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FAO-ICLARM
stock assessment tools

Reference manual

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ABSTRACT

This manual presents key concepts and methods found useful for assessing the components of tropical and subtropical fish stocks, with emphasis on short- and medium-lived species of finfish and invertebrates (shrimps, squids, etc.) and on approaches based on the detailed analysis of length–frequency data. This account covers the preprocessing of length–frequency and ancillary data, growth estimation, mortality, gear selection, virtual population analysis and yield prediction.

The manual is illustrated by means of computational examples, graphics and tabular printouts generated by the **FiSAT** software (FAO-ICLARM Stock Assessment Tools), and thus complements the **FiSAT** User's Manual.

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Chapter 1. Introduction

What you will learn from this chapter

In this chapter, you will be introduced to the rationale and fundamentals behind fish stock assessment, and to specific problems of tropical fish stock assessment.

Why stock assessment?¹

Capture fisheries exploit living and, hence, renewable resources. In the overwhelming majority of cases, fisheries resources are “common property”. In many cases they are also “open access”—i.e., fishing licenses are not required, or are available at nominal fees, or other limitations to entry are not effectively enforced. Open and free access generally implies competition for the resources which, in an unregulated fishery, leads ultimately to biological and economic overfishing.

Biological overfishing has different effects (growth and/or recruitment overfishing with regard to single species, ecosystem overfishing with regard to a multispecies resource), all discussed, if briefly, in this manual.

Economic overfishing is also multifaceted. When one considers the first boat operating in a fishery, “trouble” actually begins when a second unit starts fishing, thus reducing the biomass (and hence, catch/effort and economic returns) available to the first unit. Progressive reduction of the resource then occurs, until there are so many units in the fishery that the boats cannot manage on average to break even, and fishery

¹ Adapted from Pauly et al. (1991) and Sparre and Venema (1992).

operators clamor loudly for subsidies (for example in the form of tax reductions on fuel or gear, subsidies for the renewal of boats, or even more research and management).

At the level of society, trouble begins when the difference between the total revenue in a fishery and the total cost of fishing—i.e. the net economic yield or resource rent—starts to decline. Fisheries resource rents can be considerable, but are dissipated in unmanaged fisheries.

Providing a basis for a rational management of exploited resources thus involves dealing with a wide variety of issues, ranging from political problems to socioeconomic and resource conservation issues. However, this manual emphasizes only the biological aspects, i.e. fish stock assessment. Needless to say, when used as the basis for management, the other components—economic and sociological—should also be considered (see Coppola et al. 1992, Cochet and Gilly 1990, Sparre and Willman 1992).

In essence, the ultimate goal of fish stock assessment is to provide technical advice to maintain the productivity of fish stocks.

To further illustrate this basic objective, consider Fig. 1.1. On the horizontal axis is fishing effort, f (measured here in number of boat days). On the other axis is yield, i.e. landings (usually in weight; however if the landings consist of different groups of animals, for example shrimp, finfish and squid, it may be more appropriate to express the yield in terms of value). The figure shows that up to a certain level we gain by increasing fishing effort, but beyond that level, the renewal of the resource (through reproduction and the body growth of individuals) cannot keep pace with the removal caused by fishing, at which point (MSY or “maximum sustainable yield”) any further increase in exploitation level causes yield to fall.

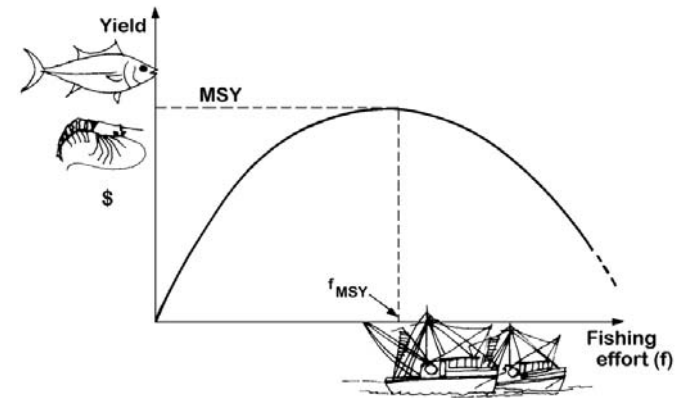


Fig. 1.1. Typical relationship between the yield of a fishery (in weight or value) and fishing effort.

