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Minimum size Regulations and the Implications for Yield and Value in the Canadian Atlantic Halibut Fishery

by

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ABSTRACT

The effect of a minimum size regulation in the Canadian Atlantic halibut fishery was assessed from the point of view of yield and value per recruit. The model indicated that under most scenarios, the imposition of the size limit would not result in increased yield per recruit. In general, yield per recruit was more sensitive to fishing mortality than age of first entry to the fishery. While reduced yields were usually associated with the minimum size limit, the minimum size regulation appeared to be an attractive option when value was considered, reflecting the higher value of the larger market categories. Both yield and value per recruit were found to be sensitive to the choice of the natural mortality rate.

RÉSUMÉ

On a évalué l'effet qu'aurait l'imposition d'une taille minimale réglementaire du flétan capturé dans la région canadienne de l'Atlantique sur le rendement et la valeur par recrue. D'après le modèle utilisé, il est apparu que dans la plupart des scénarios l'adoption d'une taille minimale n'aboutirait pas à une augmentation du rendement par recrue. En général, ce dernier s'est avéré dépendre davantage de la mortalité due à la pêche que de l'âge de l'entrée initiale du poisson dans les stocks pêchés. De fait, une baisse de rendement était habituellement associée à la taille minimale; en revanche, quand il était question de valeur, la taille minimale devenait une mesure attrayante, permettant de tabler sur la valeur plus élevée des grosses catégories marchandes. On a constaté que le rendement et la valeur par recrue dépendaient du taux de mortalité naturelle choisi.

INTRODUCTION

Atlantic halibut (Hippoglossus hippoglossus) is the most highly valued groundfish species (per unit weight) occurring on the Canadian Atlantic coast and, as such, has attracted considerable attention from both fishermen and researchers. However, the generally small landings in terms of weight and the difficulties associated with obtaining commercial fishery samples have meant that there has been serious deficiencies in our understanding of the biology of this exploited species.

Regardless of the lack of information concerning the biology of Atlantic halibut, there has been an increasing number of calls for management measures to conserve the stocks. As part of the response, an 81-cm (32") minimum size for retained Atlantic halibut was implemented in 1988. An identical size limit has been in place for many years for the fishery on the closely related Pacific halibut (Hippoglossus stenolepis) (Myhre 1974). To determine the utility of the proposed minimum size limit, a study of the survival of trawl and longline caught fish was completed in 1987 (Neilson et al., in press). Those authors examined the survival of Atlantic halibut caught in longline and bottom trawl gear, using a live holding facility onboard a research vessel. Attempts were made to simulate commercial practices during the fishing operations, although commercial set durations and handling time of catch were often longer. During the research vessel experiment, only 35% (70 of 198 total) of fish less than 81 cm survived more than 48 h after capture in bottom trawl sets of 120-min duration, whereas 77% of longline-caught fish less than 81 cm survived (10 of 13 total). In light of those results, a minimum size limit of 81 cm was adopted in 1988 on an interim basis only, subject to an analysis which determined the effectiveness of the minimum size limit from the point of view of fishery yield. Such an assessment is the subject of the present contribution.

Recognizing that there are different prices associated with the various market sizes of halibut and that imposition of a minimum size regulation could affect the market size composition of landings, an examination of the utility per recruit was undertaken in addition to the more traditional yield per recruit (biomass). The technique employed here used value as the utility function, as also done in a recent analysis by Die et al. (1988). The analysis presented here is for the management unit encompassing the North Atlantic Fisheries Organization statistical divisions 4VWX, 3NO and 3Ps (Fig. 1), the largest of the two Atlantic halibut stocks thought to occur in Canadian Atlantic waters (Neilson et al. 1987).

METHODS

The model of Ricker (1945) was used for estimating the optimum age of entry into the fishery, as growth and mortality are treated as age-specific. More recently, this technique was also used to support the choice of the 81-cm size limit currently in effect for Pacific halibut (Myhre 1974). The yield, Y, obtained each year from the hypothetical population is:

$$Y_t = 1/2\ N_t W_t [1+\exp^{(-F_t S_t (1-K+KR)-M_t+g_t)}] F_t S_t R$$

where:

N_t is number at age;
W_t is mean weight at age;
F_t is fishing mortality;
M_t is natural mortality;
S_t is the gear selection ratio during t and takes values $0 \leq S_t \leq 1$;
K is the survival rate of released fish (undersized fish returned to the water), and takes values $0 \leq K_t \leq 1$;
R is the retention factor which is 0 if t is less than the age of entry (age corresponding with the minimum size regulation); and
g_t is the instantaneous growth rate during the period t.

