PART 5: CONCEPTUAL/ANALYTICAL BASIS FOR PLAN DEVELOPMENT

§5.1 Conceptual Guidance

The policy statement, articulated by the Council as the overall management philosophy for the multispecies fishery, is concerned with promoting the continuation of sufficient spawning potential to preserve the multispecies character of the resource. One of the major strengths of the New England multi-species fishery is the diversity of important species which comprise the resource. The task of fishery management is to preserve that mixture of species at sufficient abundances possessing an adequate reproductive potential such that the capacity of the resource to recover from unfavorable circumstances may not be jeopardized. A responsive pursuit of that task may be expected to result in a long-term average optimum yield from the fishery which approaches, to the extent possible within the context of the multispecies character of the fishery, the maximum sustainable yield. It should be recognized, however, that the multispecies nature of the fishery may impose the necessity to manage certain minor components of the resource at less than optimal conditions in favor of the more economically important species.

Management efforts intended to assure sufficient spawning potential within the multispecies resource by preserving an adequate spawning stock are mediated through appropriate adjustment of the age at entry to the fishery and the fishing mortality rate. It is inappropriate to judge the adequacy of current or projected levels of spawning stock on the basis of a comparison with previously established minimum spawning stock constraints. The definition of a minimum acceptable spawning stock biomass may depend upon the long-range goals of management and the degree to which future stock sizes may be expected to be influenced by the management program designed to achieve those goals. Although the concept of a minimum acceptable spawning stock size may appear valid when viewed in the context of the management objective it may also be a conceptual trap which demands a wealth of largely unavailable information for proper evaluation. The imprecise nature of the stock-recruitment relationship among marine species demands a long-term view of that relationship in any application to fishery management. The very existence, however, of specified minimum stock size constraints may obligate fishery managers to adhere to those constraints on an annual basis, but such may incur unnecessary costs to the fishing industry.

The spawning potential of a stock of fish may be most appropriately assessed on the basis of the total fecundity of that stock under the prevailing conditions of mortality and age structure. Such a calculation is a relatively straight-forward biological problem. The maximum possible spawning potential is obviously embodied within the virgin stock (ie., the stock which existed prior to any fishing). Spawning potential should not be confused with recruitment. Recruitment is a highly variable parameter, but on the average, tends to be maximized at some intermediate stock level.

To maintain a constant stock size in the virgin condition, the required level of recruitment need only be high enough to replace individuals lost from natural mortality. With the introduction of additional mortality from fishing, more recruits are needed to replace total losses. But, at any constant level of fishing mortality, the stock size tends to stabilize at a lower level, relative to the virgin condition, since the stock can only partially compensate for the additional mortality.

As fishing mortality incrementally increases, the stock size will tend to stabilize at successively lower levels. But, with such a trend, the total fecundity of the stock becomes more and more concentrated in the younger age groups. Thus total fecundity (and subsequent average recruitment) is increasingly dependent upon the strength of recently recruiting year classes. Under all conditions, recruitment may be expected to exhibit fluctuations, but continued increases in fishing mortality will tend to reinforce that variability, finally leading to an unstable situation which jeopardizes the capacity of the stock to quickly recover from unfavorable circumstances.

§5.2 Current Stock Biomass

Two major considerations for guiding the design of the management program for econmically important species within the multi-species complex are the current status of the spawning stocks and the current trends in the stock sizes (i.e., whether the stocks are increasing, decreasing, or stable due to recent recruitment.

Graphic presentation of information concerning the current condition of important stocks appears in Figures 5.1-5.3. The individual bar graphs represent the range in the relative total stock size, by species, based upon a variety of assessment information typically spanning a period of about 20 years. The "preferred zone" delimits the range, with the year of observation, when the stock was not exhibiting obvious symptoms of recruitment overfishing. Relative total stock sizes at lesser levels have been variously categorized, "warning zone" or "danger zone" to denote zones of risk with respect to recruitment overfishing. Superimposed on each bar graph is a symbol indicating the current estimated total stock level which also depicts the current trend which is expected in the immediate future.

A variety of stock assessment data form the basis for Figures 5.1-5.3, ranging from relative abundance indices derived from research vessel survey results to fully developed stock assessments based upon virtual population analysis. Where a significant wealth of information is available relating stock and recruitment, such as in the case of haddock, a more precise definition of zones of risk is possible. In other cases, such as gray sole (witch flounder), the "preferred zone" simply represents the range of relative stock sizes which have been observed in the historic fishery. Any stock size at a lower level has been arbitrarily designated, "warning zone".

The following is a brief discussion of stock parameters for those species where assessment information is available and which have been illustrated in Figures 5.1-5.3. We may remind the reader that pertinent data were presented in Table 2A6.

