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NUMERICAL METHOD FOR ESTIMATION OF FISH BIOMASS PARAMETERS

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ABSTRACT

A numerical method for estimation of biomass distribution with age, growth, and mortality parameters of a stock of any given species is described. Mean annual weights, distribution of numbers in fully exploited part of the biomass and turnover rates are used as basic input data for the computations. A procedure to obtain numbers of fish in juvenile year classes is also described. Examples of computed biomass parameters of Pacific ocean perch (Sebastes alutus) from the eastern Bering Sea are given as examples.

1. INTRODUCTION

Traditionally, the work on fisheries population with single species models has been number based and deals mainly with cohorts (year classes). Some new ecosystem and multispecies models (such as DYNUMES) are, however, biomass based and require various biomass parameters, such as biomass growth coefficients. Furthermore, both the single species population dynamics as well as ecosystem models, require age-dependent mortality coefficients, especially for the pre-fishery juveniles (mainly predation mortality), rather than the traditionally used mean "natural mortality" coefficient.

Many rates (e.g. growth) are changing considerably with age of the fish. Therefore the computation of age-dependent biomass parameters requires quantitative knowledge of biomass distribution with age. A numerical method is outlined in this paper for computation of biomass parameters, including the juveniles, using traditional available empirical data.

2. THEORY AND ASSUMPTIONS OF THE METHOD

Reliable biometric measurements of fish are usually available only for the exploited part of the biomass of exploited species. To obtain the necessary data for prefishery juveniles, some plausible assumptions and theory must be established for the extrapolation.

If we desire long-term average biomass distribution with age of the fully exploited part of the biomass, the available age-length data, collected at least over 10 years, must be summarized and normalized (e.g., to 100%). From these data we can compute average total mortality per exploited year class by computing the growth of previous year class, adding it to this year class biomass and subtracting the biomass of the next year class (see Figure 1).

$$Z_n = B_n\,(1-e^{-g}) + B_n - B_{n+1} \tag{1}$$

Consideration has been given to the possible nonlinear effects of nonlinear mortalities and growth with age on this calculation. However, these nonlinear effects were found to be small in relation to possible inaccuracies in the basic data used.

The same procedure (Figure 1, Formula 1) can also be used for computation of total mortality in juvenile year classes. However, the number (and biomass) distribution of juvenile year classes must first be extrapolated, using the assumption that each year class must produce the next mean year class and must provide also for predation mortality (which is the main component of "natural mortality" in the juveniles.

Rough estimation of total predation mortality of given species can be made from extensive quantitative fish food studies, such as Daan, 1973.

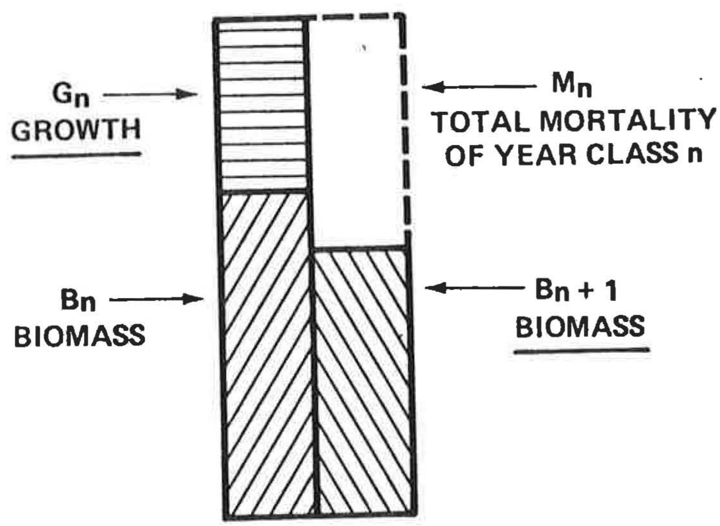

Figure 1.--Schematic presentation of mean total mortality of biomass of a year class (the quantities given are underlinded).

However, the recent holistic ecosystem models (Andersen and Ursin 1977, Laevastu and Favorite 1978a and b) provide relatively reliable predation mortality in the form of biomass turnover rate. In addition, a mean progressive numerical ratio of the adjacent year classes, relative to next oldest year class, must be established (see next chapter).

Having the two estimates (turnover rate and progressive numerical ratio of adjacent year classes), the long-term mean age composition of fully exploited part of the population, annual mean weights and growth rates, an iterative numerical extrapolation method (described below) can be used for the computation of juvenile numbers and biomasses relative to fully exploited year classes.

3. AVERAGE NUMERICAL RELATIONS OF ADJACENT YEAR CLASSES

Cushing's (1973) statement that "The age structure of a marine fish population has rarely been described in full," is still valid. The following is an attempt to establish an average number distribution for marine fish, being aware that this distribution would vary from species to species and region to region--depending on growth rate, fecundity, and life length. This average distribution of numbers of juveniles serves as a first guess in the computations of species and area specific number distribution with age. The mean numbers are adjusted in computations to produce a biologically plausible number distribution based mainly on two conditions:

1) The number of fish in a given year class must be bigger than the number in the next older year class by the amount of mortality in the year class under consideration.