A few fisheries resources in the world may still be underexploited—particularly in inland water bodies in which a combination of factors (remoteness, lack of suitable gear and crafts, lack of markets, or insecure conditions) have hindered the build-up of fishing capacities. To account for such cases, fish stock assessment should also:

- evaluate the potential yields of underutilized water bodies, taking the need for resource conservation into account;
- consider adoption and improvement of suitable fishing gear and craft combinations (for example through fishing trials), and of processing methods and marketing;
- define technical assistance schemes that allow a phased growth of the fisheries, and the adjustment of effort to those levels leading to high, but sustainable yields.

Living aquatic resources have become a major source of food protein, especially in the tropics, providing around a quarter of the total animal protein in many developing

countries and up to three quarters in some others. Yet despite their importance, tropical and subtropical fisheries are most often badly managed (if at all)—the resources are generally overexploited and the fisheries overcapitalized.

Fisheries scientists alone cannot remedy this situation; however, they can provide the biological advice required to rehabilitate stocks that are mismanaged. The methodology for this exists. It consists of various refinements of standard assessment techniques, together with the judicious application of new methods developed for use in tropical waters. This manual is structured around a methodology of this sort.

Basic concepts of fisheries science

Fish are usually not seen, counted or weighed before they are caught, and hence fisheries research has, from the very start, depended on indirect inferences (mathematical and statistical) for quantifying the vital statistics of fish populations required for fisheries management.

Thus, some of the earliest applications of mathematics and statistics (outside of the physical sciences) are those of fisheries biologists. However, when describing the dynamics of an exploited aquatic resource, the first concept that needs defining is that of the *stock*.

The stock concept²

A stock is a subset of a *species*, the species itself being the basic taxonomic unit. Thus, a prerequisite for the identification of stocks is the ability to distinguish between different species. Because of the great number of different, often similar species observed in tropical fisheries, their identification can be

² Adapted from Sparre and Venema (1992).

difficult. The fishery scientist, however, must master the techniques of species identification if any meaningful fish stock assessment is to come out of the data collected. Tools to solve species identification problems are provided by the *FAO species identification sheets for fishery purposes* (Fischer 1978, Fischer and Bianchi 1984, Fischer, Bianchi and Scott 1981, Fischer and Whitehead 1974), the *FAO species catalogues* (Allen 1985, Carpenter 1988, Carpenter and Allen 1989, Cohen et al. 1990, Colette and Nauen 1983, Compagno 1984 and 1984a, Holthuis 1980 and 1991, Marquez 1990, Nakamura 1985, Roper, Sweeney and Nauen 1984, Russel, 1990, Whitehead 1985, Whitehead, Nelson and Wongratana 1988) and most recently by the development of a computerized global fish database on fish biology, **FishBase**, also usable for species identification (Froese and Pauly 1996), available on CD-ROM.*

By a *stock* we mean a subset of one species having the same growth and mortality parameters, and inhabiting a particular geographical area.

A group of animals for which the geographical limits can be defined may be considered a stock for the purposes of fish stock research. Such a group of animals should however share a common gene pool. For species showing little migratory behavior (mainly demersal species), it is easier to identify a stock than for highly migratory species such as tunas.

Cushing (1968) defines a stock as a subset of a species with a single spawning group which the adults join year after year. Larkin (1972) defines a stock as "a population of organisms which, sharing a common gene pool, is sufficiently discrete to warrant consideration as a self-perpetuating system which can be managed", while Ihssen et al. (1981) define a stock as "an

* Contact ICLARM (or fishbase@cgnet.com) for information on this joint ICLARM/FAO product.

Chapter 4. Analysis of Growth

What you will learn from this chapter

In this chapter, you will learn about the models that can be used to estimate directly or indirectly the parameters of the von Bertalanffy growth function from length frequencies, size-at-age data or growth increment data. The growth performance index ϕ' and related concepts will also be introduced.