As noted by Myhre, the exponential term controls change in population biomass during t, and can be viewed as the "production" term. Removals from the fishery are governed by F_t, S_t, K and R. No yield to the fishery will accrue when R = 0 (minimum size is in effect and undersized fish are caught) but the numbers of fish that remain will decline according to M and K. The total yield expected from a year-class is the sum of the annual yields during its period of vulnerability to the fishery.

A constant initial biomass is assumed although in actuality, recruitment is expected to vary with environmental and fishery-related factors. A fixed selection curve is employed, but with the imposition of a size limit, fishermen might be expected to shift their fishing grounds to avoid concentrations of small fish. Retention is also assumed to be "knife-edged."

Length-frequency and age information (N = 3008) obtained from sampling the commercial fishery throughout the management unit (including the Grand Bank and St. Pierre Bank off Newfoundland and the Scotian Shelf) were used to derive estimates of catch-at-age and mean length-at-age. A length-weight relationship (Bowering 1986) was used to calculate mean weight at age. Such values were judged to be accurately estimated for ages 4-12 inclusive. However, for age 3 and 13 onward, insufficient data were available and it was necessary to fit a von Bertalanffy growth curve to the available data, and extrapolate. The von Bertalanffy equation was:

$$l_t = 201.5(1-e^{-0.0852026(t-0.640041)}).$$

In the absence of data pertaining to size selection for the Atlantic longline fishery, it was assumed that comparable Pacific coast longline fishery data were applicable. Such an assumption seemed reasonable as a first approximation given the congeneric status of both forms and the similarity of the gear employed. However, Pacific halibut appear to grow in length faster than Atlantic halibut (Fig. 2), hence the Pacific halibut selection factors were lagged by 1 year. Based on an exchange of otoliths between age readers responsible for the Pacific and Atlantic age determinations, such differences at age did not appear to be due to differences in techniques. The generation of the selection ratios for the

Atlantic coast otter trawl fishery was based on evaluation of the proportion of fish at age taken in the longline and otter trawl fisheries (Fig. 3). Typically, the proportion of younger fish taken by otter trawl gear was greater than that taken by longline gear. In view of the uncertainty regarding gear size selection, two scenarios were developed. In both cases, selection by the otter trawl gear was taken as the ratio of proportion of numbers caught at age in otter trawl:longline multiplied by the longline selection ratio, and gave values 0.113 at age 3, 0.227 at age 4, 0.331 at age 5, 0.464 at age 6, 0.654 at age 7 and 0.876 at age 8. However, the first scenario assumed that selection was 1.0 at age 9 and thereafter (flat-topped). In the second, the ratios were calculated by the ratio method throughout the range of exploited ages, as done for ages 3 through 8 described above. This method yielded a roughly dome-shaped curve, a result also found in Pacific halibut studies (Myhre 1969). Based on examination of Fig. 3, we concluded that the period of vulnerability to the fishery was from ages 3-12 inclusive. However, to examine the sensitivity of our conclusions with regard to period of vulnerability, we also included a second scenario wherein fish were exploited from ages 3-20 inclusive.

To reflect the mixed gear nature of the fishery, a composite value of K (0.658, approximate 95% confidence interval was 0.472-0.843) was determined using the longline and otter trawl values, weighted by the proportion of catch by the gear types over 1985-87. The analyses were completed using a range of F's and M's of 0.1 and 0.175. The latter value of M was also chosen by Myhre (1974).

Value data were obtained by multiplying the mean weight at age by the conversion to gutted head-on weight (0.85). These values were grouped by market category (1-7 lb = "snapper," 7-12 lb = "chicken," 12-60 lb = "medium," 60-125 lb = "large," >125 lb = "whale") and multiplied by the mean monthly value noted in 1987, weighted by the relative contribution of each monthly landings to the total landings by market category. In this fashion, the effect of including relatively extreme values often associated with short-term variations in supply was reduced. The resulting values per pound were as follows: snapper: $2.04, chicken: $2.19, medium: $3.59, large: $3.02, whale: $2.50.