2) The mortality of juveniles is mainly predation mortality and increases with decreasing size of the fish. Furthermore, the total predation mortality of the species is determined by the turnover rate of its biomass in the ecosystem, which in turn is largely a function of the growth rate, magnitude of biomass present, and its vulnerability to predation. It could be pointed out that the belief that predation mortality is largely controlling the year class strength is rapidly gaining ground (Rothschild 1979).

The reduction of numbers in fish populations is a remarkably constant phenomenon: for example, from 200,000 eggs spawned by a female walleye pollock (*Theragra chalcogramma*) on the average only two survive to age 4. If a minor disturbance in this reduction process occurs, e.g. in a given short period of time when average reduction of numbers from say 286 to 232 should normally occur, two more fish would survive (i.e. the number at the end of this period would be 234 instead of 232), it could result in twice the year class strength at age 4 if normal (average) reduction of numbers would take place during the rest of the time.

Cushing (1973) calculated the trend in numbers with age for North Sea plaice (*Pleuronectes platessa*) (Figure 2). This calculation was largely dependent upon the estimate of larval mortality. Some additional estimates of number distribution with age can be obtained by considering the size dependent predation and food requirements and using holistic ecosystem models. Using the data on walleye pollock from the PROBUB model for the eastern Bering Sea, we can normalize the number of 600 to 1000 g pollock (age 5.8 years) to two individuals. Consequently we find that there must be 7.7 fish at average age of 3.5 years (200 to 600 g). We can compute from the food requirement and food composition data that a normalized pollock population

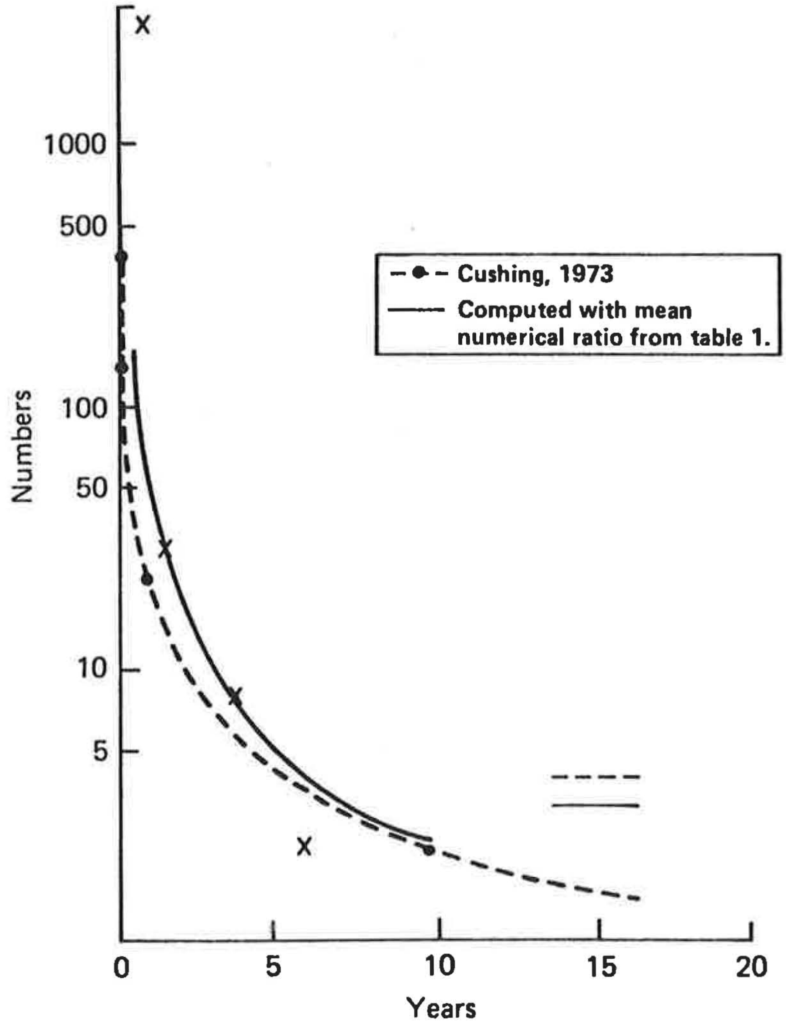

Figure 2.--Mean distribution of numbers in year classes, normalized to age 10 (i.e. 2 fish at age 10).

will eat about 2600 fish of about 4 g each (6 to 9 month old pollock) and about 25 fish of about 20 g (1.2 years old). The above normalized numbers are shown with an "x" on Figure 2.

