NORTHWEST & ALASKA FISHERIES CENTER PROCESSED REPORT

ECOSYSTEM MODEL ESTIMATIONS OF THE DISTRIBUTION OF BIOMASS AND PREDATION WITH AGE FOR FIVE SPECIES IN EASTERN BERING SEA

by

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I. PURPOSE OF THE PREPARATION OF BIOMASS/CONSUMPTION DISTRIBUTION GRAPHS

In many fisheries research and management problems, as well as in ecosystem modeling, it is important to know the relation between biomass and age for a given species over the full range of its lifespan.

For those species which are caught with commercial gear and for which information on age and/or size frequencies has been obtained, the exploitable part of the biomass can be estimated without a model; however, the results are totally dependent on how representative the data are of the time/space distributions of the individual species and the techniques used to estimate abundances. On the other hand, the paucity of information on the biomass distribution of juveniles necessitates computations with a model such as that described briefly in this report if total stock abundances are to be estimated. Furthermore, the ecosystem internal consumption of a given species is size-dependent and is large at small sizes. This ecosystem internal consumption can be quantitatively determined only with complete dynamical numerical ecosystem models. Among the application of age-biomass distribution are:

--partitioning of the biomass into prefishery juveniles and exploitable biomasses; with variable but defined mesh size or other gear selectivity parameters,

--assessment of food composition and food requirements with age, and

--determination of the rate of change of the biomass at various ages.

Although no information is available on the biomass distribution over the whole lifespan of the species in the past literature, such information can be estimated from ecosystem models developed at the NWAFC. Because preliminary studies have revealed several results applicable to management and research, the biomass/consumption relations of five important species in the Bering Sea--yellowfin sole, walleye pollock, Pacific herring, Pacific cod, and sockeye salmon--are presented here.

It appears that fisheries biologists still consider biomass parameters static rather than highly variable as they are in nature. It is, therefore, emphasized that although some "mean" biomass distributions are presented here, the biomass distributions *per se* are variable in space and time, as most of the input parameters, such as growth rates and ecosystem internal consumption ("natural mortality" in conventional population dynamics approach) vary in space and time.

The present paper is more a description of the methods and some generalization of the results rather than exhaustive study of "instantaneous" biomass distributions. The "instantaneous" biomass distribution with age/size of a given species pertaining to a given time and defined region can be computed with the method described in this paper, and would reveal the possible fluctuations in year-class strengths of specific year-classes if some additional information from dynamic numerical ecosystem models is used.

It is assumed that local conventional data such as age and size distributions and growth, are readily accessible.

II. METHODS

Some basic empirical data (such as weight and length of the species) are required for the computation (see examples in V. Graphs of Basic Data, e.g., Figure A1). Annual growth rates (e.g., Figure A2) or growth rates at shorter intervals are computed from weight/age data. The age composition of exploitable population is derived from available data (e.g., Figure A3). It is assumed that the younger year-classes are not fully retained by the commercial gear, therefore, the first year-class which "peaks" is selected as the youngest year-class or "first fully recruited" size or year-class which is fully exploitable with presently used gear, and the rest of the year-class numerical strengths are adjusted correspondingly (e.g., Figure A4), i.e., assigning 100 percent to the fully recruited population and computing the individual year-class numerical strengths as dictated by the data.

Because there can be different spatial distributions of different age/size groups of fish even at the exploitable age/size, several samples of age/size frequency data are often required to form a composite sample (e.g., Figure 12).

Using the age frequency composition of the exploitable population, its mean annual biomass, its growth and consumption by other species (i.e., the sum of ecosystem internal consumption, fishing mortality, and natural mortality from old age and diseases) is computed. These quantities cannot be converted to percentages per year class until the total species biomass distribution with age is known. Other available age dependent parameters, such as age at maturity, are of no direct use in the present endeavor, although these parameters are used in various situations in our other ecosystem models. Therefore, the juvenile component of the biomass must be computed by means of extrapolations and successive approximations using an iterative procedure in which the solutions converge to predetermined criteria. The iterative computation procedure is as follows:

—The first-guess field of relative numbers of juvenile year classes is estimated by extrapolation and the biomass increase (growth) and its consumption is computed. The initial use of number frequency facilitates the first estimate.

—The computed "guess" consumption, as well as the consumption of the exploitable part of the biomass, is summed and compared to the turnover rate, obtained from the Bulk Biomass Model (BBM) and/or the DYNUMES model. Turnover rate (annual) is the annual consumption divided by annual mean biomass.

—Using the turnover rate as one of the criteria, adjustments are made to the first estimates of juvenile year classes, and a second iteration of biomass, growth, and consumption is computed.

—This procedure is repeated until a distribution of biomass is found which corresponds to established criteria. The two main criteria are that each year class biomass reflects its growth and the ecosystem internal consumption required by turnover rate for this year class, and the sum of biomass difference (i.e., growth minus the next year class biomass) must yield the required total turnover rate.

The percent distribution of biomass versus numbers of individuals is computed from the biomass distributions (e.g., Figure 1). This permits determination of the percentage of the individual year classes consumed annually (upper curves on Figure 2), which can be presented for better quantitative comparison as percentage of total biomass of the species (upper curve on Figure 3). It may not be immediately apparent why the annual consumption of a given year class and/or total mean biomass can exceed 100%. The basis of the misunderstanding seems to be that mean biomass (and/or populations) have often been considered in the past as static entities. However, biomass is a dynamic entity, having only an imaginary static phase, which might be better called instantaneous biomass. However, time-averaged quantities can be formed from a dynamic entity, such as monthly and/or annual mean biomass. The biomass increases (grows) and decreases (consumed) with time. Again, time averages of the increments/decrements can be formed, such as annual mean consumption. This time-summed consumption can exceed the time-averaged biomass, thus, yielding over 100% annual consumption.

The proportioning of food consumption on Figures 2 and 3 (and other corresponding figures for other species) is somewhat subjective. The following information is used in estimating the proportioning; fishing mortality, size composition of prey in stomach analysis, consumption by mammals and ecosystem internal consumption requirements (the latter from the ecosystem model computations). The consumption is food item size dependent; therefore, the initial estimates are plotted on a graph for review where size is on a linear scale (Figure A5 as an example).

Because of the variety and incompleteness of time/space data in relation to distributions and abundances of species, it is difficult to discuss precision and accuracy of results at this time. The study points out the necessity of understanding multi-species interactions and of being able to quantify the dynamics of such complex relationships if the variabilities in the abundances of stocks is to be determined. The study also reveals that juvenile-adult interactions have important consequences within species as well as among species, and that considerable more research effort should be directed toward such investigations.

III. DISCUSSION OF BIOMASS/CONSUMPTION DISTRIBUTION GRAPHS

A. Biomass

It is apparent that the percentage of the exploitable biomass varies considerably from species to species, and is a function of growth rate and liefespan of the species (examples of exploitable portion: yellowfin-46%, pollock-71%; herring-30%, cod-61%, (sockeye-86%).

The first year class of (or age at) full exploitation seems to coincide in many species with the year class of maximum biomass (examples: yellowfin, pollock, cod). The salmon biomass distribution is quite different from the other pelagic species because of its anadromous nature. The biomass distribution graphs demonstrate a well known and accepted fact in fisheries management: if a species matures before it comes under exploitation or during the first year of exploitation, it can be fished more intensely than those species maturing after they are exploitable.

The whole biomass/consumption/age system is very sensitive to the relatively pronounced changes of growth rates with the age of the species.

The extrapolation of numbers and biomass of the species to ages less than about 6 months (0+ year class) is at present quite uncertain. The numbers in 1+ to 0+ year classes increase quite rapidly with decreasing age in some species (e.g., pollock) and slower in other species (e.g., yellowfin sole). Apparently this is caused by differences in fecundity and in the habitats of the 0 and 1 year classes which affect the ecosystem internal consumption ("natural mortality" in conventional terms).

B. Consumption distribution

There are considerable differences in the distribution of food consumption between species that seem to depend to a large extent on the growth rate of the species. There are two maxima in the food consumption graphs in the exploitable part of the biomass. The significance of these maxima is not fully clear, but they seem to be greatly influenced by the fishery and may be caused by the large seasonal differences in fishing intensity in the Bering Sea.

IV. TENTATIVE CONCLUSIONS

Some preliminary observations and conclusions can be drawn from the examination of the biomass/consumption distribution graphs:

1. The ecosystem internal consumption and mortality of young year classes (0 and 1) greatly determines the subsequent year class strength. In these early stages the environment has also the largest influence on most species, affecting the mortality by (a) influencing the availability of proper food, (b) influencing the presence and distribution of predators, and (c) affecting the growth and mortality (e.g., changing metabolic rate).

2. Slow growing species are subject to greater ecosystem internal consumption pressure (i.e., being subject to predation for a longer time than the faster growing species). As a consequence, it is therefore expected that there should be an inverse relation between the abundance of yellowfin sole and pollock in the Bering Sea.

3. The consumption graphs depict clearly the serious competition by mammals in the utilization of fishery resources by man.

4. The biomass and its consumption distribution graphs allow rough estimations of the maximum allowable catch (optimum catch or any other catch quantity criteria--taking into account the spawning population requirements) (procedure: estimate the total biomass of the species under exploitation; assume quasi-steady state and compute the growth of this biomass; allow a "portion" (e.g., 40%) of this growth to be taken by fishery, the determination of the "portion" being subjective and depending on such factors as requirement for spawning population).

5. The biomass distributions allow the estimation of size composition of the catch, assuming a long-term mean age composition. If, on the other hand, the size composition of the catch changes in different years (e.g., due to strong year classes), estimation of the total biomass changes can be made.

6. The effects of mesh-size regulations can be estimated, using the biomass distribution graphs and considering in addition the age at maturity (requirements for spawning population).

The above are only a few preliminary notes and observations relating to biomass/consumption graphs. The study and use of the biomass/consumption/age relations will continue with DYNUMES III ecosystem model.

V. GRAPHS OF BASIC DATA USED

(Figures A1-A19)

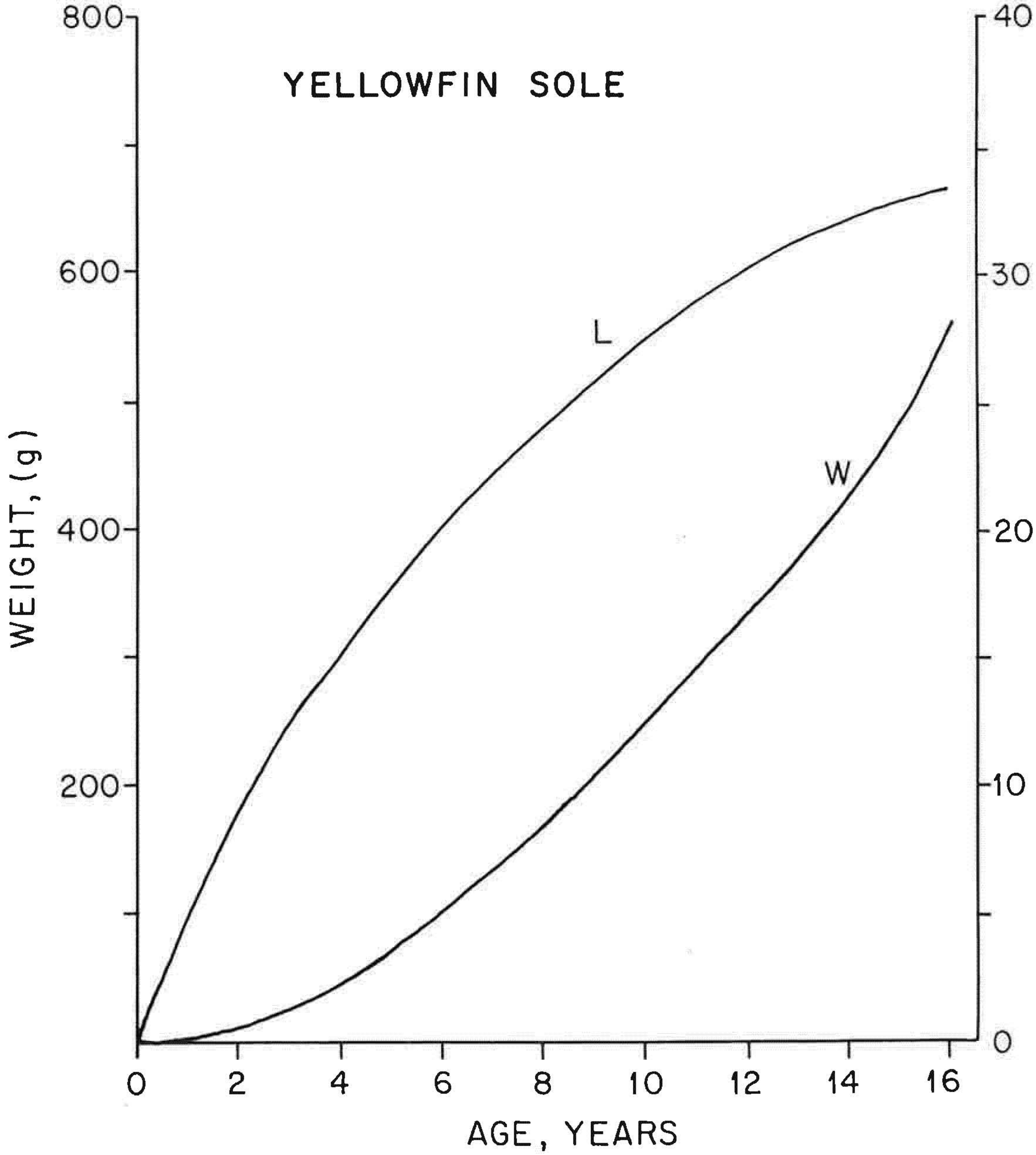

Figure A1. Weight and length of yellowfin sole at different ages.

