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INTERACTIONS OF SIZE-SELECTIVE FISHING WITH VARIATIONS IN GROWTH RATES AND EFFECTS ON FISH STOCKS.

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ABSTRACT

Both the intrinsic and apparent growth rate of fish of given age class from a given stock varies within certain limits. Apparent growth rate differences are partly caused by prolonged spawning times of most species. Size selective gear would remove proportionally higher amounts of faster growing recruiting fish than slower growing fish of the same age class. Furthermore, maturation is in most species more size than age dependent. Thus faster growing fish would mature earlier, and consequently at a given post-maturation age would have been subjected more to spawning stress mortality than slower growing fish (the Lee's phenomenon). These two processes would cause the older population of a stock to contain more slower than fast growing

fish. This condition is shown to occur in moderately heavily fished Bering Sea pollock stock. In this stock the oldest fish (older than 8 years) show an equal or shorter mean length than 8 year old fish. Furthermore the modal length in older fish is smaller than mean length, and age distribution at a given length as well as length distribution at a given age show the presence of more slow than fast growing fish. This phenomenon is not clearly indicated in faster growing cod stock from the same region in 1977 to 1979, when this species was subjected to very slight fishing pressure (ca 50 thousand tonnes caught from a biomass of about 1 million tonnes).

Earlier investigations have indicated that in some species the egg size is slightly larger in late maturing spawners and resulting larvae have greater vitality and faster growth. Thus it might be expected that the size selective fishing on recruiting age classes could influence the coming generations by favoring larger eggs and faster growing specimens. This hypothesis, which would counteract the fishing effects described earlier, cannot be tested on data at hand in the author's laboratory, but might be testable in North Atlantic area.

1. INTRODUCTION.

Most fishing gear is size selective, retaining larger (and older) fish whereby the size selectivity is most pronounced on recruiting age classes. With increasing fishing intensity the amounts of older (larger) fish left in the sea will decrease and the exploitable stock and catches from it will consist of younger fish (rejuvenation of population). The recruiting age class which will become dominating in heavily fished stocks will contain predominantly immature fish in most species. Fish growth rate can vary intrinsically as well as under the influence of environmental factors (e.g. temperature, availability of food). Due to size selectivity of most gear, faster growing fish are recruited earlier and subjected to greater fishing pressure than slower growing fish. Consequently an apparent size selective mortality results which is known as Lee's phenomenon: "There is a greater mortality among larger individuals than among smaller ones of a given age", (Ricker, 1969). This selection is expected to have some consequences to the exploitable stock, such as possible predominance of slower-growing specimens in fully recruited stock, increased number of later maturing fish, possibly increased egg size of first spawners, and decreased spawning stress mortality. These consequences and their possible effects on fish stocks are briefly explored in this paper.

2. THEORIES OF INTERACTIONS AND THEIR CONSEQUENCES.

Most fishing gear is by design selective of larger, older fish. Moderately heavy fishing year after year causes the mean age of exploitable population left in the ocean to become younger and new recruits will constitute greater fraction in the catch. Several biological properties of the species are age and size dependent, such as maturation and spawning stress mortality, which will interact with size selective fishing and modify the characteristics of remaining population. Existing knowledge permits the formulation of a qualitative theory of the effect of size selective fishing, which can be partly tested on available empirical data.

Lee's phenomenon ("apparent change of growth rate") has in the past been observed mainly by backcalculation of growth whereby it has been found that most fish caught at the older ages were those whose backcomputed growth in earlier years was slow. This method of the determination of the magnitude of Lee's phenomenon is affected by errors in backcalculation of growth. Furthermore, uncertainty in age determination exists in most species. LaLanne (1978) found that agreement in age reading decreases with age, being 73% for 2 year old pollock and only 50% at age 15. This uncertainty in age determination is also limiting the use of fish aging for evaluation of size/age dependent changes in fish stocks.

There are also stock intrinsic fish size dependent properties and interactions, such as older, larger fish being more piscivorous and cannibalistic. The removal of these older fish by fishing would relieve predation pressure on juvenile fish and thus affect recruitment to exploitable population and will result in cyclic changes in stock size. These interactions have been ventilated by Laevastu and Favorite, 1988, and will not be discussed here.