RESULTS

An example of a typical result obtained in the yield per recruit analyses is given in Fig. 4, which shows the response surface for the model when K=0.658 and M=0.1. In that instance, yield is maximized at an F of 0.2 and an age of entry to the fishery of 6 years. With increasing fishing mortality and age, yields decrease markedly.

In general, repeated analyses similar to Fig. 4 indicated that results were sensitive to the choice of M, the range of ages assumed to be exploited and the shape of the selection curve. Therefore, several scenarios involving a range of the above variables were considered and the percent increase/decrease in yield per recruit of the population is summarized below. For illustrative purposes, the fishing mortality is taken to be 0.3. The age of entry (age corresponding to the length of the minimum size now in effect) is 8 years.

Scenario	% increase(+)/decrease(-)
M=0.1, ages 3-20, flat-top selection	+5.9
M=0.1, ages 3-20, domed selection	+5.0
M=0.1, ages 3-12, flat-top selection	-5.8
M=0.1, ages 3-12, domed selection	-4.5
M=0.175, ages 3-20, flat-top selection	-9.0
M=0.175, ages 3-20, domed selection	-7.9
M=0.175, ages 3-12, flat-top selection	-17.8
M=0.175, ages 3.12, domed selection	-15.7

If the desired effect of a minimum size regulation was increased yield, such an effect would be most pronounced if M were comparatively low and older fish were available to the fishery. Hence, under all but the most extreme of scenarios illustrated above, the imposition of the minimum size limit leads to reduced yield per recruit. However, if the value vector is included in the model, somewhat different results are obtained (Fig. 5). The figure shows both value and yield at a fishing mortality of 0.3, and illustrates the effect of varying natural mortality. However, under the scenario of M=0.1, yield is roughly stable through ages of entry of 4 through 8, but value is increasing up until age 7. Under the scenario of M=0.175, yield declines from age 4, yet value increases until age 7.

DISCUSSION

Referring to the text table given in the Results, increased yield per recruit resulted from the imposition of the minimum size limit in only two of the eight scenarios. To obtain those benefits, it was necessary to assume a comparatively low M of 0.1. In comparison, the International Pacific Halibut Commission used 0.175 in a similar analysis (Myhre 1974). Hence, it seems unlikely that the imposition of a minimum size regulation will result in increased fishery yield per recruit. Similar results were obtained for other plausible values of F. This result is due to the comparatively long period that halibut are vulnerable to exploitation; a released fish may be removed by natural mortality before it is again harvested.

Figure 4 shows the interrelationship of fishing mortality and age at entry on fishery yield. The effect of varying age at entry seems to be of secondary importance relative to fishing effort, as indicated by the repidly decreasing slope along the fishing mortality axis after F = 0.2, compared with the relatively flat surfaces along the axis of age at entry.

However, the reflection of the changing value of the landings resulting from a change in market size composition gives a different impression of the utility of the size regulation (Fig. 5). While yield is either stable or declining up until the current age of entry to the fishery, value is close to its maximum in both situations. The value analysis, therefore, illustrates the potential danger in relying solely on the traditional measure of biomass as an indicator of the utility of the management measure. The figure also demonstrates how sensitive the model is to choice of the rate of natural mortality. Unfortunately, as is the case for most other exploited fish populations, the rate of natural mortality is poorly defined.

A limitation of the analyses presented here is that only a deterministic view of the model is provided. Recent advances in the application of yield per recruit modeling have explicitly included parameter uncertainty (Restrepo and Fox 1988). An example of the uncertainty present in our analyses is that Neilson et al. (in press) indicated a K of 0.35 and 0.77 for bottom-trawl caught and longline-caught halibut. An approximate 95% confidence interval based on the binomial distribution would be 0.287-0.420 and 0.540-1.0, respectively. Furthermore, a more realistic approach might include scope for variation in K with length, as Neilson et al. (in press) have indicatred that those factors do indeed covary. Another improvement to the model would be the inclusion of cost information, as suggested by Die et al. (1988). However, given the number of assumptions already implicit in the analyses, the data were not deemed adequate to warrant such refinements to the model at present.

As noted by Ricker (1945), optimization of a fishery based on yield per recruit considerations alone is only part of a rational scheme for management. Even when value considerations are included, there are other factors to consider. One important consideration is what effect a change in number of spawners would have on the abundance of recruits, and how such changes would affect the rate of growth of the stock. In the case of the Atlantic halibut fishery, such data are not available at present.