Using Cushing's curve and other available estimates of juvenile year class strength (e.g., from Andersen and Ursin 1977), the numerical ratio of adjacent year classes with reference to next oldest year class (the increase factor) was computed and is presented in Table 1.

Table 1.--Numerical ratio of adjacent year classes (the number presents the factor with which the number of fish in previous year class must be multiplied to obtain average number of fish in the year class under consideration).

Age (year class)	(0.5)	1	2	3	4	5	6	7	8	9	10
Increase factor	(2.50)	2.10	1.71	1.49	1.36	1.28	1.22	1.17	1.13	1.10	1.075

Using the increase factors from Table 1 and normalizing the number of plaice at age 10 to two individuals, the resulting curve is plotted on Figure 2 together with Cushing's curve for easy comparison.

The average increase factor should apply only to prespawning and prefishery year classes. The numbers in fully recruited year classes can be obtained from actual year class composition of catches or from long term mean year class strength as described earlier.

It could be emphasized that the factor in Table 1 is used only as first guess input into an iteration program and is modified in this program (see description of the computations in Chapter 5). This factor is used with all species, the species to species differences will appear in final computations.

4. BASIC INPUT DATA

Empirical data on weight at age are needed for computation of growth rates and biomass. These data are usually available in literature, separated by sexes. For the present purpose the data for both sexes are combined. Some difficulties are usually encountered in obtaining accurate weight data for the youngest ages (e.g., below 2 years). Therefore, the mean weight of juveniles is often extrapolated from the available data on adults.

As the condition factor of marine fish does not change materially, except during sex product development, the length at age data which are more readily available can be converted to weight at age data with a predetermined length versus weight key. The von Bertalanffy equation, although useful in some earlier population dynamics work, is not useful for the present purpose because of its inherent inaccuracy in younger and older ages and because it smoothes out some small, but biologically significant changes in growth rate. There are differences in growth of the same species in different regions with different temperature and food conditions. Thus other biomass parameters are also different in different regions. Examples of the differences of growth of Pacific ocean perch (*Sebastes alutus*) in the eastern Bering Sea and off the Washington-Oregon coast are shown in Figure 3.

The second set of basic data required for biomass parameter computations is the long-term mean age frequency distribution of fully recruited year classes. The data series should cover at least 10 years, to eliminate the effects of strong and weak year classes. Furthermore, the annual means should include data from different seasons and from different fishing grounds in a given region in order to eliminate bias caused by spatial and temporal variations in age composition of catches in many species. Only the fully exploited year class numbers should be considered and those which are only partially retained by the gear should be eliminated.