Introduction¹⁷

Growth may be defined as the change over time of the body mass (= body weight) of a fish, being the net result of two processes with opposite tendencies, one the building-up of body substances (anabolism) and the other the breaking-down of these substances (catabolism), or

$$dW/dt = HW^d - kW \quad \dots 4.1)$$

where dW/dt is the change in body weight per unit time, H is the coefficient of anabolism and k is the coefficient of catabolism. The process of anabolism is here viewed as being proportional to a power (d) of fish weight (W), while catabolism is proportional to weight itself (Bertalanffy 1934, Pauly 1981).

Details on the integration of Equation 4.1 to a growth curve have been presented in Taylor (1962) and Pauly (1979a). It suffices to mention here that, in the course of this integration, it is assumed that

$$HW \propto pL^a \quad \dots 4.2)$$

and

$$W \propto qL^b \quad \dots 4.3)$$

where $b = 3$, $a = 2$, and hence $d = 2/3$. This, following integration gives the equation defining the length (L_t) at age t

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)} \right] \quad \dots 4.4)$$

where

L_∞ is the asymptotic length, that is the mean length the fish of a given stock would reach if they were to grow indefinitely;

K is the rate (of dimension time^{-1}) at which L_∞ is approached; and

t_0 is the "age of the fish at zero length" if they had always grown in the manner described by the equation (note that t_0 is generally negative).

Equation 4.4 is the VBGF (von Bertalanffy growth function; Bertalanffy 1934). The equation can also be expressed in terms of weight, as

$$W_t = W_\infty \left[1 - e^{-K(t-t_0)} \right]^3 \quad \dots 4.5)$$

where W_∞ is the asymptotic weight and all other parameters are as defined above.

When, as in Equation 4.5, the exponent of the (implied) length-weight relationship set is equal to 3, fitting the equation to weight-growth data is the same as fitting it to length-growth data, except that the cubic root of all weight values is taken prior to all calculations, these cube root values being then

¹⁷ Adapted from Pauly (1984a).

treated exactly as if they were length values. This is justified because, when weight growth is isometric:

$$L \propto (W)^{1/3} \quad \dots 4.6)$$

More generally, weights can be rendered proportional to length by raising them to the inverse of the power of the length–weight relationship b , or

$$L \propto W^{1/b} \quad \dots 4.7)$$

which can be used when weight growth is either isometric or allometric to obtain growth parameters (K , t_0) generally equivalent to those that would be obtained by fitting the corresponding length data. Note, however, that when empirical data are used, slight differences might still occur between values of K and t_0 computed from weight and length data, depending on sample sizes and method of fitting.

This is illustrated by the set of constructed data in Table 4.1, in which values of W_∞ , L_∞ , K and t_0 were obtained for data with the length–weight relationships $W = aL^{2.5}$, $W = aL^{3.0}$ and $W = aL^{3.5}$. These data demonstrate that this property can be used when using **FISAT** to fit weight data with the programs that fit length data, the only prior requirement being that the weight data must be converted to "length" using the appropriate routine.

	Age (year)	Length (cm)	Weight (in arbitrary units)		
			b = 2.5	b = 3.0	b = 3.5
A	1	15	871.4	3,375	13,071
	2	18	1,375	5,832	24,743
	3	20	1,789	8,000	35,777
	4	21	2,021	9,261	42,439
B	W_∞	—	2,450	11,669	55,572
	L_∞	22.68	$22.68(W_\infty^{1/2.5})$	$22.68(W_\infty^{1/3.0})$	$22.68(W_\infty^{1/3.5})$
	K	0.511	0.511	0.511	0.511
	t_0	-1.116	-1.116	-1.116	-1.116
	r^2	0.999	0.999	0.999	0.999

^aThe length–weight relationship used here was of the form $W = a \cdot L^b$, with "a" set equal to unity.