ACKNOWLEDGMENTS

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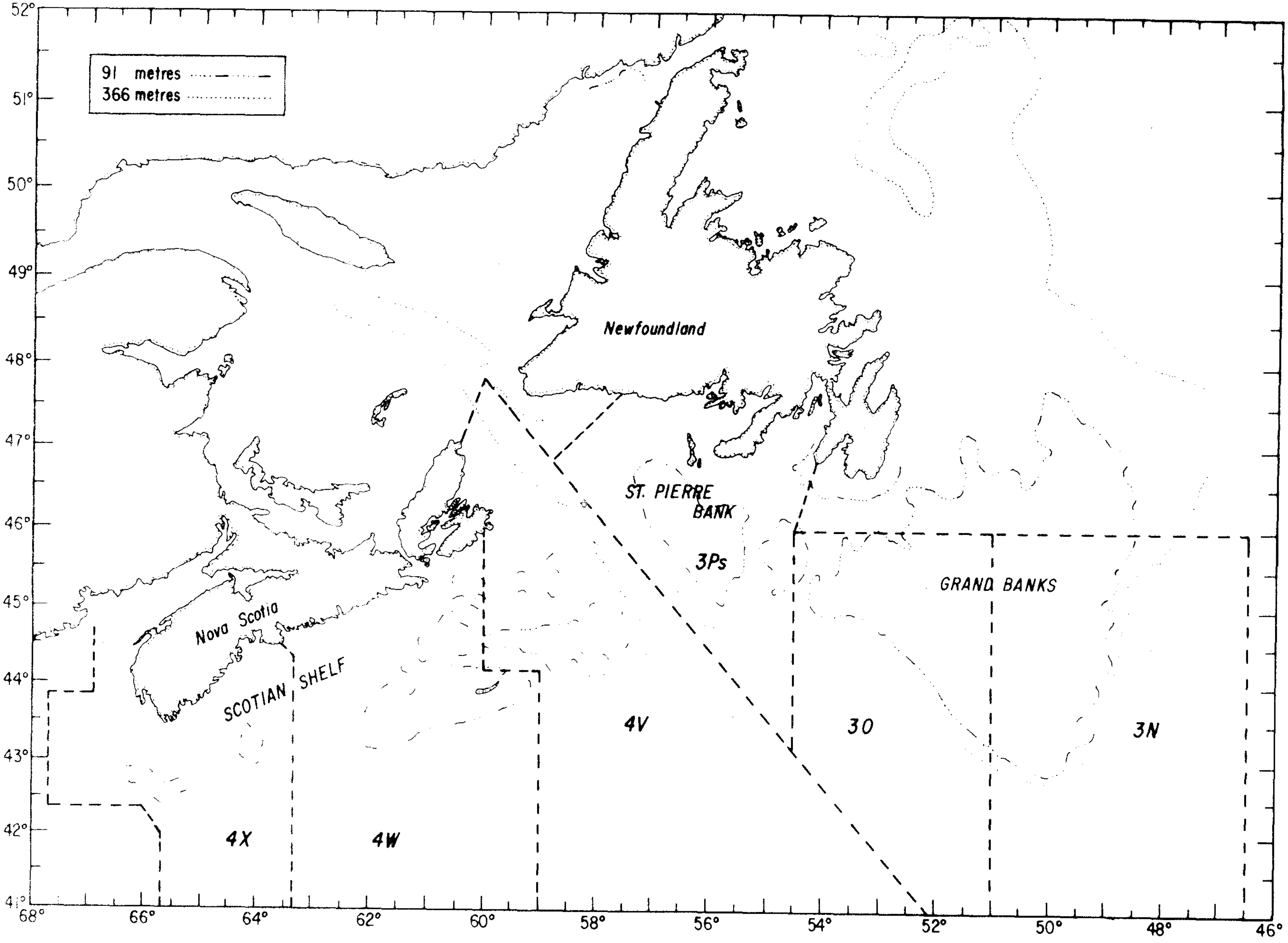

Fig. 1. The coast of Atlantic Canada, showing the North Atlantic Fisheries Organization Statistical Boundaries and the bathymetric features referred to in the text.