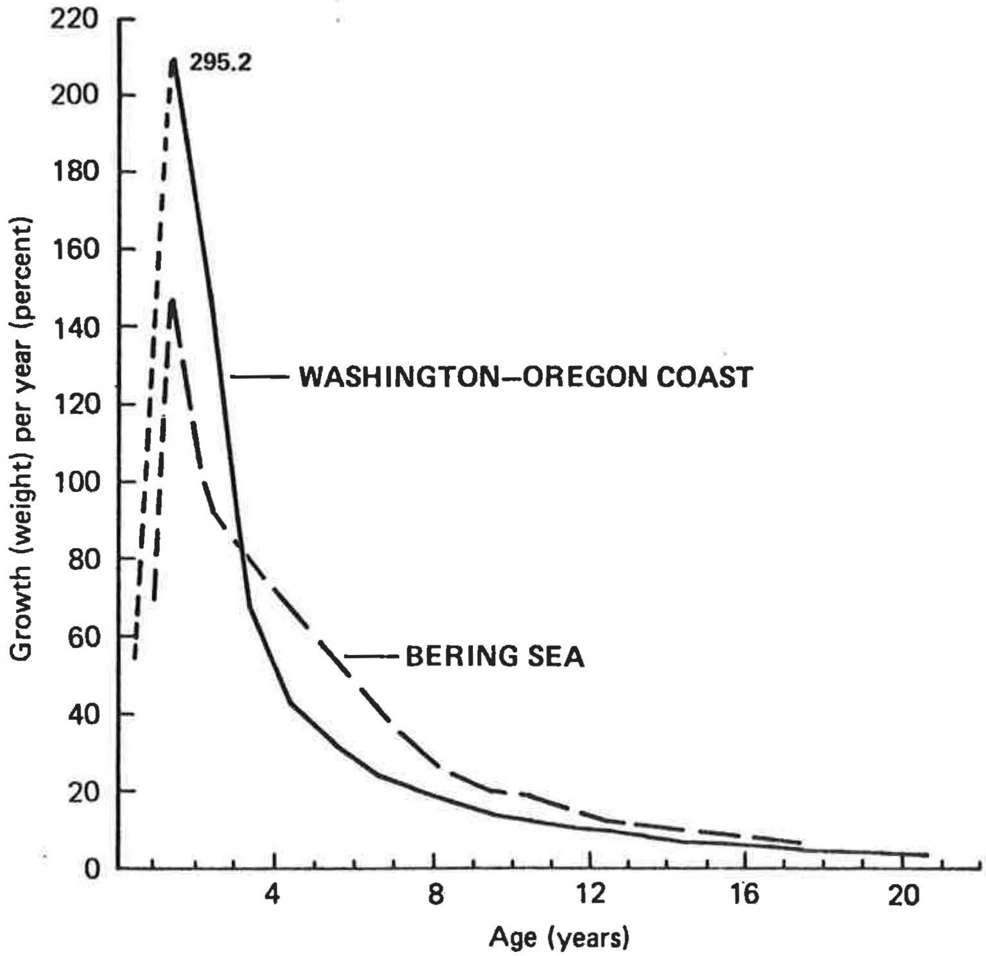

Figure 3.--Biomass growth (in percent per year) of Pacific ocean perch from the eastern Bering Sea and from the Washington-Oregon coast.

The third data set - the numerical rate of adjacent year classes or the "increase factor," described in the previous chapter, is "fixed" data, common to all species (Table 1). These increase factors are used to obtain an initial distribution of numbers of fish in juvenile (prefishery) year classes. This computation starts with the youngest fully exploited year class, which is multiplied with a factor presenting the next younger year class, to obtain the initial number of fish in this year class; the computation thus moves stepwise towards younger year classes.

The fourth basic data required for the computations is the annual turnover rate of the biomass. This turnover rate is usually obtained from ecosystem models, such as DYNUMES and PROBUB (Laevastu and Favorite 1978 a and b). The turnover rate varies from species to species and is normally in the range of 0.5 to 0.9. In case turnover rate is not available and/or known, computations are carried out with several plausible turnover rates (see examples on Figures 4 to 9).

5. FORMULAS AND COMPUTATION PROCEDURE

The following parameters are computed in the fish biomass parameters estimation programme (the computer programme BIODIS (Laevastu 1978) in FORTRAN is available upon request from NWAFC, Seattle):

1. Annual and monthly growth rates of different year classes
2. Biomass distribution in different year classes
3. Distribution of numbers in different year classes
4. Portions of exploitable and juvenile biomasses and numbers
5. Total mortality in different year classes (in numbers and in biomass)