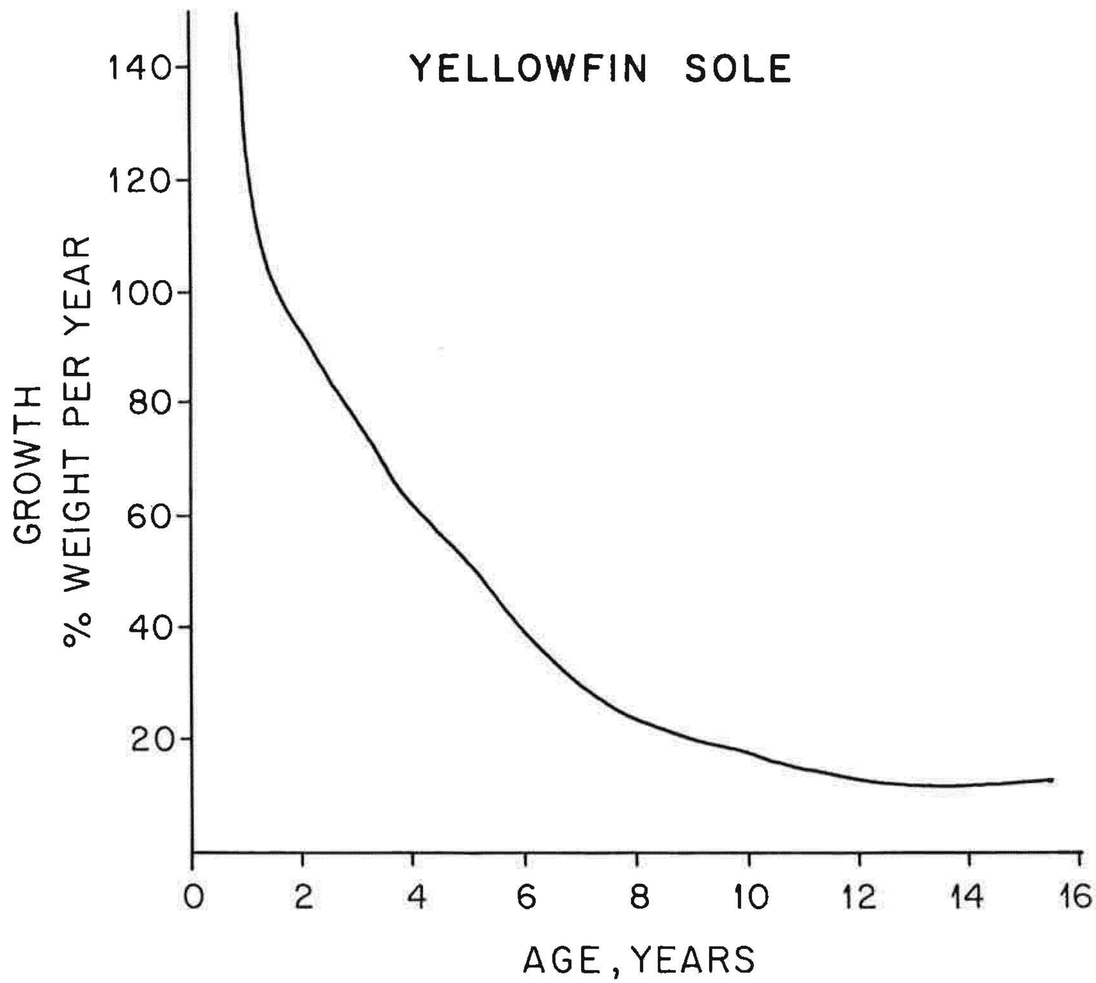

Figure A2. Growth of biomass (weight) of yellowfin sole at different ages, as percent per year.

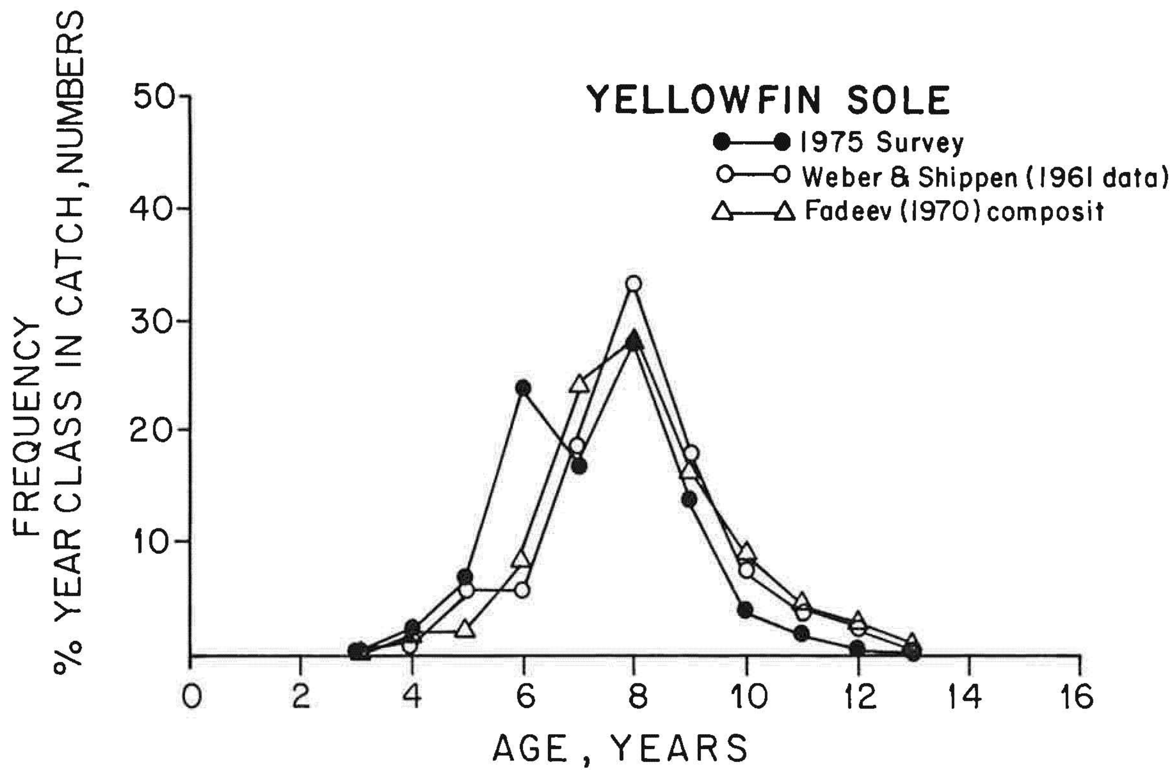

Figure A3. Age distribution of catch (in numbers) of yellowfin sole from the Bering Sea (various sources).

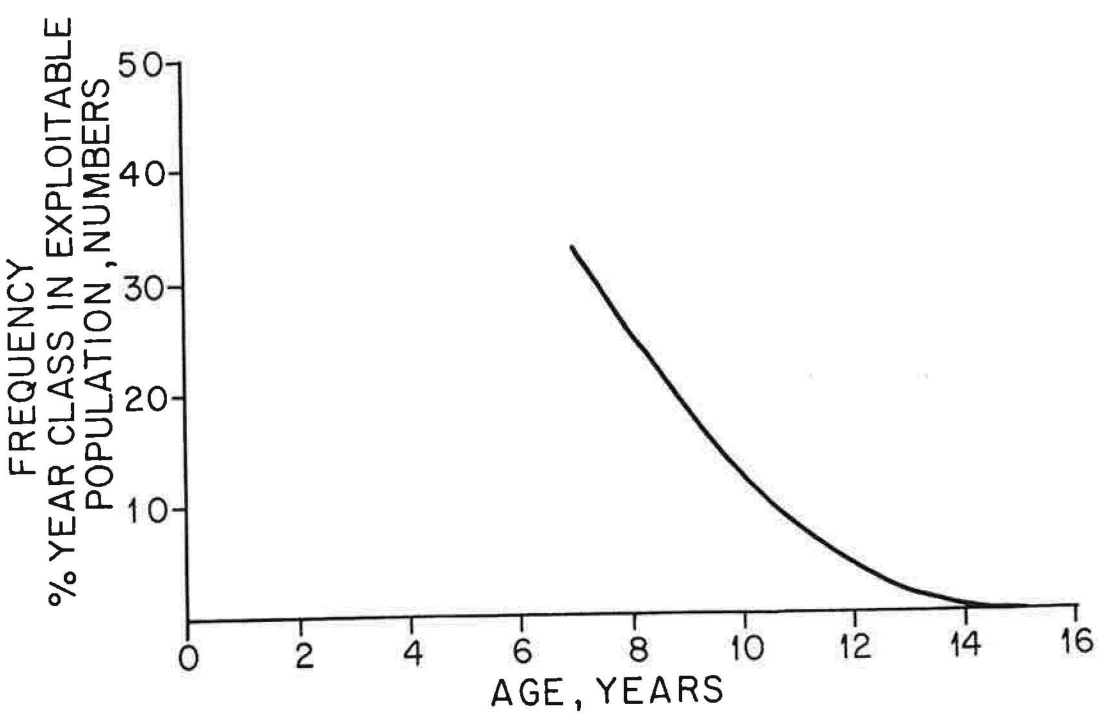

Figure A4. Estimated mean age distribution of catch (in numbers) of fully exploited year classes of yellowfin sole from the Bering Sea.

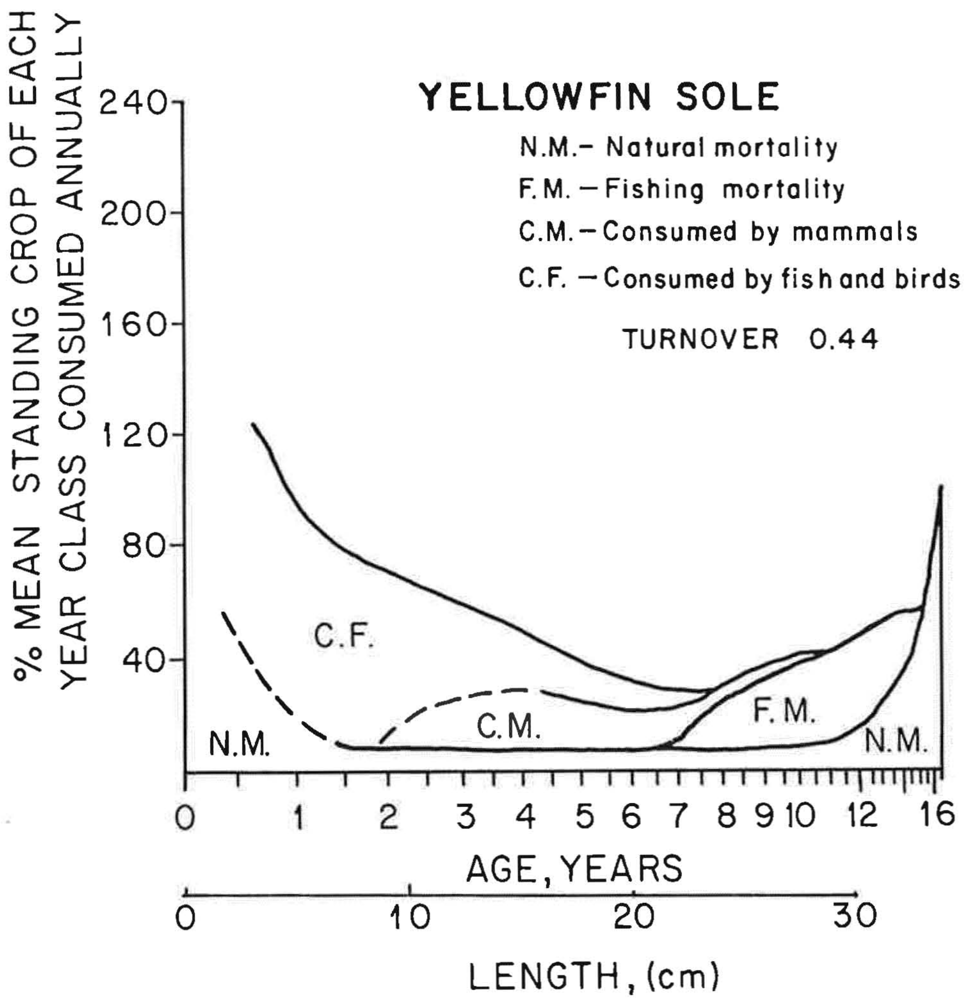

Figure A5. Computed and estimated distribution of "consumption" with size (and age) of yellowfin sole, as percent of mean standing crop of each year class.

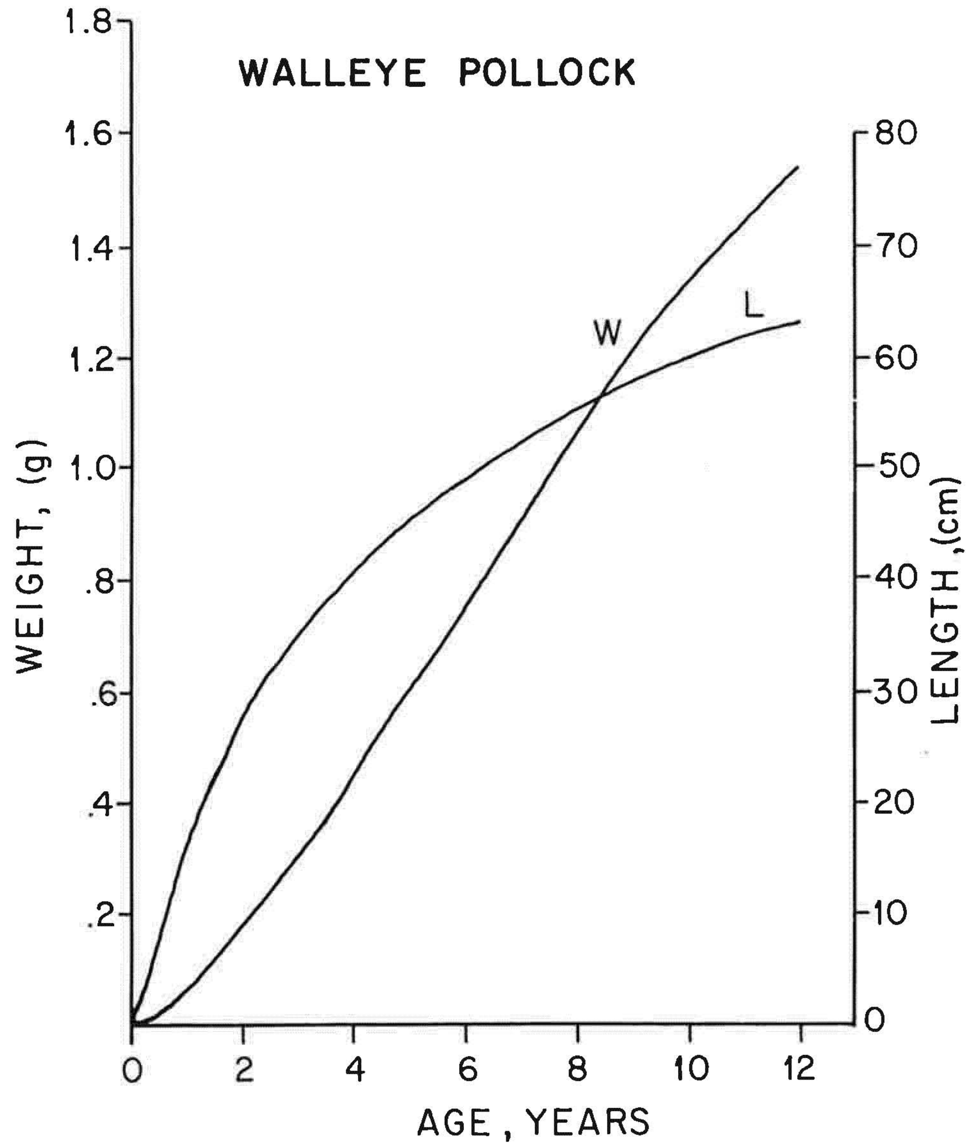

Figure A6. Weight and length of walleye pollock at different ages.