Changes in growth rates of stocks of some species have been observed (halibut, IPHC, 1987; herring, Saville, 1978). It can be thought that these changes might have been influenced or even caused by size-selective fishing which has caused the increase of later-spawning, slower-growing fish in spawning population.

2.1 Interaction of size selective fishing and variation of growth rate.

1. Fish recruits to most fishery by size rather than by age, faster growing fish are recruited first and subjected to earlier fishing mortality.

2. Fully recruited fish to trawl may be equally vulnerable through whole length range--unless changes in behaviour and distribution (e.g. shoaling by size) changes the picture.

3. With increased fishing intensity over the years, greater proportion of the exploitable stock will consist of new recruits. Consequently, with continued fishing the fishing pressure on recruits increases, which is accompanied by greater size/age selectivity.

4. Growth rate of fishes of the same age class in a given stock varies mainly on four known reasons: a) Specimen intrinsic growth rate (e.g. might be influenced by egg size and early larval growth conditions (Hirschhorn and Penttila, 1989 growth completion); b) temperature regime where the larval and juvenile fish grow up; c) food availability (also the size of available proper food items, re. energy spent on food uptake); d) specimen originating from early or late spawners (most species in high latitudes have spawning periods which might last several months. Age determination does not count for real "birthday", but age in years, considering the "winter check").

5. First maturation of all specimens of a given stock does not occur at the same age. It is generally accepted that first maturation is size dependent, the faster growing fish maturing earlier. There is some experimental evidence that faster-growing fish which mature earlier also die earlier. Spawning stress (or senescent) mortality increases about ten percent after each spawning (Laevastu and Larkins, 1981). Thus late maturing and spawning fish are subjected to lower spawning stress mortality at a given age. Size selective mortalities are fully described by Ricker, 1969, including Lee's phenomenon.

6. Negative selective mortality - i.e. greater mortality among the smaller and slower-growing fish, is common in younger ages when predation mortality is size dependent. According to Anderson (1989) survival prior to recruitment remains largely

unsolved. However, higher mortality among smaller fish is undeniable. The faster the fish grows out of the "predation critical length" the better the survival.

7. Slower-growing fish are usually spawning first time at older ages and are then bigger than fast-growing first spawners. The slower-growing first spawners produce larger eggs and more viable larvae than faster-growing first spawners (Tanischuk and Ware, 1987). Thus higher survival of larvae and faster growing offsprings are expected from slower-growing first spawners (a "natural compensation mechanism").

8. Selective (size and growth dependent) mortality is difficult to detect in the variability of length distribution of catches. There exists a "growth compensation", caused by growth rate decrease with age, thus smaller fish usually start to catch up with the larger ones. As pointed out by Rodney Jones (1958), (Ricker, 1969) selective mortality need not change the shape or variability of a length-frequency distribution of catch.

The interactions of size selectivity of recruits by gear, variable growth rate, and size dependent maturation and their consequences on remaining exploitable stock can be summarized as follows:

Considering the known biological facts of growth and maturation (4 and 5 above) and that intensive, size selective fishing would remove relatively high proportion of faster growing recruits (1 and 3 above), it can be expected that: a) the remaining population will contain higher proportion of slower growing fish; b) the size (length and weight) of older specimens in the population would be smaller (i.e. below the asymptotic growth curve), and c) the spawning stress mortality (senescent or "natural" mortality) of older exploitable stock would be somewhat decreased and "life expectancy" increased. Some of the processes leading to these consequences have been described and/or alluded to by Ricker, 1969.