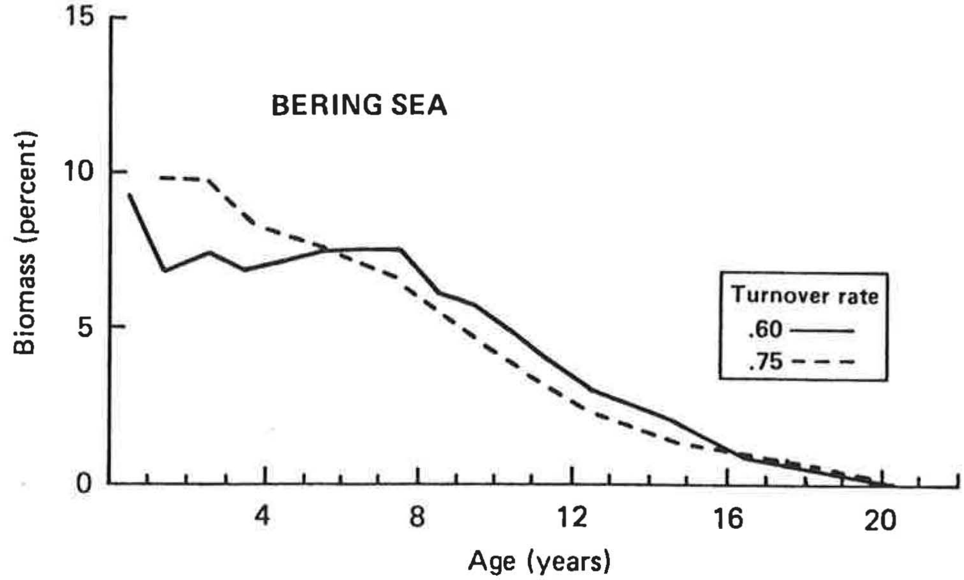

Figure 4.--Distribution of biomass with age of Pacific ocean perch from eastern Bering Sea.
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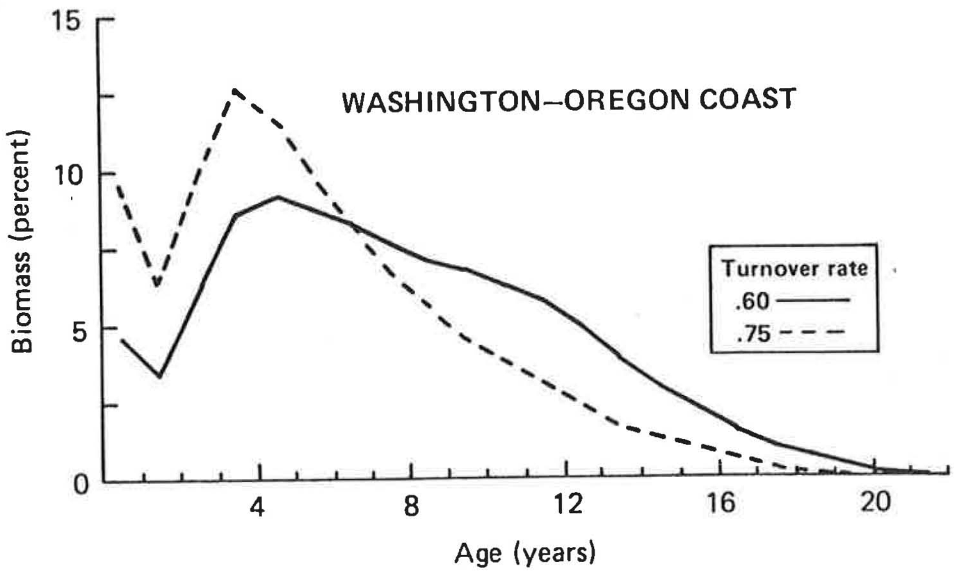

Figure 5.--Distribution of biomass with age of Pacific ocean perch from Washington-Oregon coast.

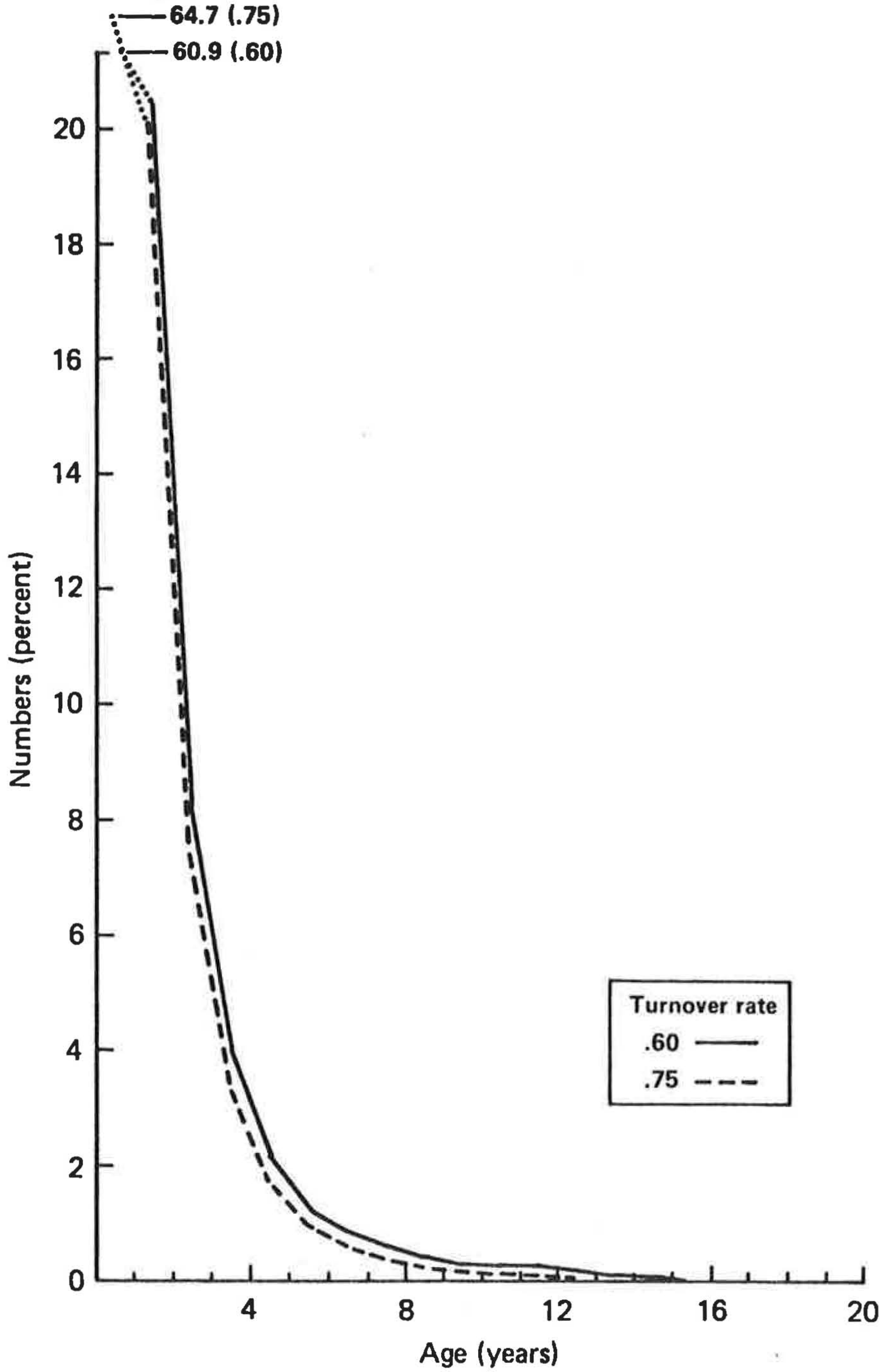

Figure 6.--Distribution of numbers with age of Pacific ocean perch from eastern Bering Sea.