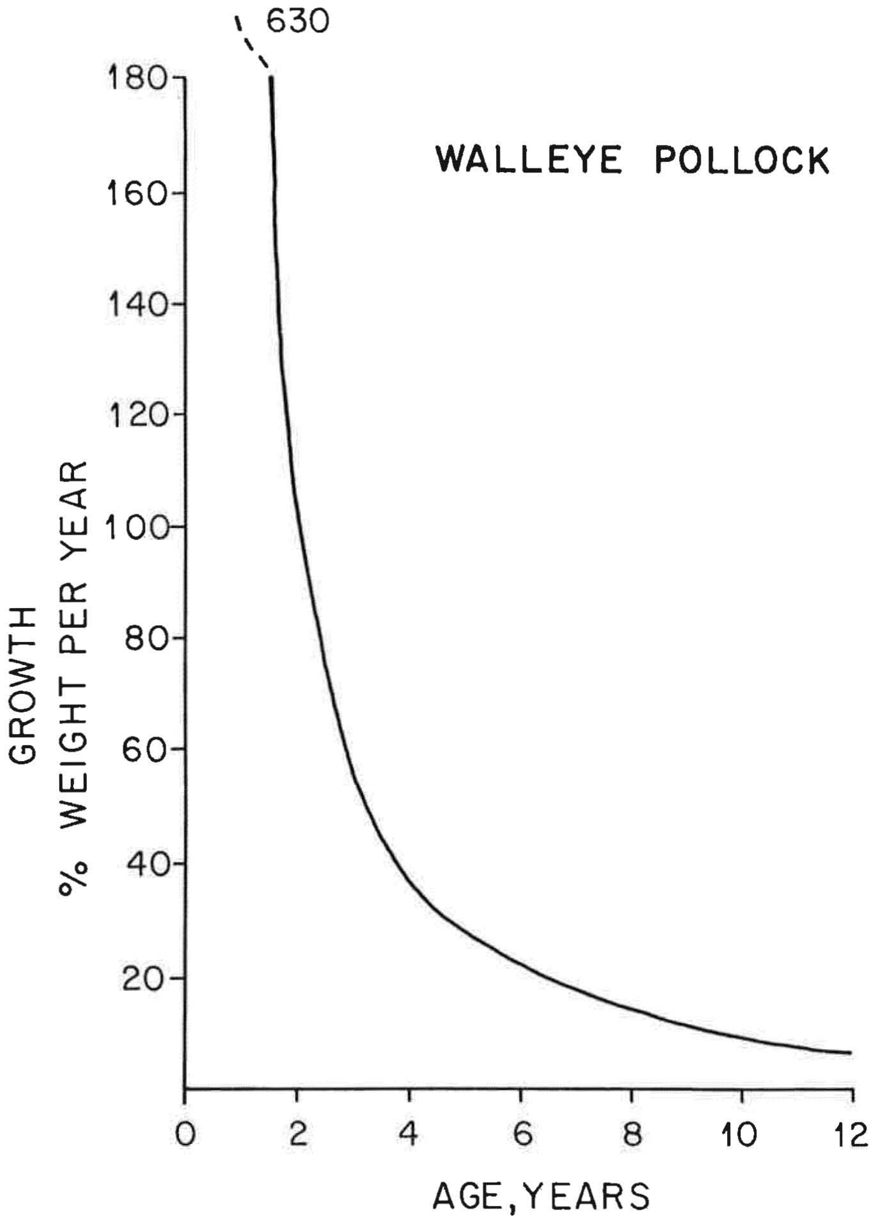

Figure A7. Growth of biomass (weight) of walleye pollock at different ages, as percent per year.

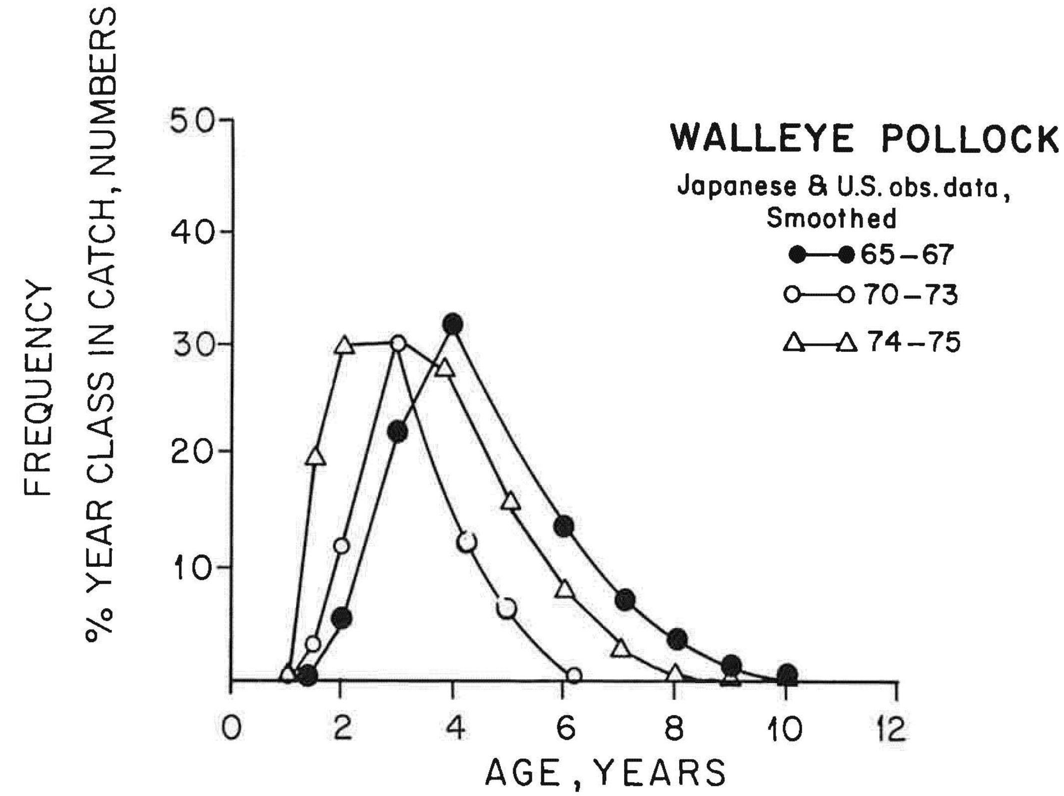

Figure A8. Age distribution of catch (in numbers) of walleye pollock from the Bering Sea (various sources).

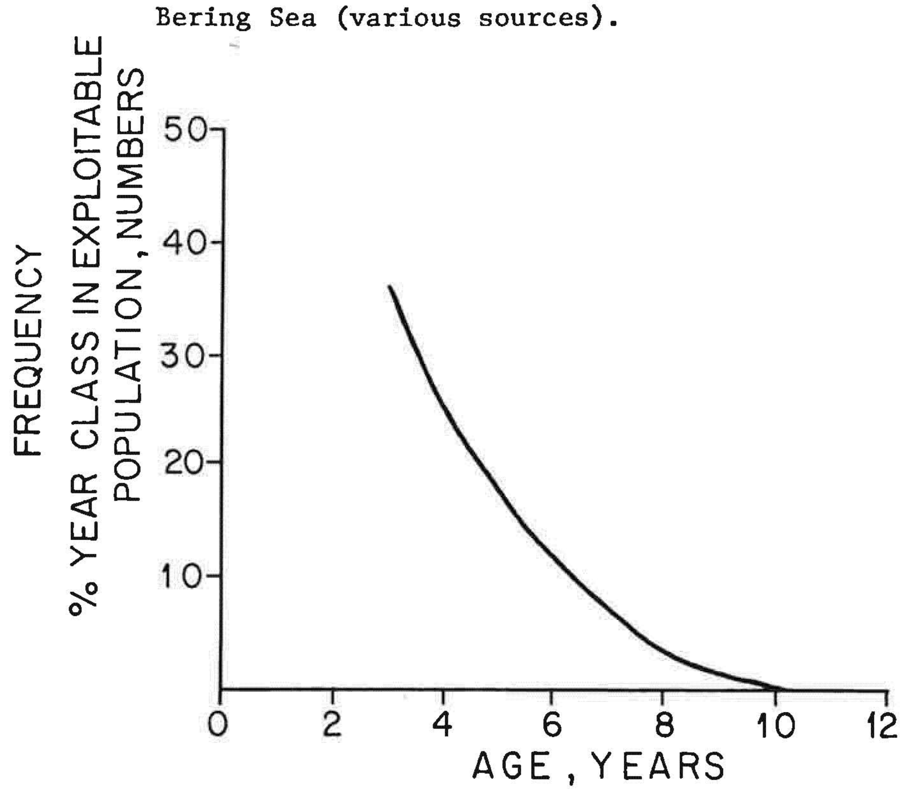

Figure A9. Estimated mean age distribution of catch (in numbers) of fully exploited year classes of walleye pollock from the Bering Sea.

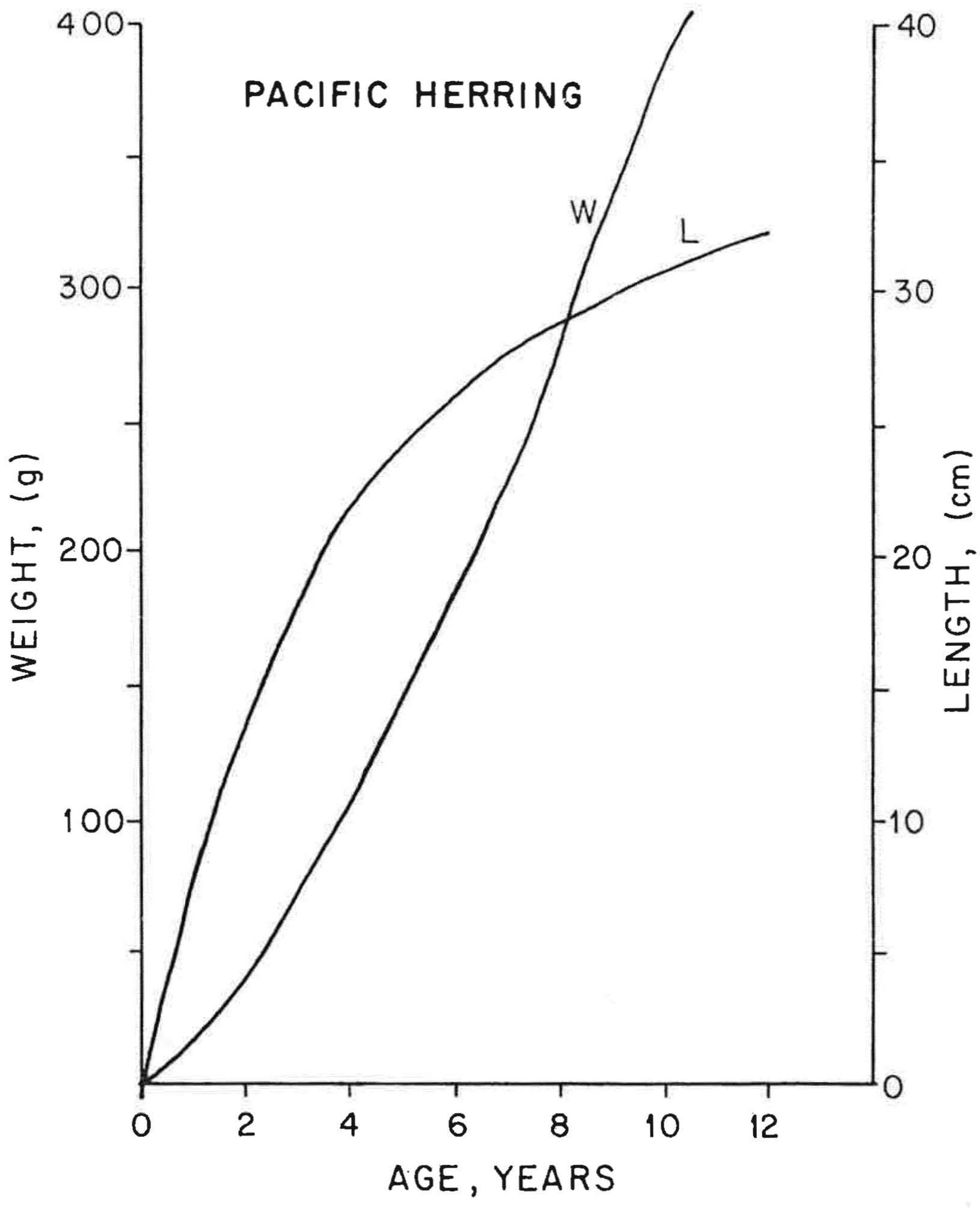

Figure A10. Weight and length of Pacific herring at different ages.