2.2 Possible effects of size selective fishing on future recruits.

The presence of greater portion of slower growing and later maturing fish in an exploitable (and spawning) population, which has resulted from size selective fishing on recruits, might have some biological consequences on future recruits resulting from this spawning population. Some laboratory evidence exists on these prospective consequences; however, some of these merit future investigations, which might be possible on the fished populations from which longer time series of data are available. Some of the possible consequences are:

a) Larger, older first time spawners, do produce larger eggs than faster-growing early spawners. Large eggs would produce larger, more viable larvae. These effects might, however, be masked by other effects such as heavy fishing removing most older, larger spawners and the consequent "rejuvenation" of the spawning population at large.

b) Viable larvae from larger eggs might result in faster growth of juveniles (and possibly in adult stages) if growth rate is intrinsic, thus increasing growth rate of the population at large. Growth rate increases have indeed been observed in several heavily exploited stocks (e.g. North Sea herring, Saville, 1978).

c) On the other hand, growth rate might be partly hereditary and the remaining slower growing spawning population might produce slower growing recruits. If a slow growing future population results from the spawn of slower growing spawners (and from size selective fishing mortality), it might also cause early maturation of first spawners at smaller sizes than before, which has been observed in Arcto-Norwegian cod.

d) It might also be thought that the different spawning size and age of predominantly slower growing spawning population and the effect of heavy fishing on stock causing the first time spawners to dominate in spawning population might result in shifts in time of peak spawning as well as shifts of traditional "upcurrent" spawning grounds. First-time spawners are known to spawn later than previously spawned specimens (Tanasichuck and Ware, 1987).

e) Growth rate changes will cause some changes in predation condition, as predation is mostly prey and predator size dependent. Slower growing larvae and juveniles are subjected for a longer time to predation, whereas faster-growers pass the "critical prey period" faster, thus decrease of predation mortality (and possibly increase of recruitment) might occur.

3. INTERACTIONS IN EMPIRICAL DATA OF THE EFFECTS OF FISHING ON SIZE/AGE COMPOSITION OF STOCKS.

Testing and verification of the hypothesis and theories presented in Section 2.1 above was attempted on walleye pollock and Pacific cod from the eastern Bering Sea. Sufficient number of age determinations of pollock was available for 1983 (7315 observations); the sampling covering all seasons and all fishing areas and gear. For 1984 only 2226 age determinations of this species were available. For Pacific cod the number of age determinations for each year was relatively small. Therefore three years' age determinations (1977, 78 and 79) were used together (total 3134 observations).

The pollock fishery was moderately heavy during 1983 and 84 and in prior years; about 1.5 million tonnes were caught each year from a total stock (including juveniles) of about 15 million tonnes. The cod fishery was, however, relatively light in relation to total stock; only about 50 thousand tonnes were caught each year from a total stock of about 1 million tonnes.

Age determination of both species was done on otoliths, and the sources of errors and biases are expected to be normal as known for age determination on gadids elsewhere.

Figure 1 shows the mean and modal lengths of pollock at age in 1983 (corresponding data for 1984 are very similar). This figure clearly shows the decrease of mean length (below the asymptotic length) at ages greater than 8 years, and especially the decrease of modal length in relation to mean length. Both conditions are indicative of the presence of slower growing specimens in higher age categories. Furthermore, this figure shows the dominance of faster growing (longer) fish among 2 year old recruits.

The mean and modal ages at length for 1983 are shown in Figure 2, indicating the increased differences between these ages at length greater than about 43 cm, which is again indicative of the increasing portion of slower growing fish at longer lengths.

Figure 3 shows the distribution of percentage of numbers of aged fish (pollock) of different age in selected three length groups. The increase of percentage of older, consequently slower growing, fish at older ages (with the same length) and wider spreading of the fish toward older ages with growing length is noticeable. Figure 4 shows the same phenomenon when the distribution of different age of pollock is plotted against the length. There are slightly more shorter fish present in greater age groups than in younger age groups.

Mean and modal lengths at age of Pacific cod does not show any essential differences between the mean and modal lengths as pollock does. The reasons may be that the fishing pressure (catch) on cod has been very light in relation to the size of the stock, and cod has a much faster growth rate than pollock.

The difference between the mean and modal ages is also nearly the same at all ages in cod, indicating no effect of size selective fishing on the recruits for the reasons mentioned earlier. The modal age is smaller in cod than the mean age. This difference is larger in cod than in pollock, and is caused by the fact that the spawning stress (senescent) mortality in cod is larger than in pollock and consequently the life span (life expectancy) is shorter in cod than in pollock.