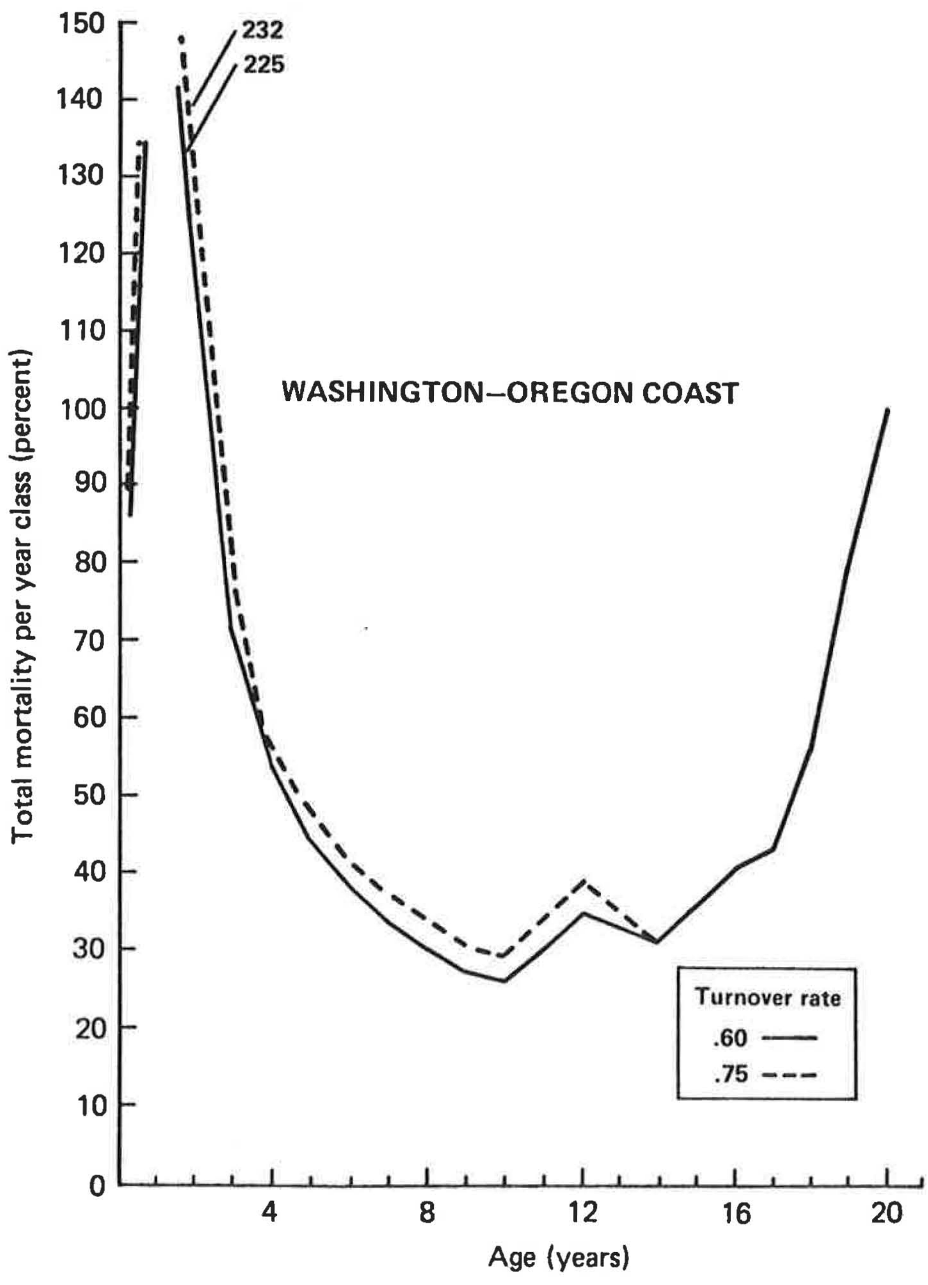

Figure 7.--Total mortality of biomass in percent per year class with reference to annual mean biomass in the year class, Pacific ocean perch from Washington-Oregon coast.