While the version of the VBGF presented above assumes constant environmental conditions, it has been demonstrated by various authors that fish live in an environment with seasonally oscillating features (temperature, food availability, etc.) and that their growth may also oscillate seasonally (Ursin 1963, Pitcher and Macdonald 1973, Lockwood 1974, Daget and Ecoutin 1976, Cloern and Nichols 1978, Pauly and Gaschütz 1979, Pauly et al. 1992). The model incorporated in **FISAT** for expressing the seasonally oscillating length growth of fishes was presented by Somers (1988) and has the form

$$L_t = L_\infty \left[1 - e^{-K(t-t_0) - (CK/2\pi) [\sin 2\pi(t-t_s) - \sin 2\pi(t_0-t_s)]} \right] \quad \dots 4.8)$$

where L_∞ , K , t_0 , t and L_t are as defined above, while the new parameters C and t_s refer to the intensity of the (sinusoid) growth oscillations of the growth curve and the onset of the first oscillation relative to $t = 0$, respectively. It is a property of the parameter C that it takes a value of 1 when the growth rate (dL/dt) has exactly one zero value per year (in which case Equation 4.8 reduces to Equation 4.4), and that it takes intermediate values when the seasonal oscillations are sufficient to reduce, but not to halt, growth in length (Fig. 4.1).

Various authors (Pauly 1984a, Gaschütz et al. 1980, Longhurst and Pauly 1987) have shown a strong correlation between C and ΔT (= difference between the highest and lowest average mean temperature to which the fish are exposed in the course of a year, in °C), which suggests that:

- seasonal length growth oscillations are caused by temperature fluctuations or by another environmental parameter which itself correlates with temperature (e.g. food availability or feeding activity);
- slight seasonal fluctuations of temperature (or of correlated parameters) such as occur in the tropics are sufficient to generate seasonally oscillating growth

Shepherd's method

Original version²⁰

Shepherd's method is conceptually very similar to ELEFAN I in that it is based on the goodness-of-fit of the modes (if any) in one or more length compositions to the locations expected from a specified growth curve. This places a strong constraint on the possible locations of modes and their relationship to one another, eliminating many non-feasible interpretations of the data and yielding direct estimates of growth parameters.

The goodness-of-fit criterion used in the original version of Shepherd's method is akin to a correlation coefficient between the data and a test function constructed from a growth curve. The idea is similar to that used in the time series analysis technique known as complex demodulation (see for example Bloomfield 1976). The criterion is designed to take account of data in proportion to their quantity and likely reliability without pre-processing, and not to be unduly sensitive to possible spurious modes created by sampling noise.

The approach interprets one or more length compositions (arising from data collected in different years, seasons or months) in terms of a single growth curve. For simplicity, this is assumed to be of the standard VBGF, i.e. without seasonal modulation of growth rate.

Given current estimates of the parameters, L_∞ , K and t_0 of the growth curve, the lengths where modes are to be expected in a season which is a fraction t_i of the annual cycle are given by

$$L = L_\infty \left[e^{-K(t+t_i-t_0)} \right] \quad \dots 4.12$$

for $t = 0, 1, 2, \dots$ etc.

Thus, observations occurring at or near these lengths may be considered as evidence in favor of the current parameter choices. Conversely, observations occurring at the intermodal lengths (given by $t = 0.5, 1.5, 2.5$, etc.) constitute evidence against them.

For any reason, one may construct a test function which is positively near the expected modal lengths and negatively near the intermodal lengths. The sum of products of the observations with this test function then constitutes a criterion of goodness-of-fit measure (or "score"), constructed by summing the totals, thereby using all available data efficiently.

Two refinements of this idea are used in practice. First, because one may expect the numbers at length in any length interval to be roughly Poisson distributed, the square root of the numbers observed is used in the summation. This provides an appropriately modest degree of dynamic range compression so that numerous observations still carry more weight than rare ones, but not overwhelmingly so.

Second, since modal lengths do not generally fall in the center of length intervals, and for length groups approaching L_∞ there may be several modes in a length interval, it is necessary to average the test function over the length intervals in use. A suitable basic test function is simply $\cos 2\pi(t-t_i)$ where t is estimated age-at-length (measured from 1 January), i.e.

$$t = (1/K) \cdot \ln \left[(L_\infty - L_0) / (L_\infty - L_t) \right] \quad \dots 4.13$$

or

$$t = t_0 - (1/K) \cdot \ln \left[1 - (L_t / L_\infty) \right] \quad \dots 4.14$$

where $L_0 = L_\infty (1 - e^{-Kt_0})$

²⁰ Adapted from Shepherd (1987).