Only a slightly increased spreading of the numbers of cod at given length towards the higher age groups can be noticed, which is an indication of longer life span in slower growing fish. Figure 5 shows length distributions at given ages of Pacific cod (5 age groups presented, the values are smoothed with 3 cm group running mean). There are slightly more shorter fish of the same age present in older age groups than in younger age groups, indicating again the slightly longer life span in slower growing fish.

The data presented in the five figures essentially verify the theory presented in Chapter 2.1. However, the testing of the hypothesis presented in Chapter 2.2 will be possible only with data available from areas with longer full exploitation of major commercial species than the about two decades for the eastern Bering Sea.

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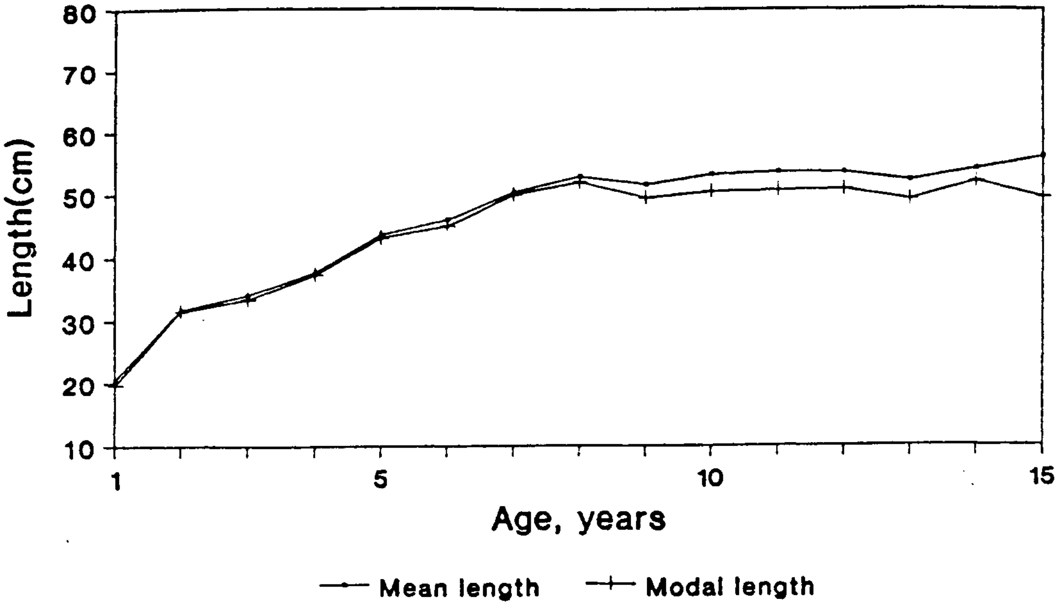

Figure 1. Mean and modal lengths at age of walleye pollock from eastern Bering Sea; 1983; 7315 observations.