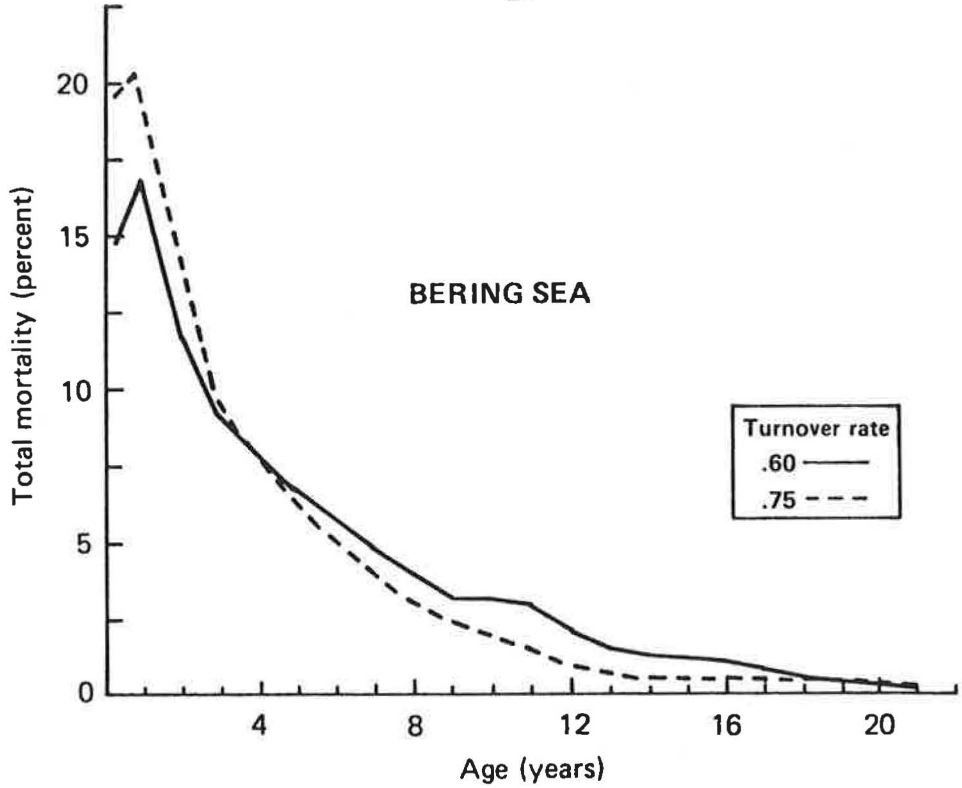

Figure 8.--Distribution of total annual mortality of biomass with age (in percent of total mortality) of Pacific ocean perch from eastern Bering Sea.

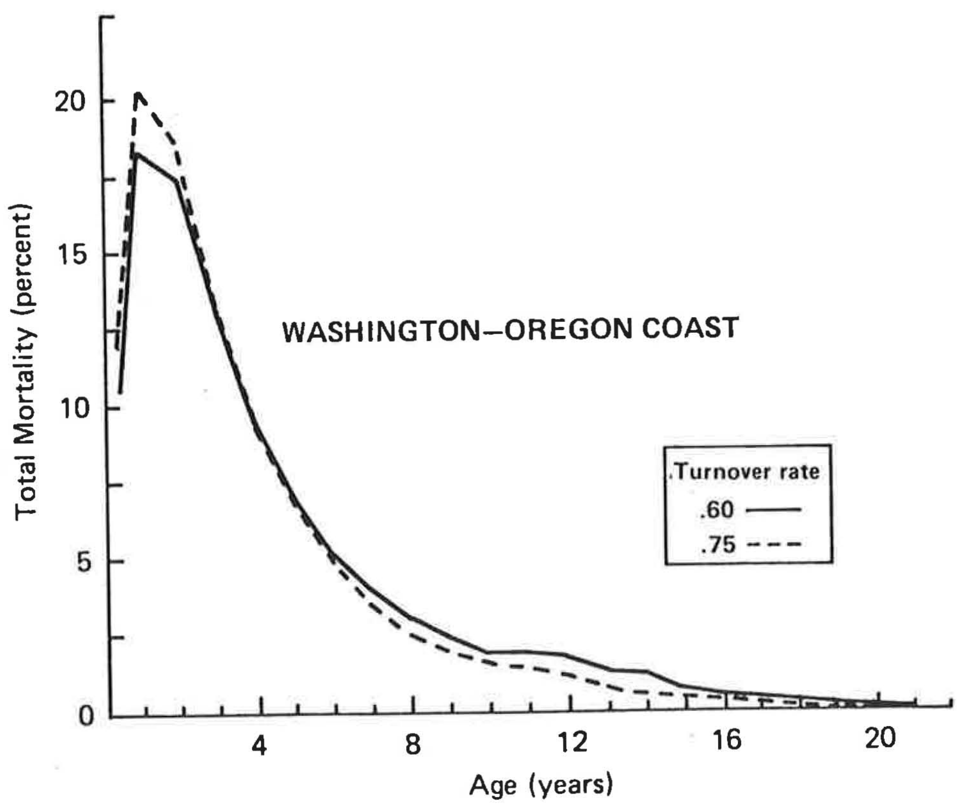

Figure 9.--Distribution of total annual mortality of biomass with age (in percent of total mortality) of Pacific ocean perch from Washington-Oregon coast.