For a length interval whose upper and lower bounds correspond to ages-at-length of t_{\max} and t_{\min} , it is easily shown that

$$T_1 = \left[\frac{\sin \pi(t_{\max} - t_{\min})}{\pi(t_{\max} - t_{\min})} \right] \cos 2\pi(\bar{t} - t_1) \quad \dots 4.15$$

where T_1 is the average of this test function over the interval, and \bar{t} is the average of t_{\max} and t_{\min} . The first term of this expression is the Fraunhofer diffraction function, which in this context allows for the number and placement of modes in the interval. It becomes small if there is more than one mode in the interval, thus correctly allowing for the obvious fact that observations in such an interval yield little evidence for modal positions and should be heavily discounted.

The goodness-of-fit (or score) function is then

$$S = \sum_l \sum_i T_{li} \cdot N_{li}^{1/2} \quad \dots 4.16$$

where l indexes the length groups and i indexes the various distributions available.

Noting that, because of Equation 4.14, t_{\max} and t_{\min} and, therefore, also t and T_1 are periodic in t_z (t_z is introduced here to denote a calendar date in terms of years as opposed to t_0 which is the age at length zero, usually not known), it is clear that S is similarly periodic (with a period of unity). It is therefore possible to determine very easily the value of t_z leading to a maximum of S for any choice of values for K and L_∞ . If we denote by A the value of S obtained with t_z set to zero, and B that obtained with t_z set to 0.25, it can be determined that

$$S_{\max} = (A^2 + B^2)^{1/2} \quad \dots 4.17$$

and

$$t_z = (1/2\pi) \tan^{-1} (B/A) \quad \dots 4.18$$

For a number of practical reasons this scoring function is, in **FiSAT**, re-expressed in relative terms, i.e. for each run the values of S are divided by S_{\max} , the maximum value of S in that run (which is also shown, however). The relative score value resulting from this, although ranging from 0 to 1, must not be seen as similar to a correlation coefficient or other measure of association. There is no "test" to tell whether the fit is "significant" or not.

Fig. 4.8 shows an application of this method to *Upeneus moluccensis* from Ragay Gulf, Philippines, with scores plotted against K values ranging, in log steps, from 0.1 to 10 years⁻¹.

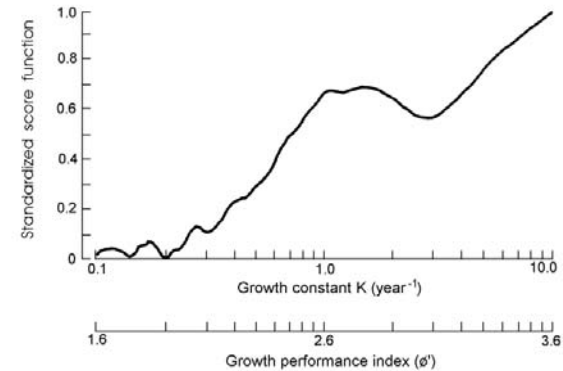


Fig. 4.8. K-scan routine for *Upeneus moluccensis* from Ragay Gulf, Philippines (L/F data of Table 3.1; note differences from Fig. 4.5).

The statistical properties of the score function are not known, so it is not possible to determine proper confidence regions for the parameter values. However, it seems plausible that the contours of constant score, output by **FiSAT**, would

$$\begin{aligned} \text{s.e.}(\hat{\theta}) &= (1/\log_{10})^2 \left\{ \left[(1/K^2) \cdot \text{s.e.}(K) \right] + \dots \right. \\ &\dots \left. \left[\left(\frac{1}{9} W_\infty^2 \right) \cdot \text{s.e.}(W_\infty) \right] + \left[\left(\frac{1}{3} K W_\infty \right) \cdot \text{cov}(K, W_\infty) \right] \right\} \dots 4.65 \end{aligned}$$

The approximate 95 percent confidence intervals of the estimated $\hat{\theta}$ can then be obtained through

$$\hat{\theta} \pm 2\text{s.e.}(\hat{\theta}) \quad \dots 4.66$$

with the assumption that the sample size is large enough to justify a normal distribution for the estimators.