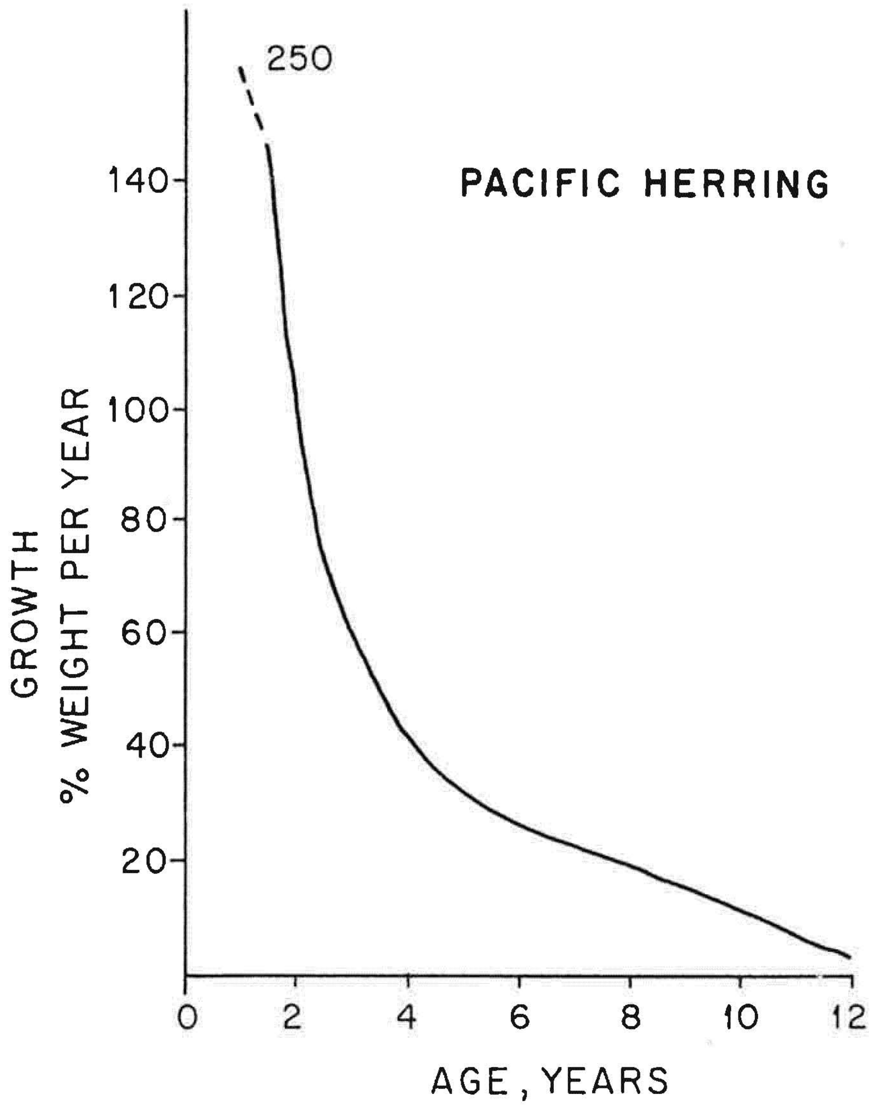

Figure A11. Growth of biomass (weight) of Pacific herring at different ages, as percent per year.

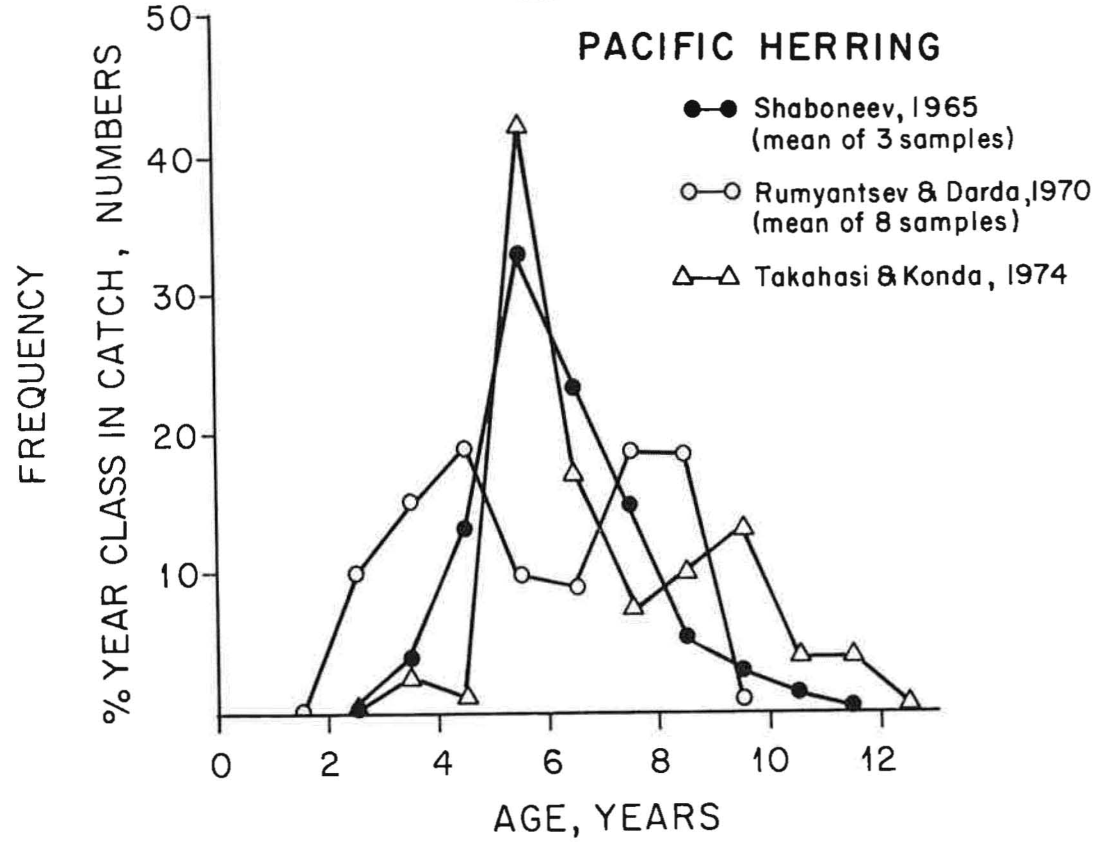

Figure A12. Age distribution of catch (in numbers) of Pacific herring from the Bering Sea (various sources).

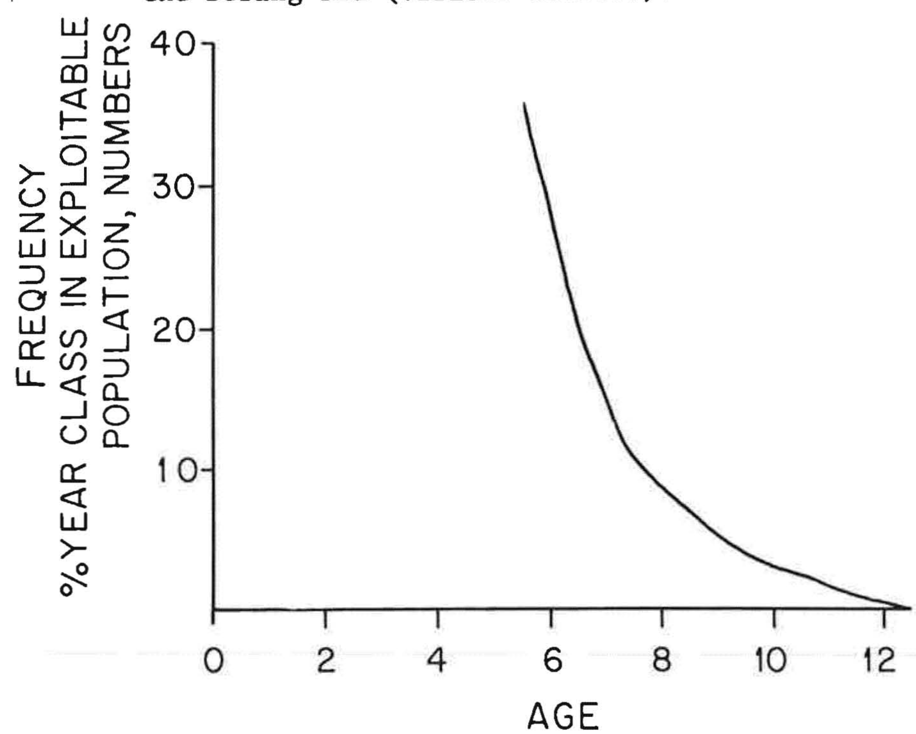

Figure A13. Estimated mean age distribution of catch (in numbers) of fully exploited year classes of yellowfin sole from the Bering Sea.

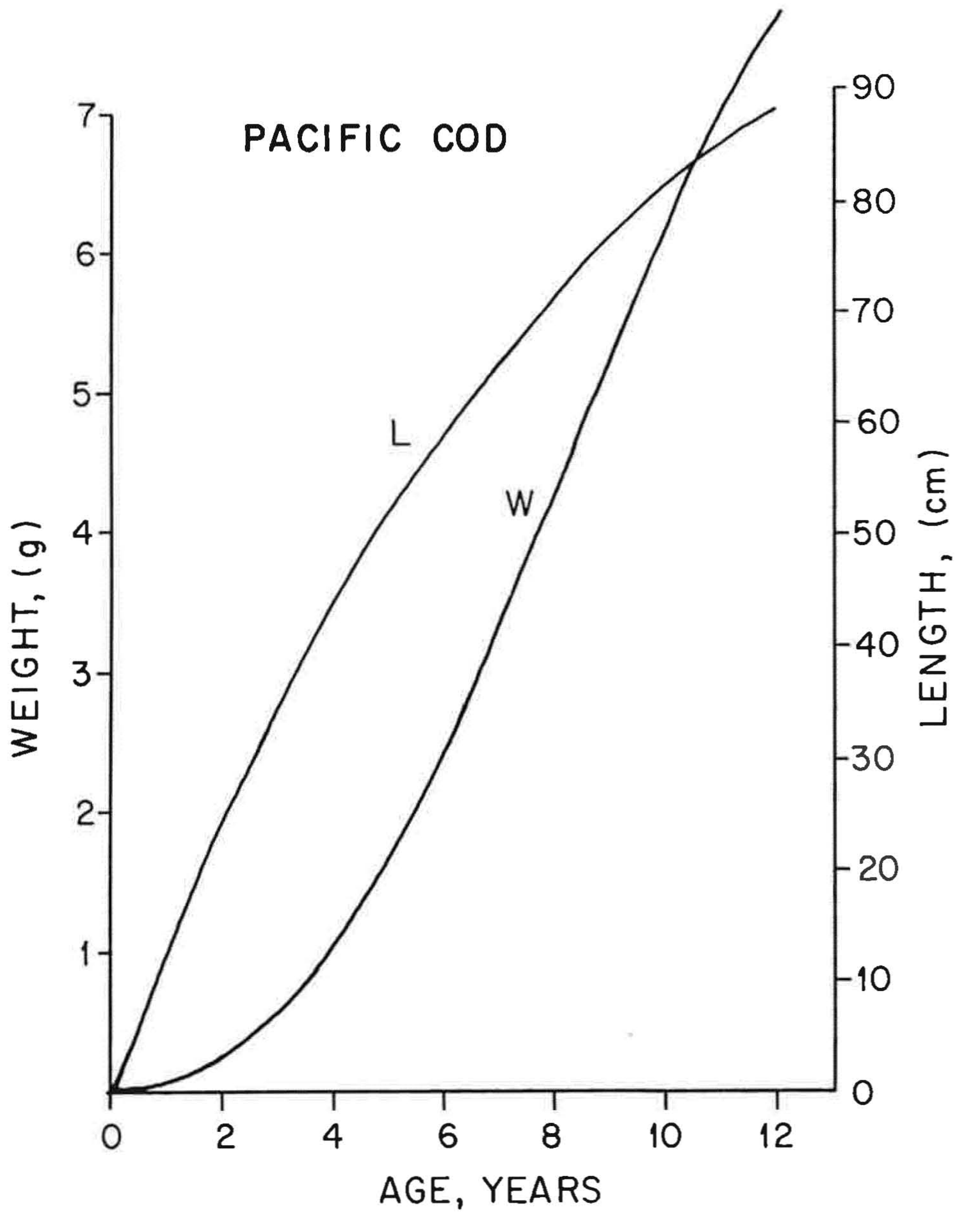

Figure A14. Weight and length of Pacific cod at different ages.