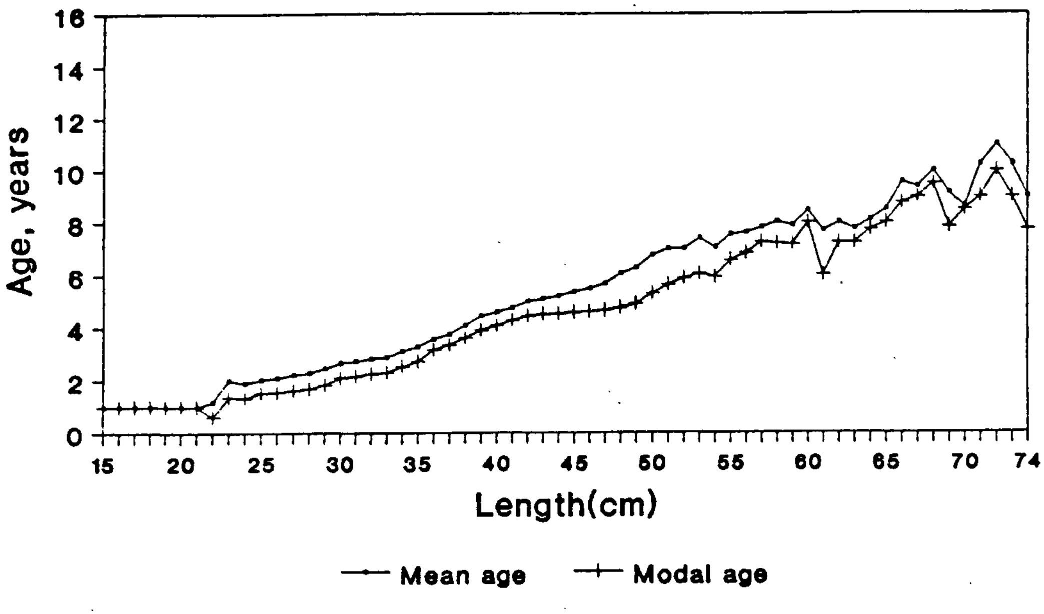

Figure 2. Mean and modal ages at length of walleye pollock from eastern Bering Sea; 1983; 7315 observations.

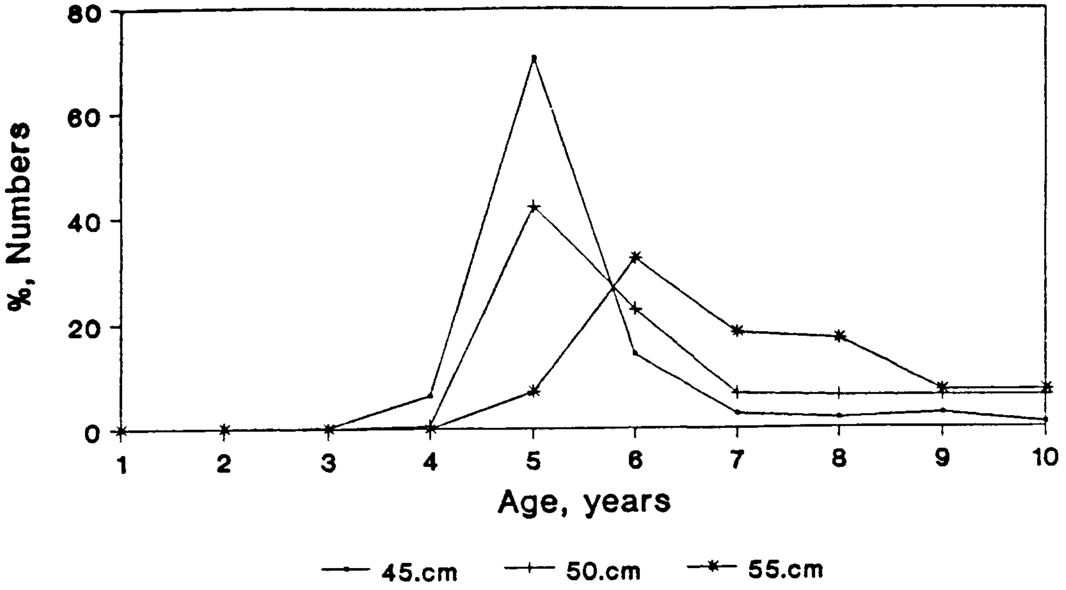

Figure 3. Distribution of selected length groups (45, 50 and 55 cm) of walleye pollock from eastern Bering Sea in different age groups in 1983 (in % number of fish in given length group).