6. Growth rates and instantaneous growth coefficients (annual and monthly) for whole population biomass and for juvenile, adult, and deceased portions of the total biomass.

The annual growth rate of biomass (in percent per year) is computed with the following formula (for symbols see Chapter 7):

$$G_{an} = \left[(W_{n+1}/W_n)\ .100\right] - 100 \tag{2}$$

The corresponding monthly growth rate is computed with the well-known compound interest formula:

$$G_{mn} = (10^a - 1)\ .100 \tag{3}$$

where $a = \log\ (W_{n+1}/W_n)/12$

The corresponding instantaneous coefficients are:

$$g = \ln\ (1 - G/100) \tag{4}$$

For the computation of biomass and number distributions, the turnover rate criterion must be satisfied. The latter requires the computation of total mortality by year classes. The following iterative procedure is used in these computations.

A first guess field of the numbers in juvenile year classes is computed by multiplying successively the next older year class with the increase factor given in Table 1, starting with the youngest fully exploited year class for which empirical data is available:

$$N_n = F_n * N_{n+1} \tag{5}$$

Thereafter the first guess of biomass in each year class is computed:

$$B_n = N_n * W_n \tag{6}$$

Thirdly, the total biomass mortality in each year class is computed, assuming it constitutes the difference between the next younger biomass plus its growth minus the next older biomass (see Figure 1):

$$Z_n = B_n\ (1 + 0.01\ G_{an}) - B_{n+1} \quad \text{or}$$

$$Z_n = B_n\ (2 - e^{-g}) - B_{n+1} \tag{7}$$

The turnover rate is computed by dividing the sum of biomass mortality by the sum of the biomass in the different year classes:

$$T_c = \frac{\Sigma Z}{\Sigma B} \tag{8}$$

The computed turnover rate is compared to prescribed turnover rate. If the difference is larger than a prescribed convergence criterion (e.g., $\pm$ 3%), an iterative procedure is initiated to converge the computed turnover rate to the prescribed one. Depending on whether the first computed turnover rate was below or above the desired (prescribed) turnover rate, the numerical increase factors (F_n) are multiplied by an adjustment factor (iteration constant) which is slightly above (e.g., 1.04) and below (e.g., 0.96) 1 and the whole procedure is repeated until the computed turnover rate converges to desired turnover rate (e.g., to $\pm$ 3% of it). First year class is assumed to be comprised of fish from 4 months after hatching to 1 year of age.

The numbers in the exploited year classes are left unchanged, except the youngest exploited year class is changed (smoothed) by a small amount to obtain a relatively smooth numbers/biomass distribution.

The annual mean growth coefficient for the whole biomass is:

$$G_A = \sum_n (G_{an} \cdot B_{pn}/100) \tag{9}$$

The computation of monthly growth coefficient for the whole biomass or for the juvenile and adult portion of it, is analogous to Formula 9 above, except corresponding biomass fractions are used in annual (or monthly) time steps. The computation of the growth coefficient of the deceased population necessitates the use of the decreased fraction of each year class which is computed with Formula 7.

All other desired parameters are computed with simple arithmetical approaches from the input and computed data above.

Examples of various computed biomass parameters of Pacific ocean perch are given on Figures 4 to 9 from two different regions: eastern Bering Sea and off Washington-Oregon coast. Furthermore, computed results are presented for two different turnover rates - 0.6 and 0.75.

The Pacific ocean perch is a relatively slow growing and long-lived species. It is fully exploited at the age of 9 to 11 years. Its biomass is at maximum at about 2 to 4 years. Its mortality has a minimum at the age of 8 to 10 years. The increase of mortality in juvenile year classes is due to increased predation mortality (re. size dependent predation), and the increased mortality in older year class is due to spawning stress mortality (Granfeldt 1979) and senescent mortality.

6. SYMBOLS USED IN THE FORMULAS

B_n - Biomass of year class n.

B_{n+1} - Biomass in next older year class.

B_{fn} - Decimal fraction of biomass of year class n.

B_{pn} - Percent fraction of biomass of year class n.

G - Growth rate in %.

G_A - Annual mean growth rate for whole biomass.

G_{an} - Annual growth rate (%) of year class n.

G_{mn} - Monthly growth rate (%) for year class n.

F_n - Mean increase factor of numbers.

N_n - Number of fish in year class n.

N_{n+1} - Number in next older year class.

T_c - Computed biomass turnover rate.

W_n - Mean weight of specimen in year class n.

W_{n+1} - Mean weight in next older year class.

Z_n - Total mortality (in biomass) of year class n.

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