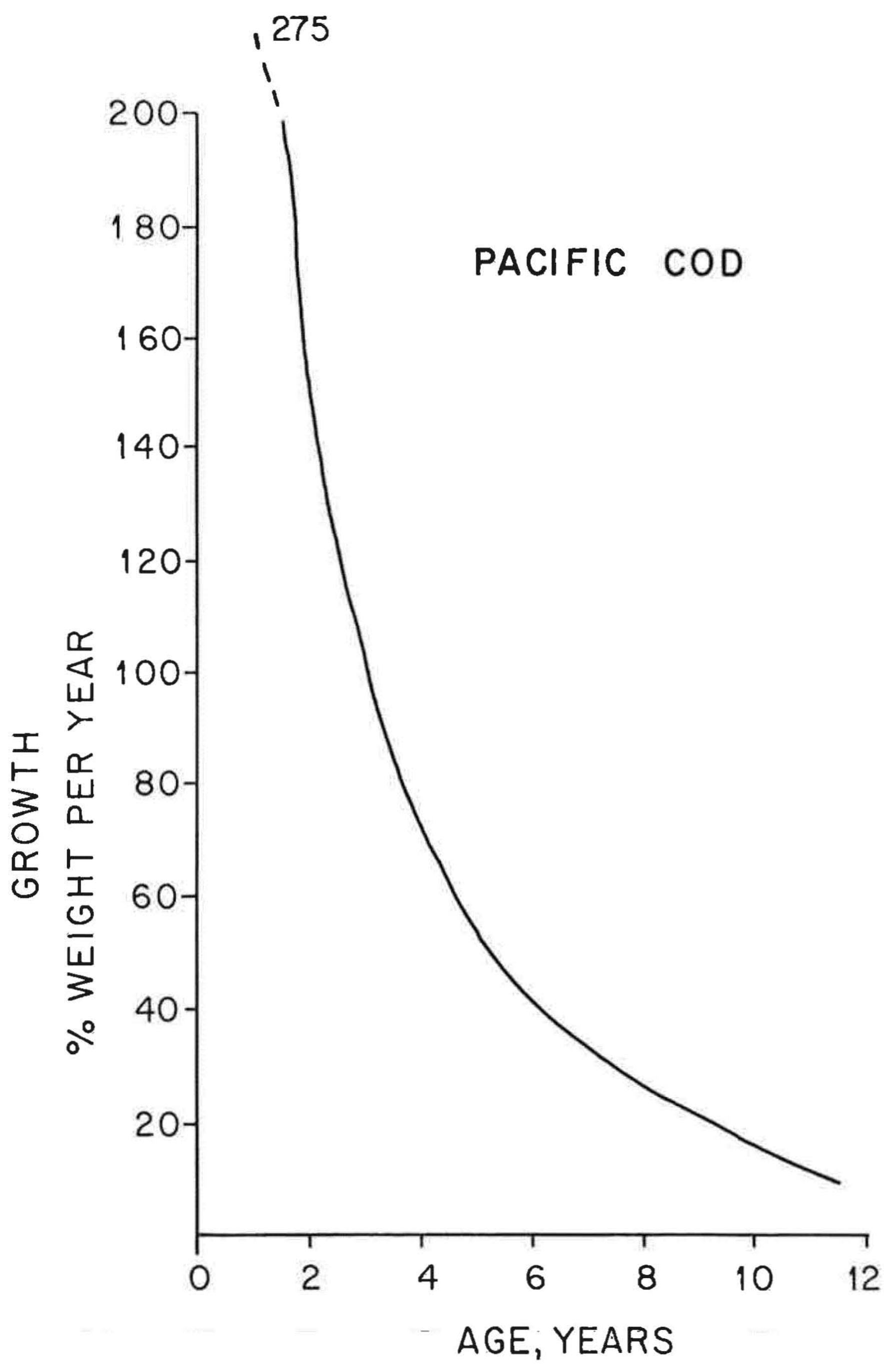

Figure A15. Growth of biomass (weight) of Pacific cod at different ages, as percent per year.

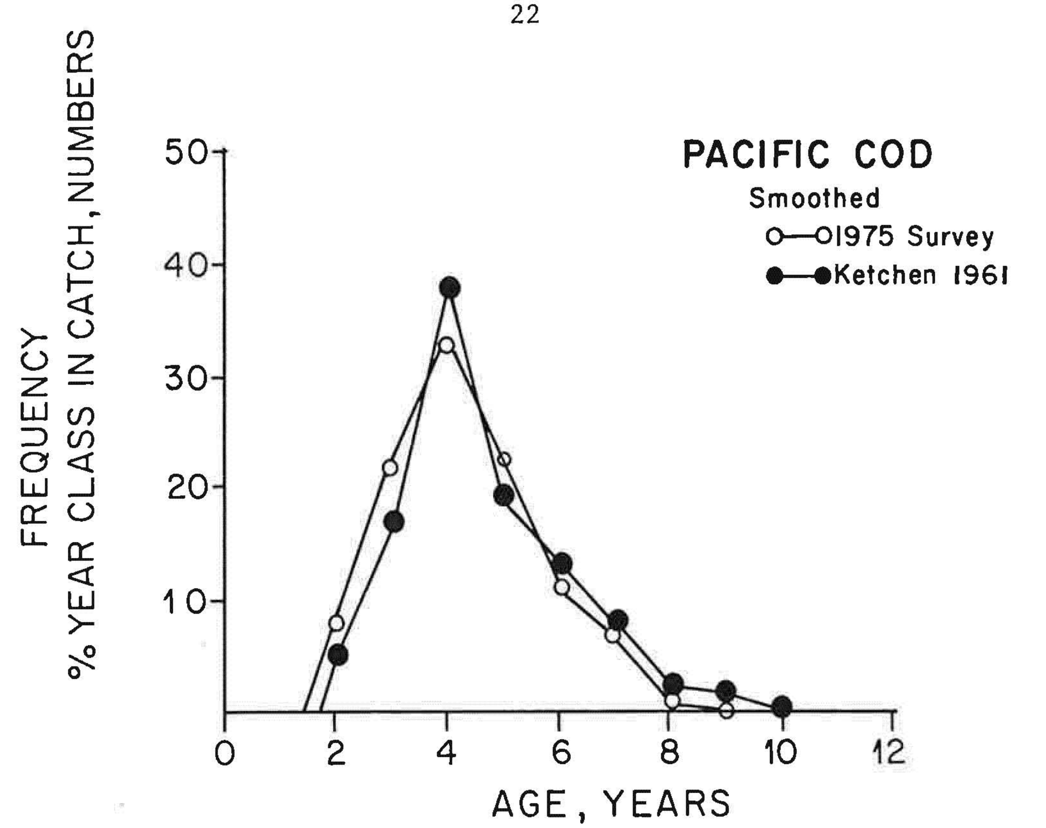

Figure A16. Age distribution of catch (in numbers) of Pacific cod from the Bering Sea (various sources).

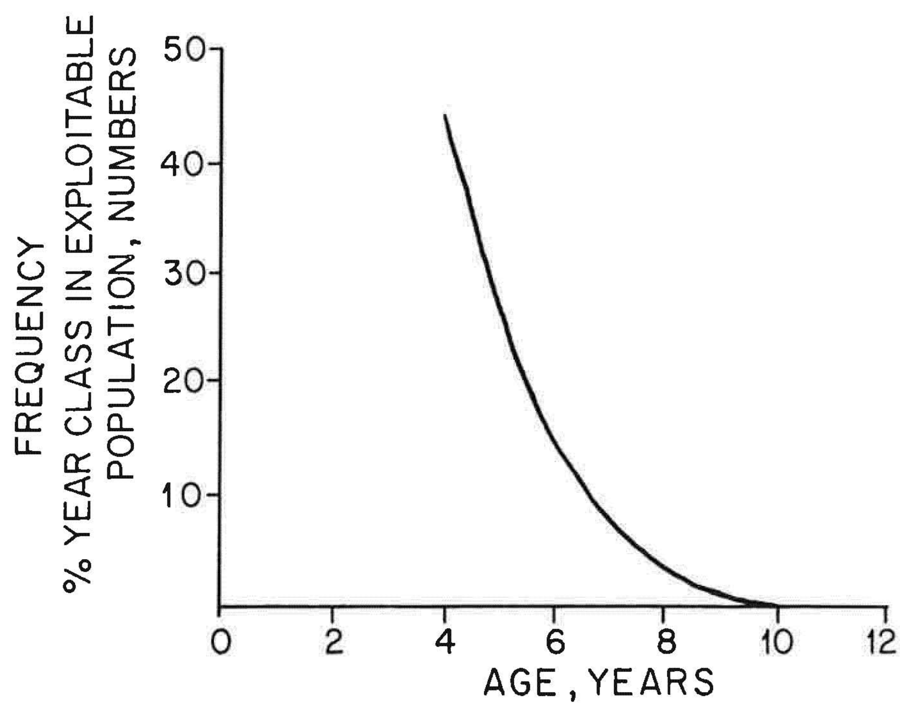

Figure A17. Estimated mean age distribution of catch (in numbers) of fully exploited year classes of Pacific cod from the Bering Sea.

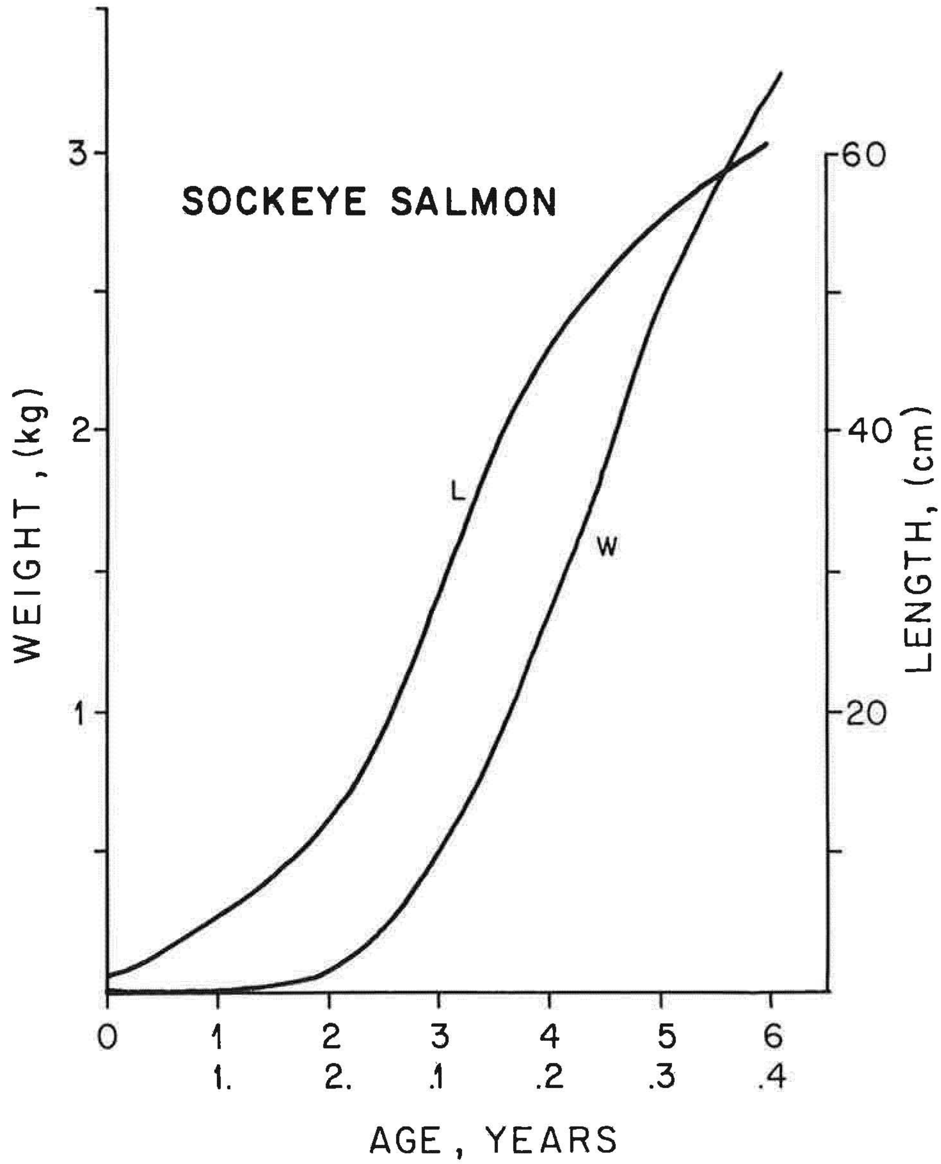

Figure A18. Weight and length of sockeye salmon at different ages.

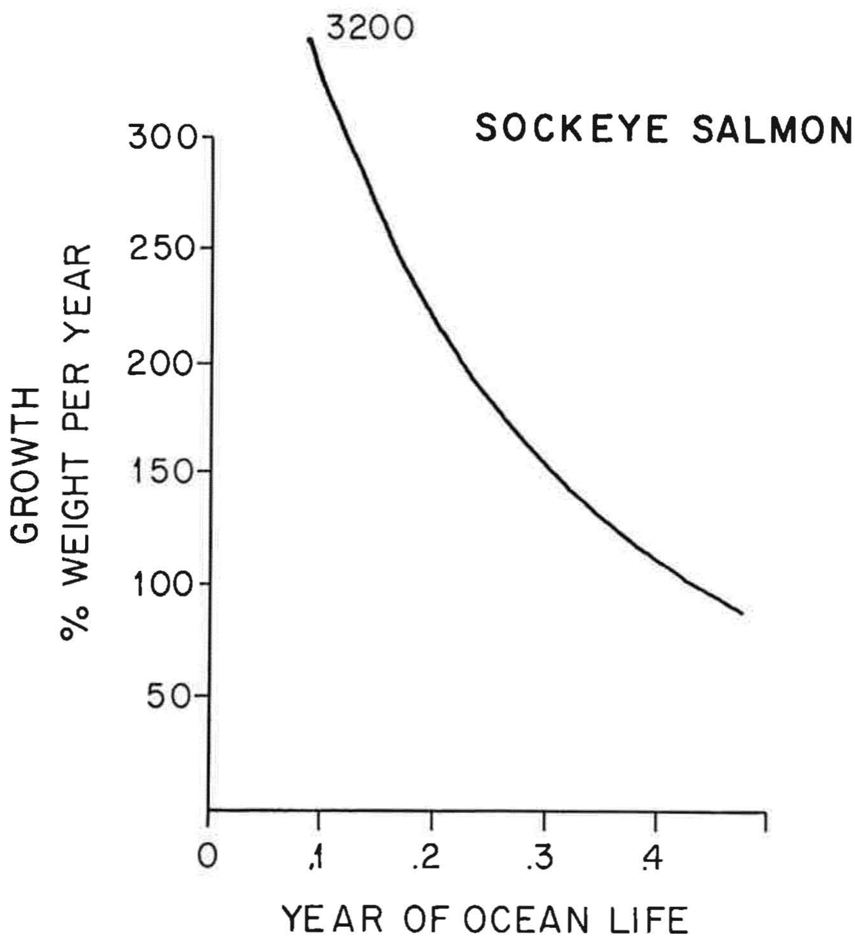

Figure A19. Growth of biomass (weight) of Pacific herring at different ages, as percent per year.