FISAT outputs $\hat{\theta}$ and its standard error, based on these equations, when it fits the VBGF to length-at-age data.

Chapter 5. Mortality, Gear Selection and Recruitment

What you will learn from this chapter

In this chapter, you will learn about length-based models that can be used to derive mortality estimates, about a methodology for deriving seasonal recruitment patterns, and procedures for deriving trawl mesh or gillnet selection curves.

Introduction³¹

In fishery biology, the most useful way to express the decay (= decrease) through time of a group of fish born at the same time (a cohort) is by means of "instantaneous" rates. These rates, of which there are three (Z, M and F), are defined by two equations, of which the first is

$$N_{t+1} = N_t \cdot e^{-Z(t_{t+1}-t_t)} \quad \dots 5.1$$

where N_t is the (initial) number of fish at time t_t , and N_{t+1} is the number of remaining fish at time t_{t+1} ; Z is the instantaneous rate of total mortality. An advantage of such decay rates is that they can be added or subtracted. Thus, we have the second equation:

$$Z = M + F \quad \dots 5.2$$

where M is the instantaneous rate of natural mortality and F the instantaneous rate of fishing mortality. Obviously, when $F = 0$, $Z = M$, which means that natural and total mortality have the

³¹ Adapted from Pauly (1984a).

same value when there is no fishing, i.e. in an unexploited stock (Fig. 5.1).

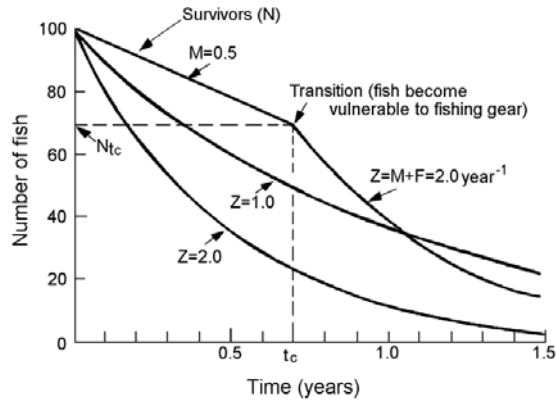


Fig. 5.1. Decrease of a cohort starting with 100 fish, subjected to different levels of natural mortality (M), and to fishing mortality (F) from age t_c on.

Instantaneous rates (i.e. "exponential" rates) of mortality can be converted to the fraction surviving through equations such as

$$S = N_{i+1}/N_i \quad \dots 5.3)$$

where S is the fraction surviving at time t_{i+1} , while

$$A = 1 - S \quad \dots 5.4)$$

is the fraction of the stock dead at time t_{i+1} . Although used by a few authors, fractional (and percentage) mortalities are not further discussed in this manual, because they are too cumbersome to handle in comparison with instantaneous rates (see Beverton and Holt 1956, p. 68).

Mortalities, whether expressed as instantaneous rates or as fractions, always refer to a certain period of time. Throughout this manual, the *year* is used as the conventional unit, unless mentioned otherwise.

Fisheries biologists have two main jobs as far as mortalities are concerned:

- to estimate total mortality;
- to split their estimates of total mortality, where appropriate, into separate estimates of natural and fishing mortalities.

A number of methods are proposed here by which these aims can be achieved, given suitable inputs.

Total mortality from catch curves³²

The most common approach in estimating total mortality is through a so-called *catch curve*, i.e. a plot of the logarithms of the numbers of survivors vs. their age. This method is based on the assumption of a *constant parameter system*.

Consider, as an example, a fish stock during the period 1971–1975 with a life span of five years. Let the numbers of survivors be those given in Table 5.1A. For simplicity, we assume only one cohort per year, recruiting on January 1. Note that a specific cohort can be followed diagonally across the table. Every year, the survivors of that cohort advance to a new age group. Each column, on the other hand, contains the numbers of survivors of five *different* cohorts on 1 January.

³² Adapted from Sparre and Venema (1992).