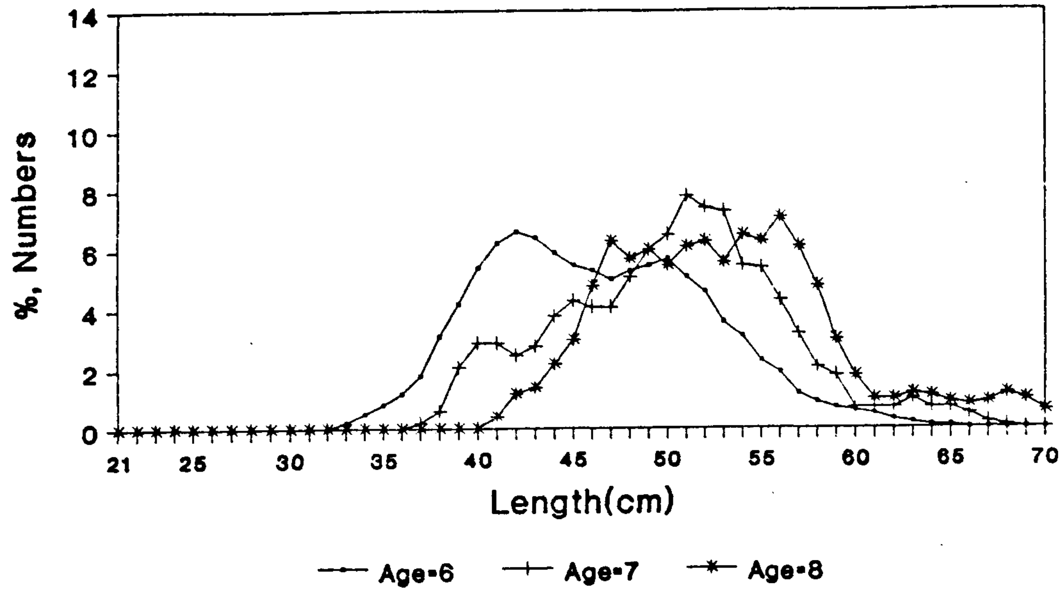

Figure 4. Distribution of lengths of walleye pollock from eastern Bering Sea in different age groups (6 to 8 years) in 1983 (in % numbers of fish in given age group).

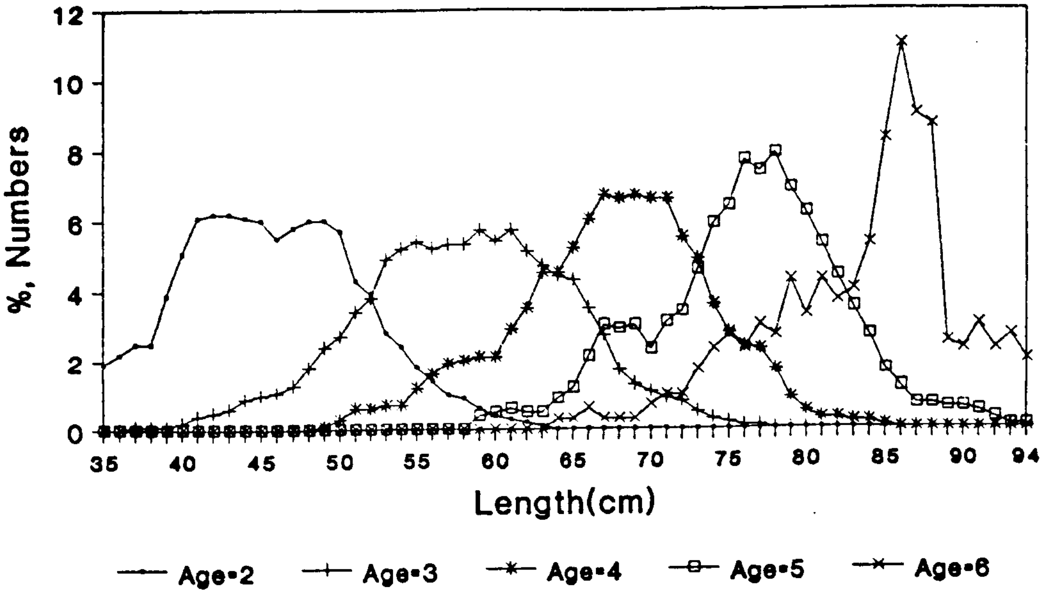

Figure 5. Distribution of lengths of Pacific cod from eastern Bering Sea in different age groups (2 to 6 years) in 1977, 78 and 79 (in % numbers of fish in given age group).