VI. BIOMASS/CONSUMPTION DISTRIBUTION GRAPHS

(Figures 1-15)

Yellowfin sole

Walleye pollock

Pacific herring

Pacific cod

Sockeye salmon

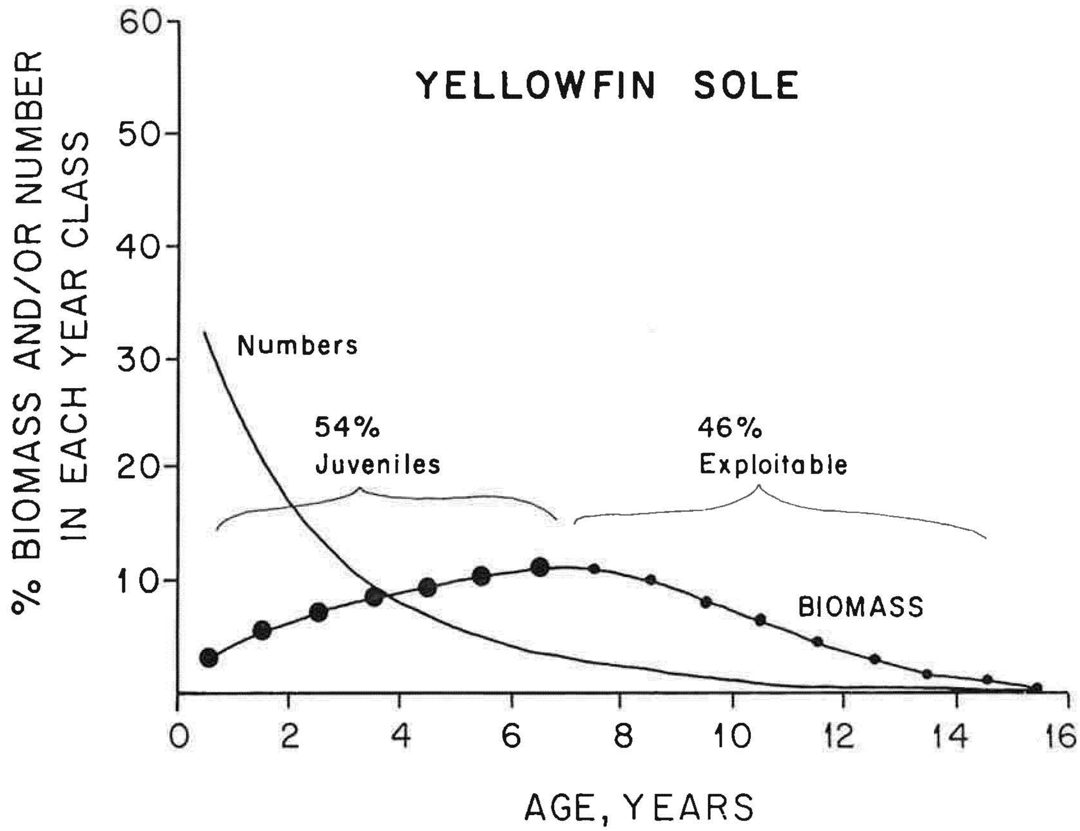

Figure 1. Distribution of biomass and numbers of yellowfin sole within different year classes (% of total).

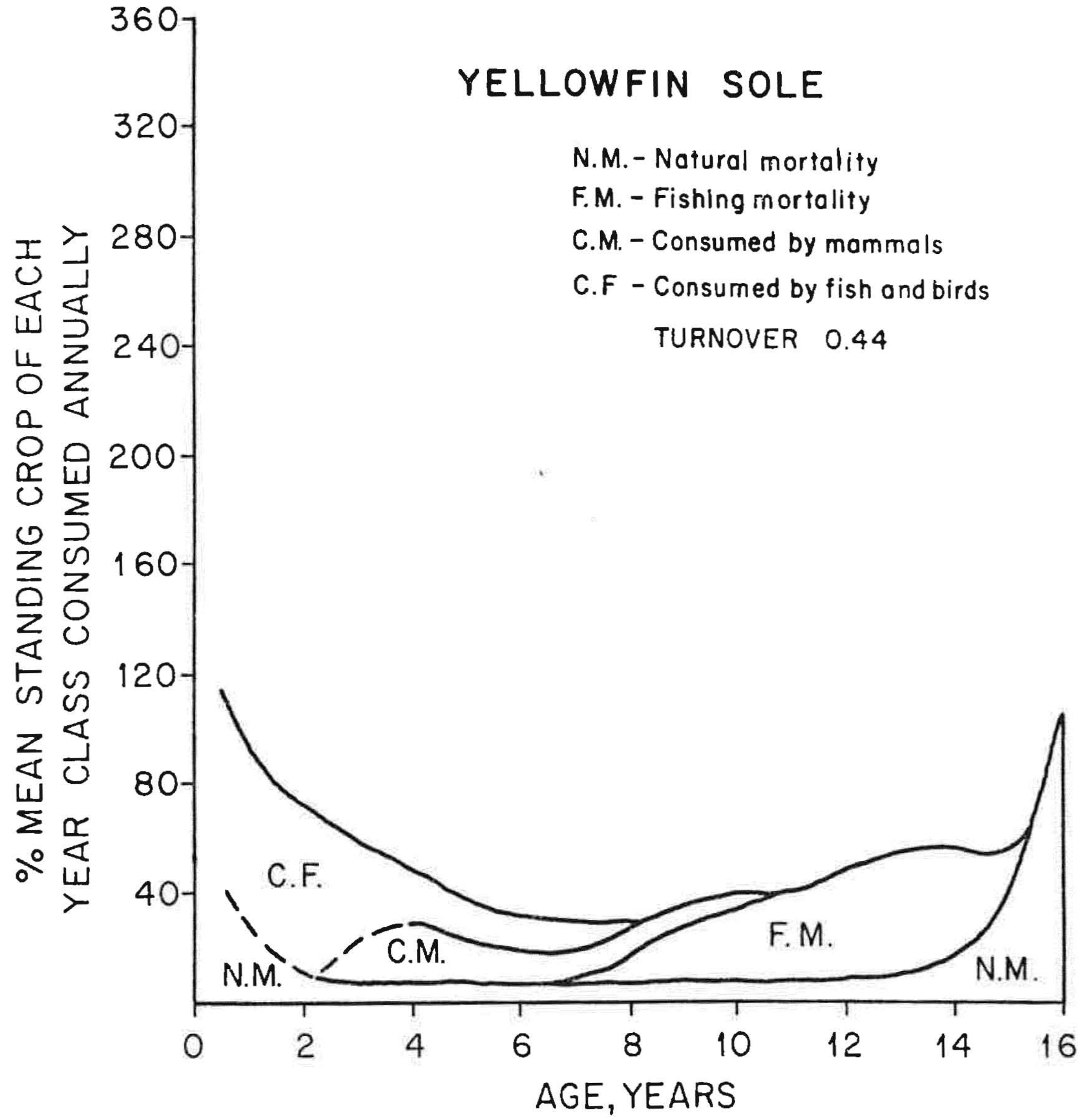

Figure 2. Distribution of "consumption" (grazing, mortality, and fishery) with age of yellowfin sole, as percent of mean standing crop of each year class.

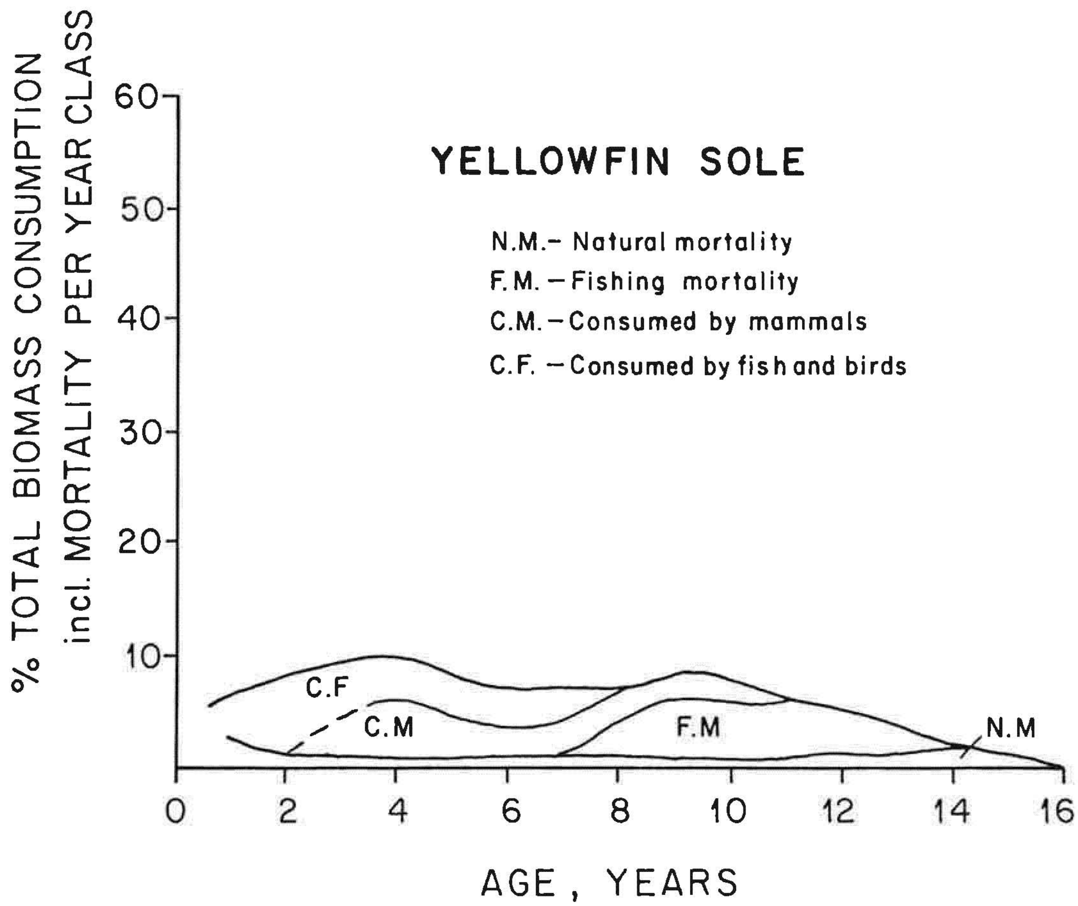

Figure 3. Distribution of "consumption" with age of yellowfin sole, as percent of total biomass.

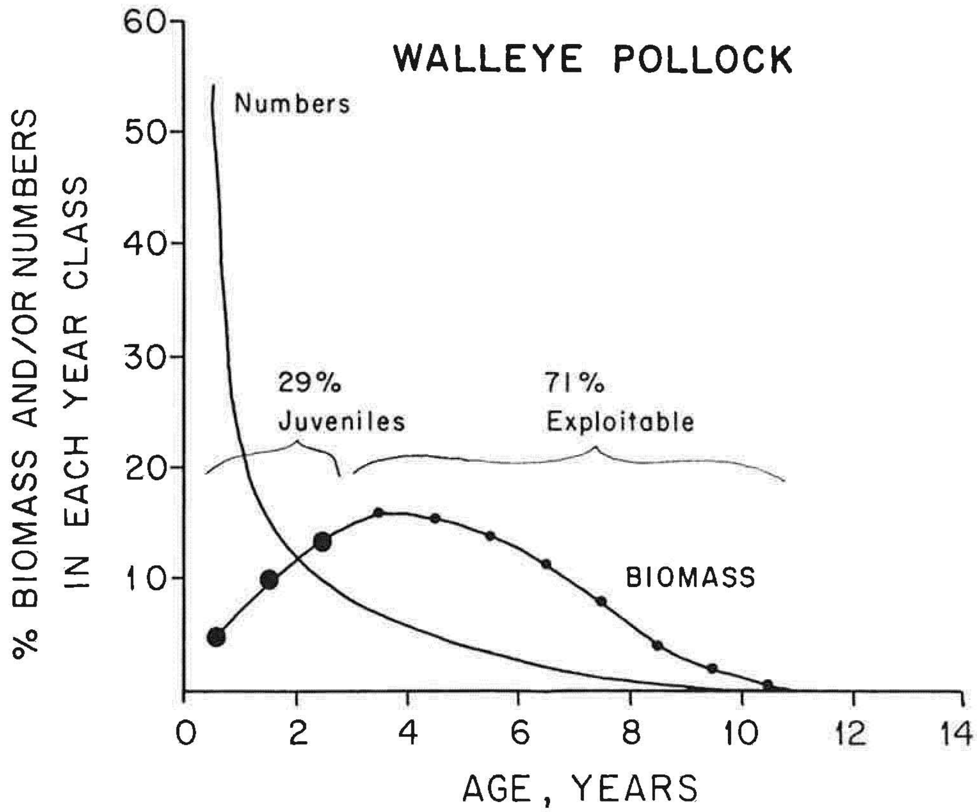

Figure 4. Distribution of biomass and numbers of walleye pollock within different year classes (% of total).

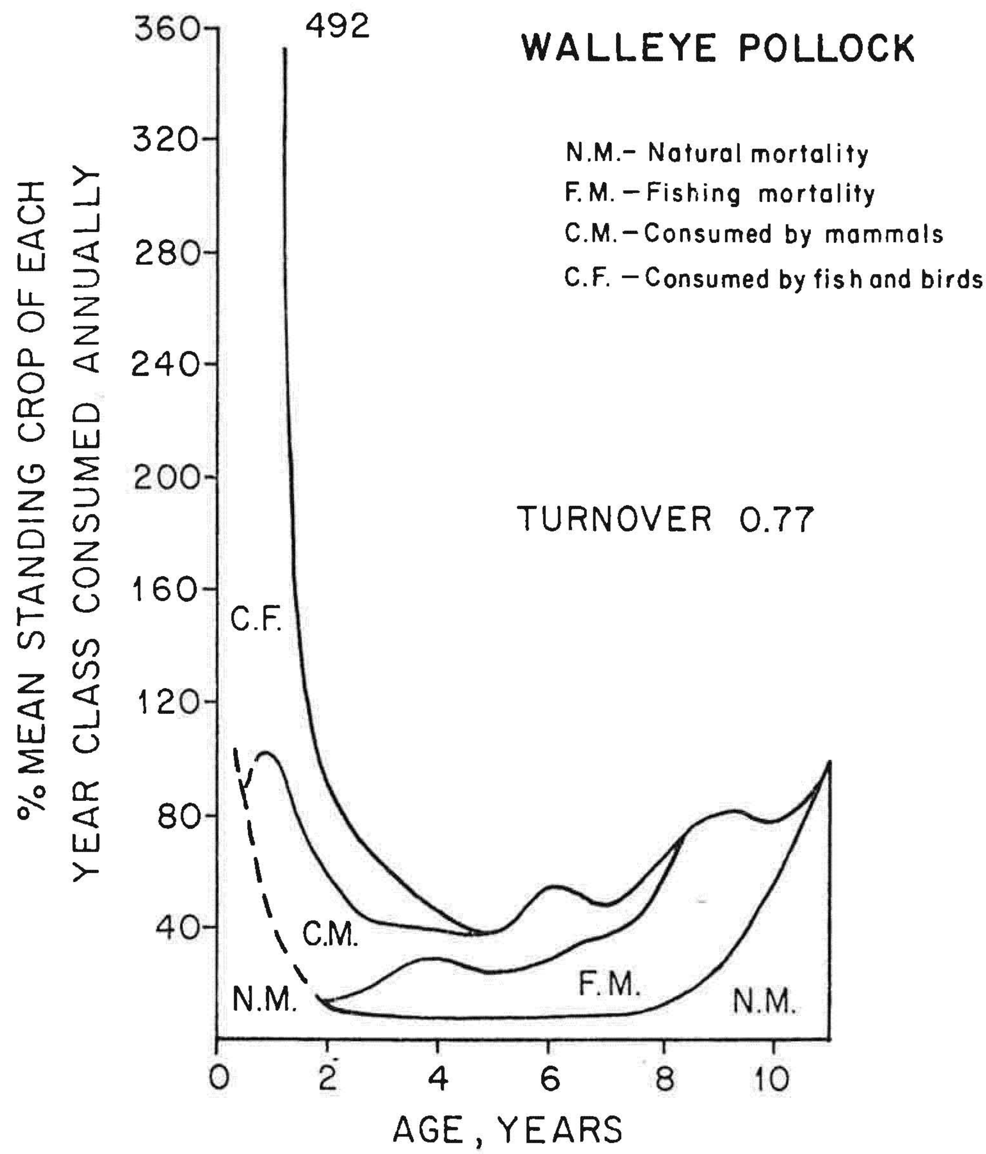

Figure 5. Distribution of "consumption" (grazing, mortality, and fishery) with age of walleye pollock as percent of mean standing crop of each year class.