Fig. 2. Comparison of length (fork length) at age of Atlantic and Pacific halibut. Atlantic data were from Canada Department of Fisheries and Oceans collections made in the management area from 1986-1987. The Pacific data are from Myhre (1974).

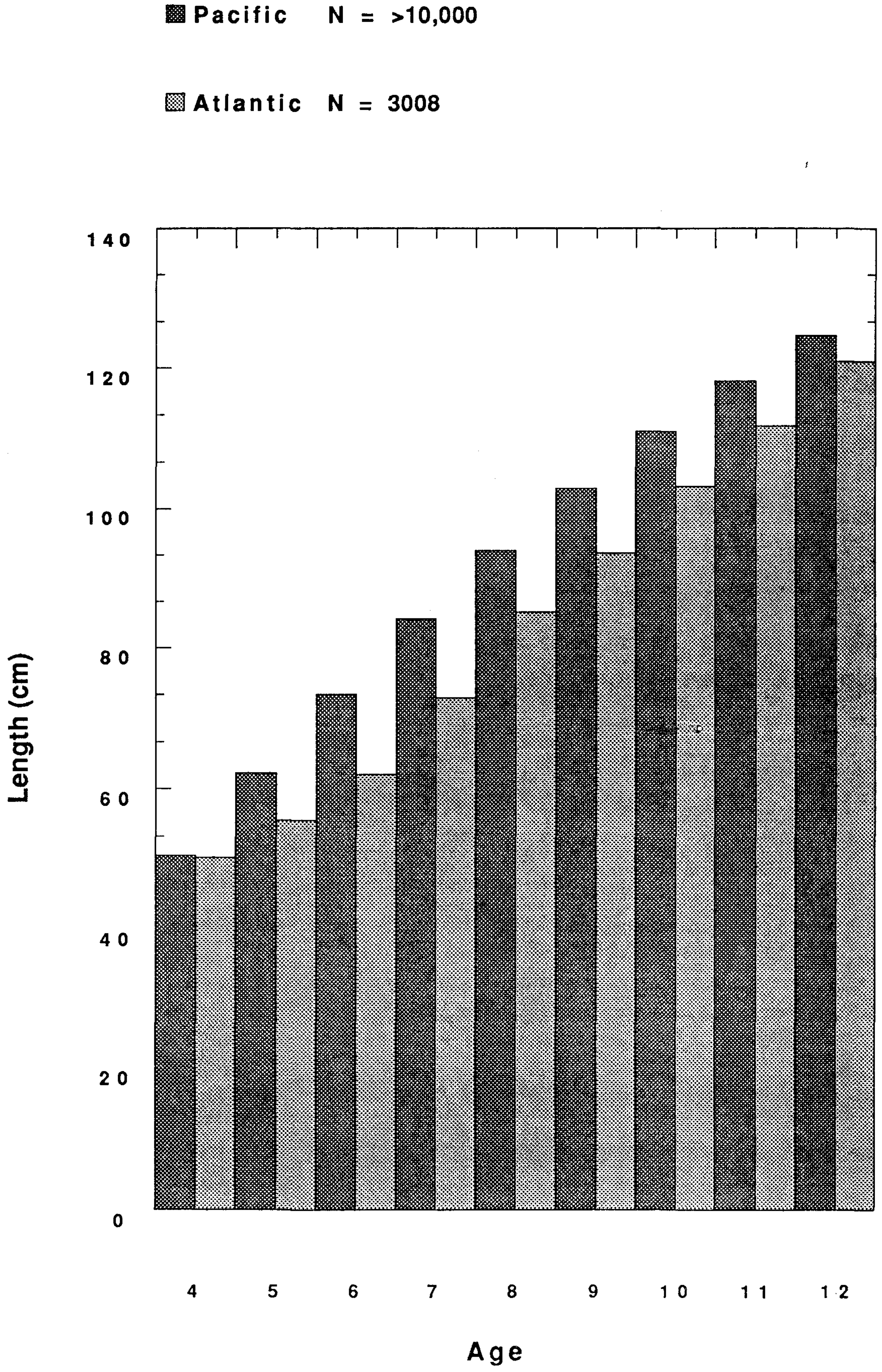

Fig. 3. Selection curves for otter trawl and longline-caught Atlantic halibut. See text for explanation of the derivation of the curves.