rates were F > 2.0 and Z > 2.2. The number of yellowtail alive after 5 years from a year class of 1,000,000 fish would be

$$1{,}000{,}000\,[e^{-2.2 \times 5}] = 17 \text{ fish!}$$

Natural mortality rate (M): That part of a fish population's total mortality caused by factors other than fishing, usually expressed as an instantaneous rate. Commonly, all sources of M are considered together since they usually account for much less than fishing mortality.

Nominal catch: The sum of the catches that are landed (expressed as live weight or equivalents). Does not include unreported discards.

Overfishing definition: Objective and measurable guideline(s) for a given stock defining the point at which the stock reaches an overfished condition; required for each fishery management plan under National Standard 1 guidelines (50 CFR Part 600) for the Magnuson-Stevens Fishery Conservation and Management Act. This may be expressed in terms of a minimum level of spawning biomass; maximum level of fishing mortality, or some other measureable standard designed to ensure maintenance of the stock's productive capacity.

Quota: A portion of a total allowable catch (TAC) allocated to an operating unit, such as a vessel size class or a country.

Recruitment: The amount of fish added to the exploitable stock each year due to growth and/or migration into the fishing area. The number of fish that grow to become vulnerable to the fishing gear in a given year would be the recruitment to the fishable population in that year. The term is also used in referring to the number of fish reaching a certain age or size.

Recruitment overfishing: The rate of fishing above which recruitment to the exploitable stock becomes significantly reduced. This is characterized by a greatly reduced spawning stock, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year.

Spawning stock biomass (SSB): The total weight of all sexually mature fish in the population. This quantity depends on year class abundance, the exploitation pattern, the rate of growth, fishing and natural mortality rates, the onset of sexual maturity and environmental conditions.

Spawning stock biomass-per-recruit (SSB/R): The expected lifetime contribution to the spawning stock biomass for a recruit of a specific age (*e.g.*, per age 2 individual). For a given exploitation pattern, rate of growth, and natural mortality, an expected equilibrium value of SSB/R can be calculated for each level of F. A useful reference point is the level of SSB/R that would be realized if there were no fishing. This is a maximum value for SSB/R, and can be compared to levels of SSB/R generated under different rates of fishing. For example, the maximum SSB/R for Georges Bank haddock is approximately 9 kg for a recruit at age 1.

Status of exploitation: In this report, the terms underexploited, fully exploited, and overexploited. These describe the effects of current fishing effort on each stock, and are based on the best judgement of the assessment scientist responsible.

Sustainable yield: The number or weight of fish in a stock that can be taken by fishing without reducing the stock biomass from year to year, assuming that environmental conditions remain the same.

TAC: Total allowable catch is the total regulated catch from a stock in a given time period, usually a year.

Vessel class: Commercial fishing vessels are classified according to their gross registered tons (grt) of displacement. Vessels displacing less than 5 tons were not routinely monitored prior to the new mandatory reporting system implemented in the Northeast in 1994, and were referred to as undertonnage. The current classification scheme is as follows:

Vessel Class	GRT
1	<5
2	5 - 50
3	51 - 150
4	151+

Virtual population analysis (or cohort analysis): An analysis of the catches from a given year class over its life in the fishery. If 10 fish from the 1968 year class were caught each year for 10 successive years from 1970 to 1979 (age 2 to age 11), then 100 fish would have been caught from the 1968 year class during its life in the fishery. Since 10 fish were caught during 1979, then 10 fish must have been alive at the beginning of that year. At the beginning of 1978, there must have been at least 20 fish alive because 10 were caught in 1978 and 10 more were caught in 1979. Working backward by year, one can be virtually certain that at least 100 fish were alive at the beginning of 1970.

A virtual population analysis goes a step further and calculates the number of fish that must have been alive if some fish also died from causes other than fishing. For example, if in addition to the 10 fish caught per year in the fishery, the instantaneous natural mortality rate was also known, then a virtual population analysis calculates the number that must have been alive each year to produce a catch of 10 fish each year plus those that died from natural causes.

If one knows the fishing mortality rate during the last year for which catch data are available (in this case, 1979), then the exact abundance of the year class can be determined in each and every year. Even when an approximate fishing mortality rate is used in the last year (1979), a precise estimate of the abundance can usually be determined for the stock in years prior to the most recent one or two (*e.g.*, for 1970-1976 or 1977 in the example).

Accuracy depends on the rate of population decline and the correctness of the starting value of the fishing mortality rate (in the most recent year). This technique is used extensively in fishery assessments, since the conditions for its use are so common: many fisheries are heavily exploited, annual catches for a year class can generally be determined, natural mortality rate is known within a fairly small range and is low compared with the fishing mortality rate.

Year class (or cohort): Fish in a stock born in the same year. For example, the 1987 year class of cod includes all cod born in 1987, which would be age 1 in 1988. Occasionally, a stock produces a very small or very large year class which can be pivotal in determining stock abundance in later years.

Yield per recruit: The expected lifetime yield for a fish of a specific age (*e.g.*, per age 2 individual). For a given exploitation pattern, rate of growth, and natural mortality, an expected equilibrium value of Y/R can be calculated for each level of F.

For further information

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