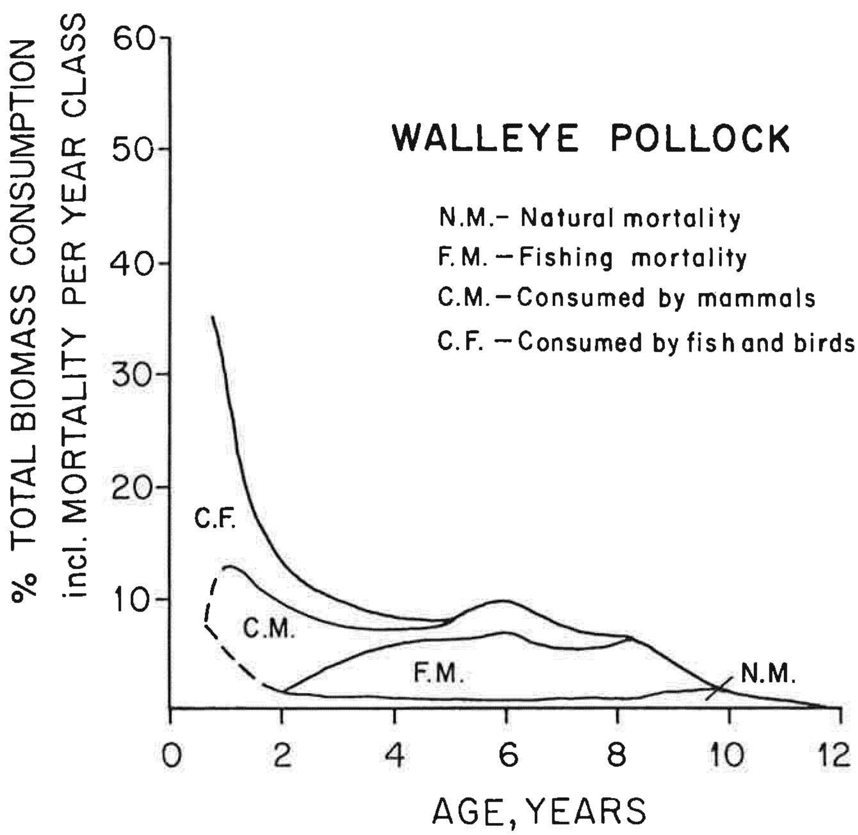

Figure 6. Distribution of "consumption" with age of walleye pollock, as percent of total biomass.

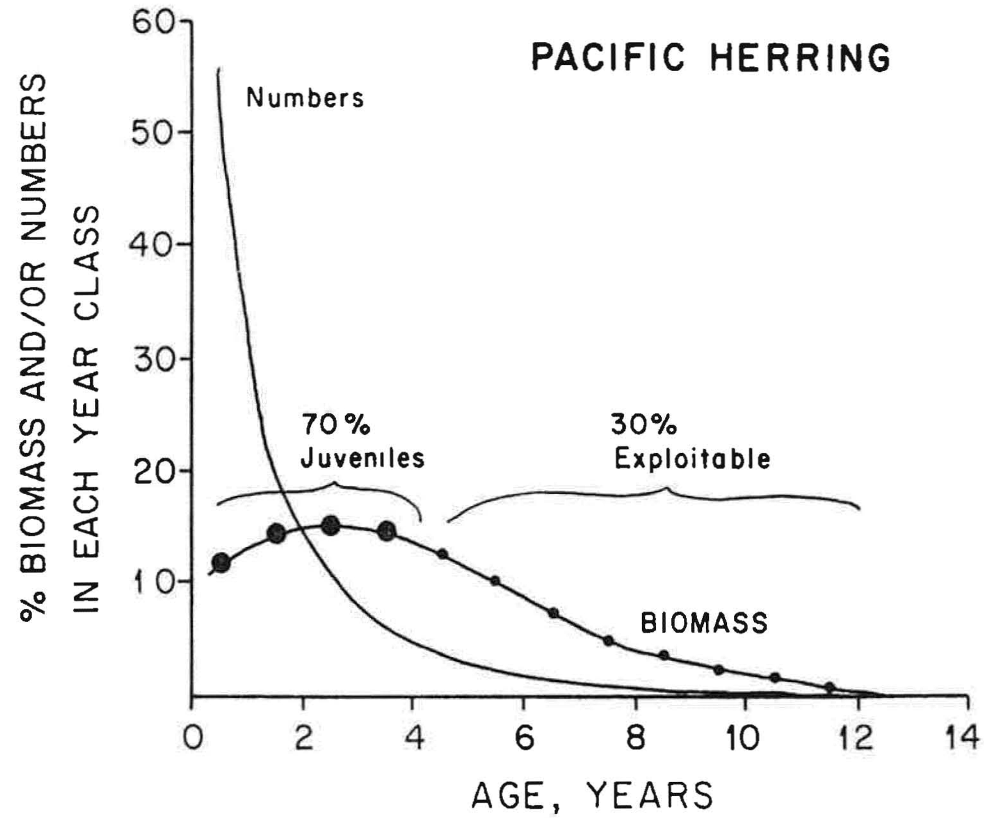

Figure 7. Distribution of biomass and numbers of Pacific herring within different year classes (% of total).

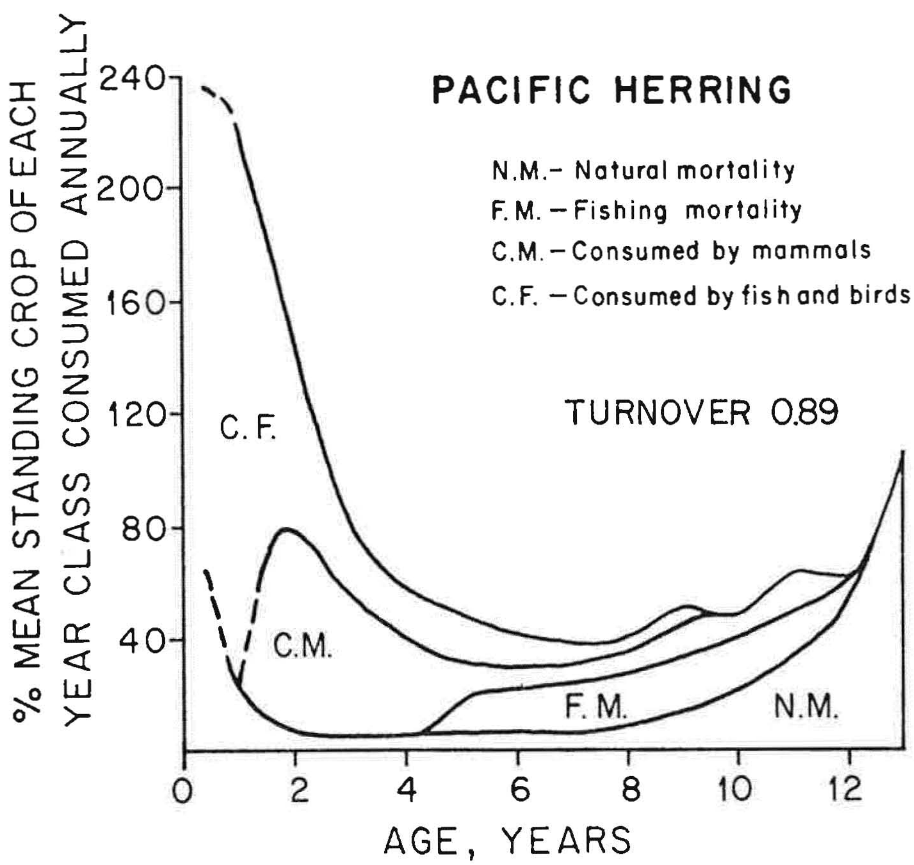

Figure 8. Distribution of "consumption" (grazing, mortality, and fishery) with age of Pacific herring, as percent of mean standing crop of each year class.

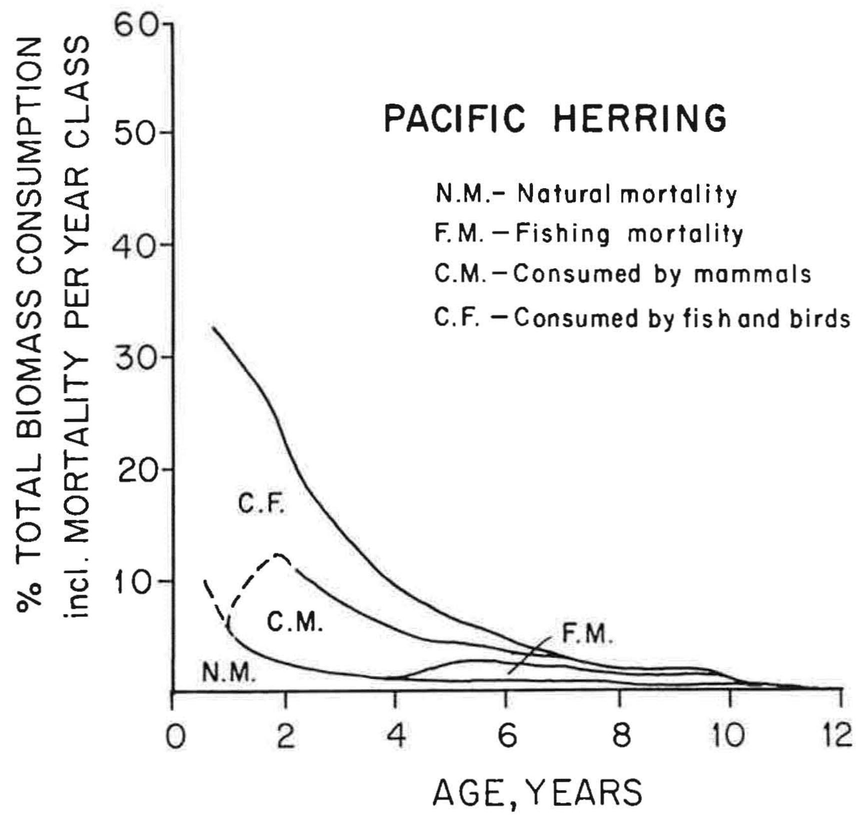

Figure 9. Distribution of "consumption" with age of Pacific herring, as percent of total biomass.

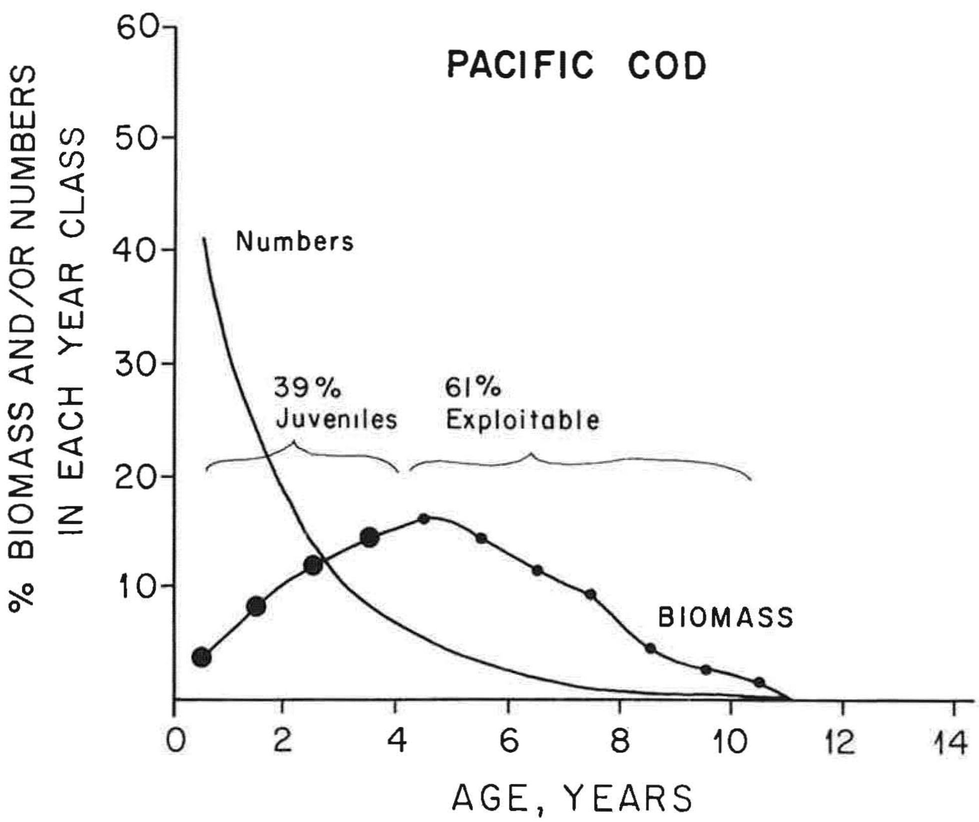

Figure 10. Distribution of biomass and numbers of Pacific cod within different year classes (% of total).