Table 5.1. Illustration of the "variable parameter system" (A) and the "constant parameter system" (B; see text).					
A: VARIABLE PARAMETER SYSTEM					
Age (years)	1971	1972	Number of survivors		
			1973	1974	1975
0	2105	1111	9560	1869	1236
1	2575	736	405	3817	618
2	155	1097	281	142	1193
3	102	58	298	109	59
4	6	38	18	138	29
B: CONSTANT PARAMETER SYSTEM					
Age (years)	1971	1972	Number of survivors		
			1973	1974	1975
0	2560	2560	2560	2560	2560
1	942	942	942	942	942
2	346	346	346	346	346
3	127	127	127	127	127
4	47	47	47	47	47

Altogether, Table 5.1A contains parts of nine different cohorts; of these, only one is represented in all years, i.e. from 1971 to 1975 (the 1971 cohort). As might be seen, recruitment (N_r) has varied from 1971 to 1975; the 1971 cohort and the 1973 cohort were strong, whereas the 1972 cohort was a weak one ("strong" means that N_r is considerably greater than average recruitment).

Now suppose that recruitment remains constant every year, as shown in Table 5.1B; assume further that F and M also remain constant. In this case, the number of survivors along the diagonals is the same as along the columns. Thus, in the case of constant recruitment, considering one cohort over a longer period is the same as considering all different cohorts (the entire stock) in one particular year.

We know that the assumptions of a constant parameter system are never strictly fulfilled in reality. However, it is only by making such assumptions that we are able to carry out an analysis of available data; also it appears that the data points used to define catch curves (as defined below) usually fall

along straight lines, suggesting that recruitment varies little, at least past the early juvenile stage.

If steady-state is assumed and Z is assumed to be constant throughout the life of a cohort, the catch can be derived from Equation 5.1 as

$$C_{i+1} = (F/Z) \cdot (N_i - N_{i+1}) \quad \dots 5.5$$

Equation 5.5 is the "catch equation" (sometimes called "Baranov's equation"—Baranov 1918), where F/Z expresses the fraction of the mortality caused by fishing (also called "exploitation rate", E).

Suppose that an estimate of the age composition of the catch during a year is available. To develop a method to estimate Z from such data, Equation 5.5 may be rewritten as:

$$C_{i+1} = N_i \cdot (F/Z) \cdot [1 - e^{-Z(t_{i+1} - t_i)}] \quad \dots 5.6$$

Equation 5.6 is not linear in t_i , (nor in t_{i+1}), but linearization can be achieved by replacing N_i using Equation 5.5 which results in

$$C_{i+1} = N_r \cdot e^{-Z\Delta t} \cdot (F/Z) \cdot (1 - e^{-Z\Delta t}) \quad \dots 5.7$$

where $\Delta t = t_{i+1} - t_i$.

If we take the logarithm of Equation 5.7 and rearrange the terms, we obtain

$$\ln(C_{i+1}) = \ln[N_r \cdot (F/Z)] + Zt_r - Zt_i + \ln(1 - e^{-Z\Delta t}) \quad \dots 5.8$$

Here, t_i appears only in one linear term, $-Zt_i$, while the term $\ln[N_r \cdot (F/Z)] + Zt_r$ can be treated as constant (a) since N_r , t_r , F

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Symbols and Definitions*

a	multiplicative factor generally used in exponential relationships linking L and W ($W = aL^b$); Y-intercept in a Type I, or AM linear regression
a'	Y-intercept in a Type II, or GM linear regression
A	number of fish dead after a given time; i.e. $A = 1 - S$, also relative abundance
AM	arithmetic mean; used to characterize Type I regressions
ASP	"available sum of peaks"; the sum of available "points" in a file restructured for analysis with the ELEFAN I routine
b	exponent of a length–weight relationship; slope of a Type I (AM) linear regression
b'	slope of a Type II (GM) linear regression
B	biomass, or stock size in weight of a population of fish
\bar{B}	mean annual biomass of a stock
B_0	biomass prior to any fishing; unfished biomass
B_∞	environmental carrying capacity for a given stock, in weight
B/R	biomass per recruit
B'/R	relative biomass per recruit
c	the fraction L_c/L_∞
c_1, c_2	multipliers for estimating Z and its standard error using one of Hoenig's methods
c.f.	condition factor
cov	covariance

* Only the most commonly used combinations of symbols and subscripts are listed here.