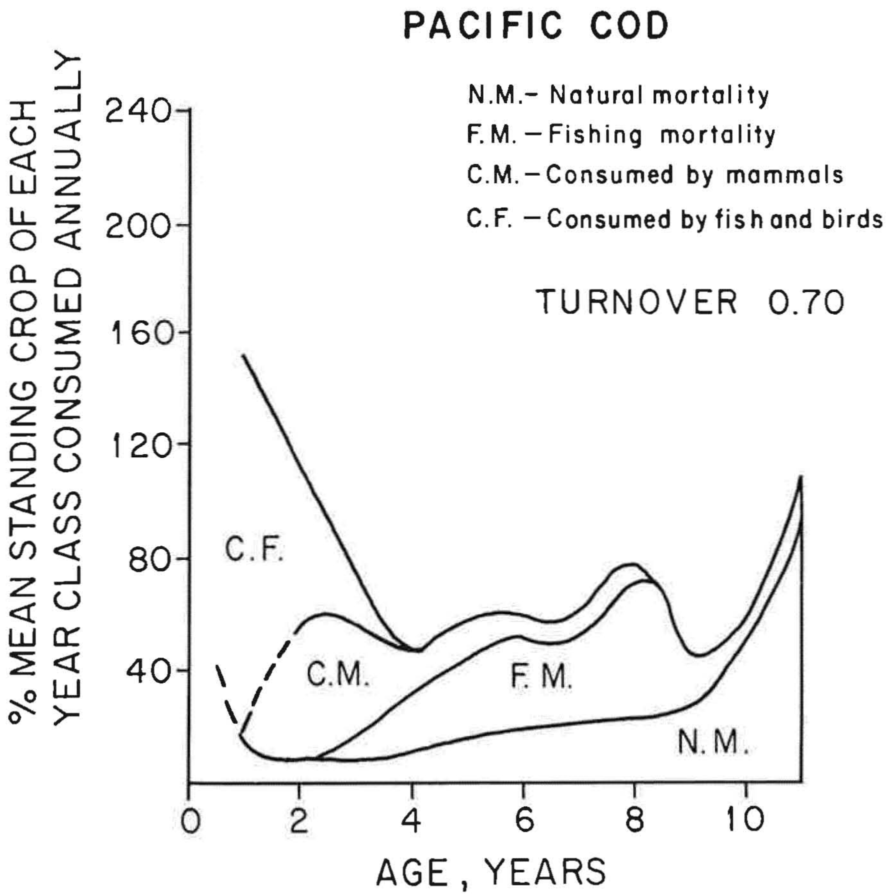

Figure 11. Distribution of "consumption" (grazing, mortality, and fishery) with age of Pacific cod, as percent of mean standing crop of each year class.

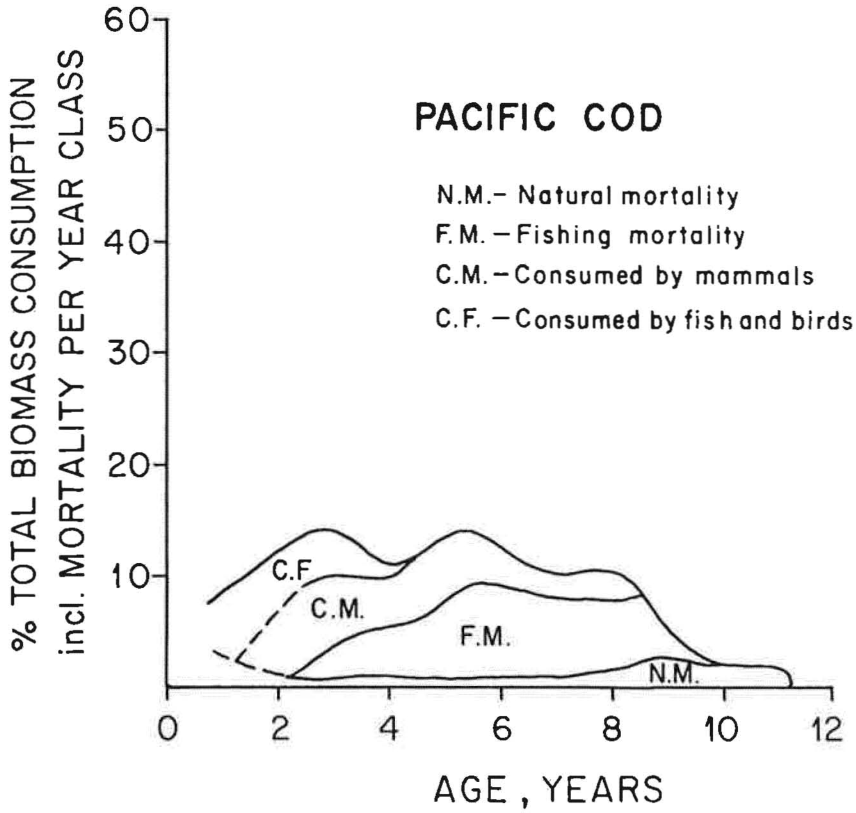

Figure 12. Distribution of "consumption" with age of Pacific cod, as percent of total biomass.

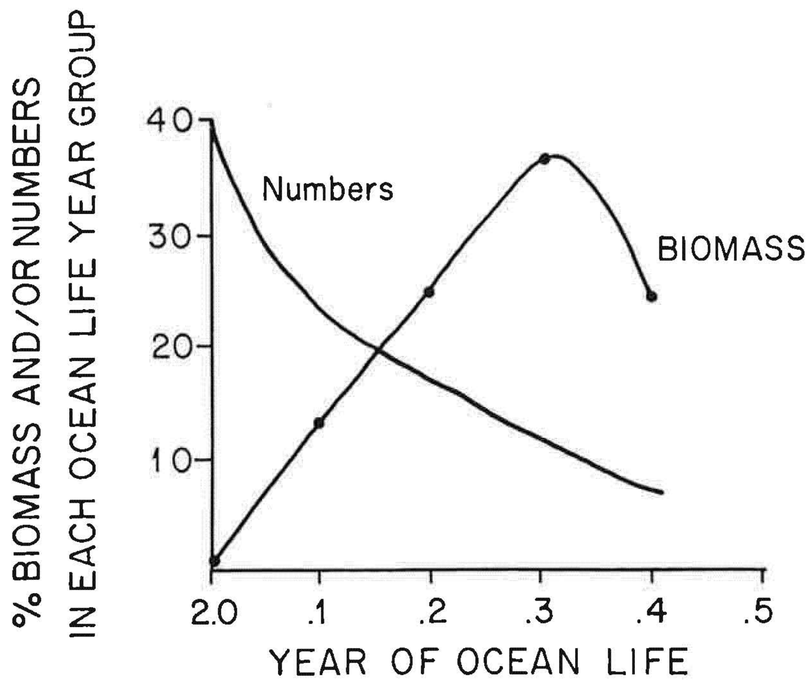

Figure 13. Distribution of biomass and numbers of sockeye salmon within different year classes (% of total).

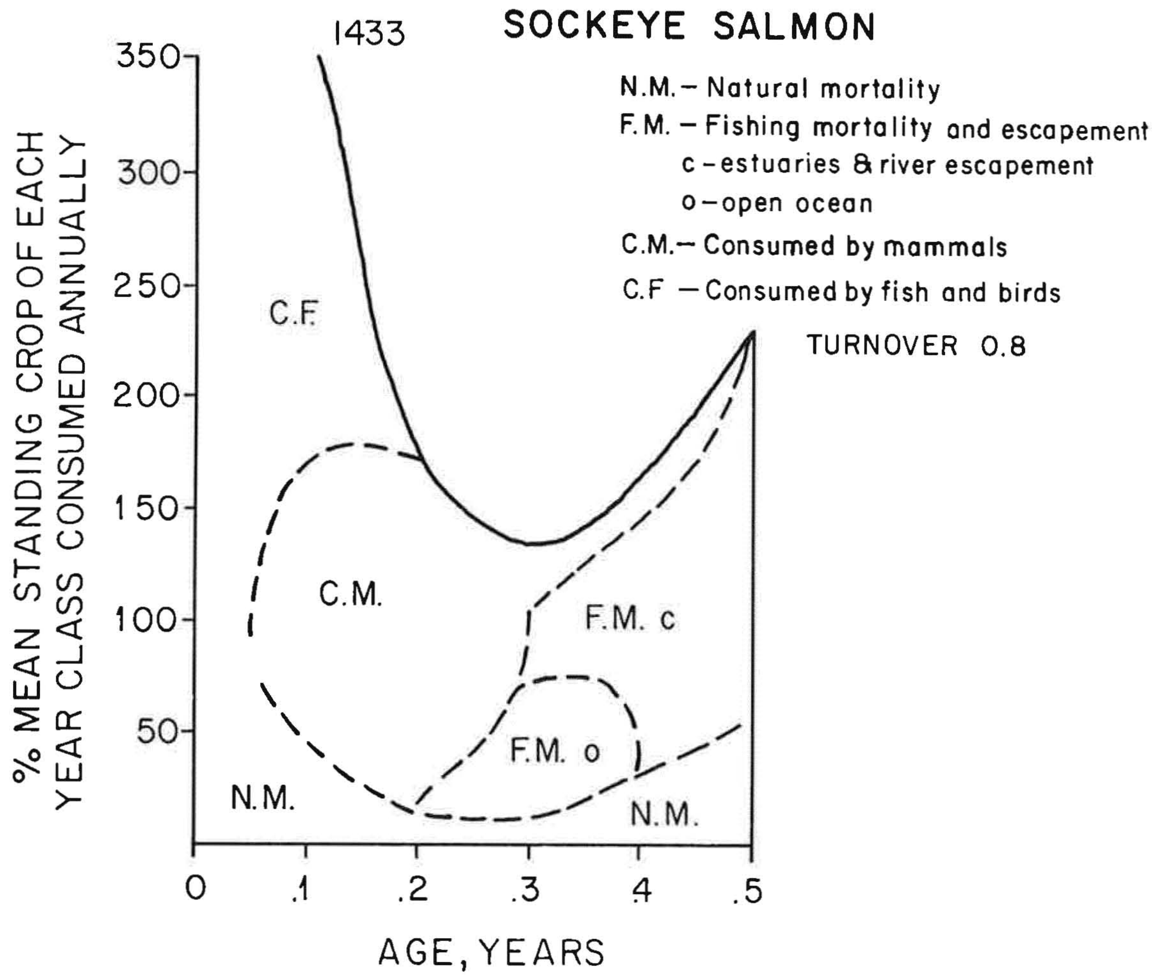

Figure 14. Distribution of "consumption" (grazing, mortality, and fishery) with age of sockeye salmon, as percent of mean standing crop of each year class.

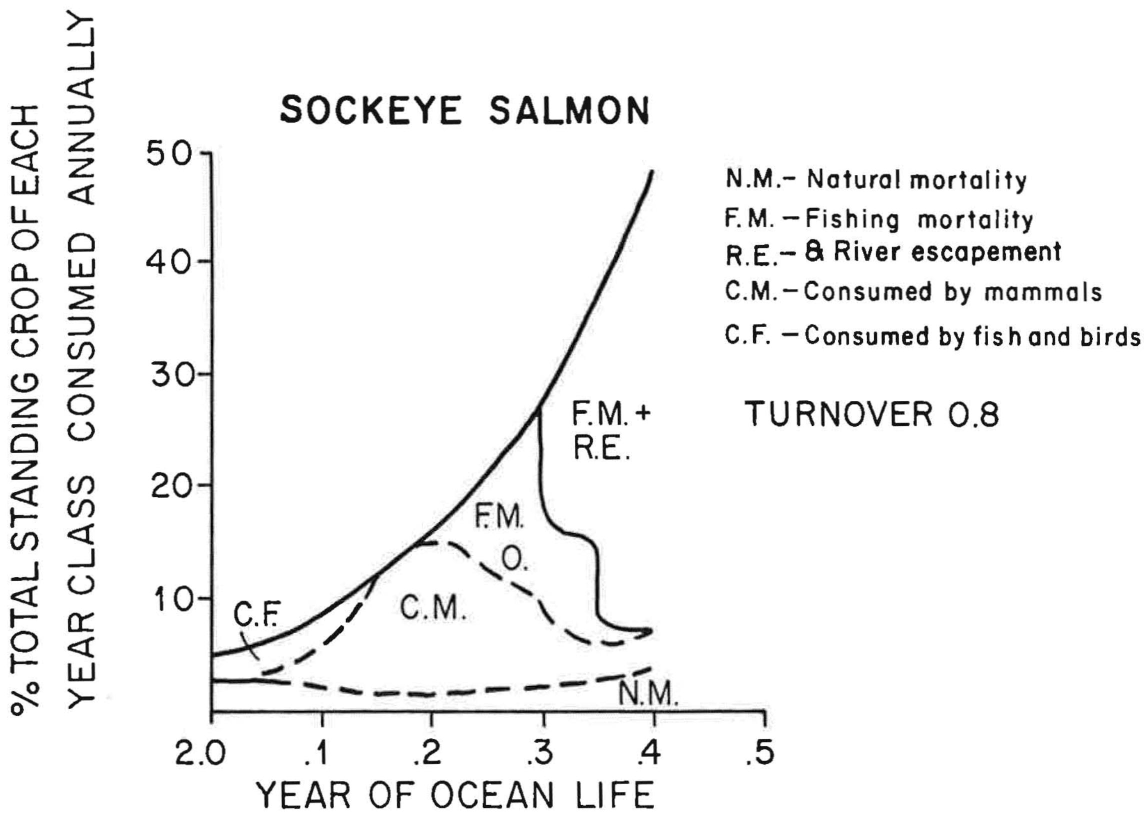

Figure 15. Distribution of "consumption" with age of sockeye salmon, as percent of total biomass.

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