As shown in Figure 5.1, the abundance of the Gulf of Maine cod stock is currently stabilized at near the highest level seen (1964) in the historic fishery. Similarily, the Georges Bank cod stock (Figure 5.2) is stabilized at a level only slightly less than was seen in 1978. In spite of high levels of fishing mortality (which is a source of concern since Fs currently range 0.6-0.8, substantially higher than F-max), all US stocks of cod appear to be very healthy as a result of a succession of good recruiting year classes, probably as a consequence of favorable environmental factors.

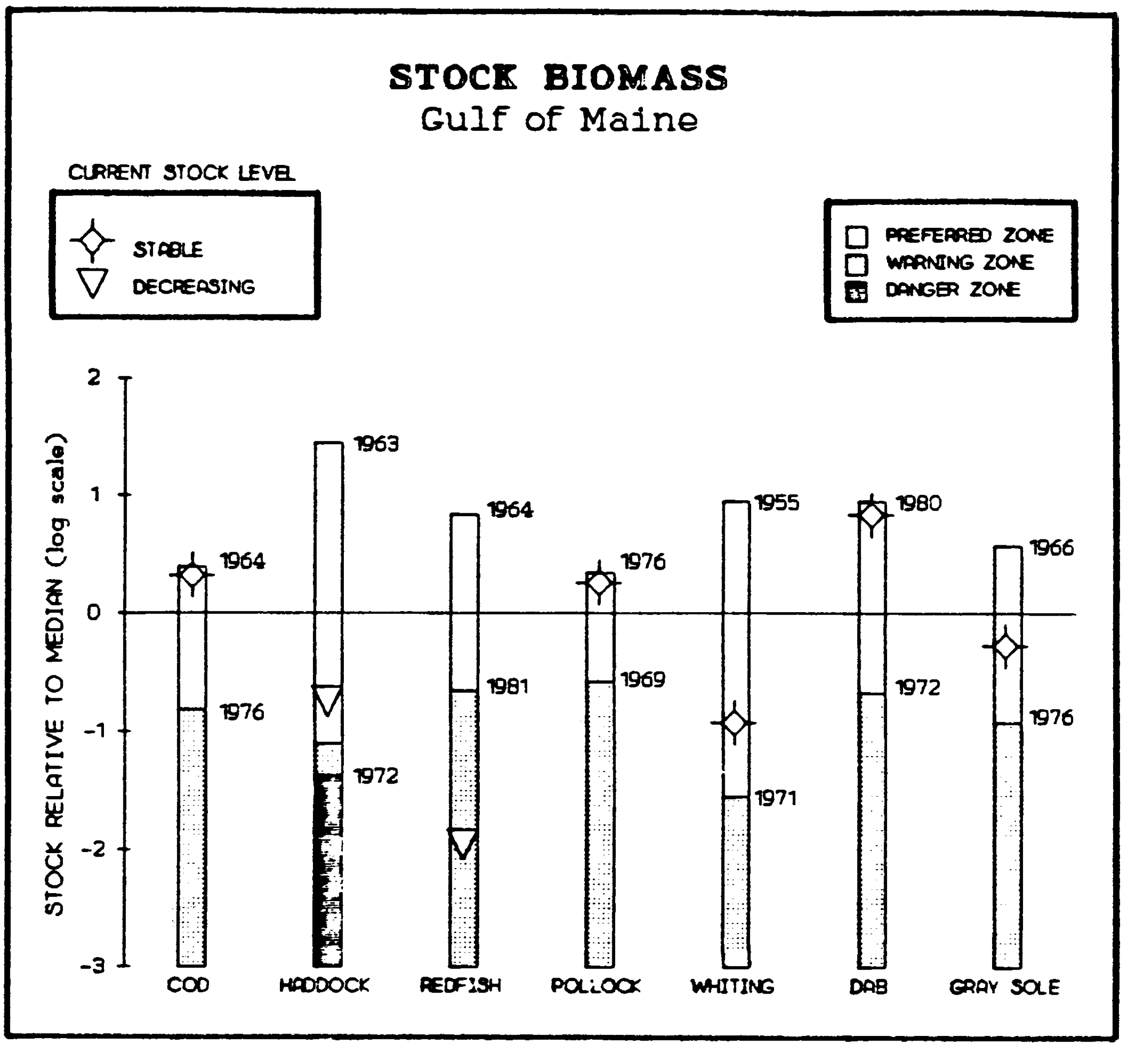


Figure 5.1. Total relative stock biomass for selected Gulf of Maine species. Histograms depict the range about the median preferred total stock biomass with the year of observation for the highest and lowest level seen - ie., the "preferred zone". Lower levels of stock size are depicted as either a "warning zone" or, where sufficient stock-recruit data are available, as a "danger zone" where there exists the risk of recruitment overfishing. The current stock level, together with an indication of whether it is increasing, decreasing, or presently stabilized, is superimposed on each histogram. Note that the vertical axis is a logarithmic scale.

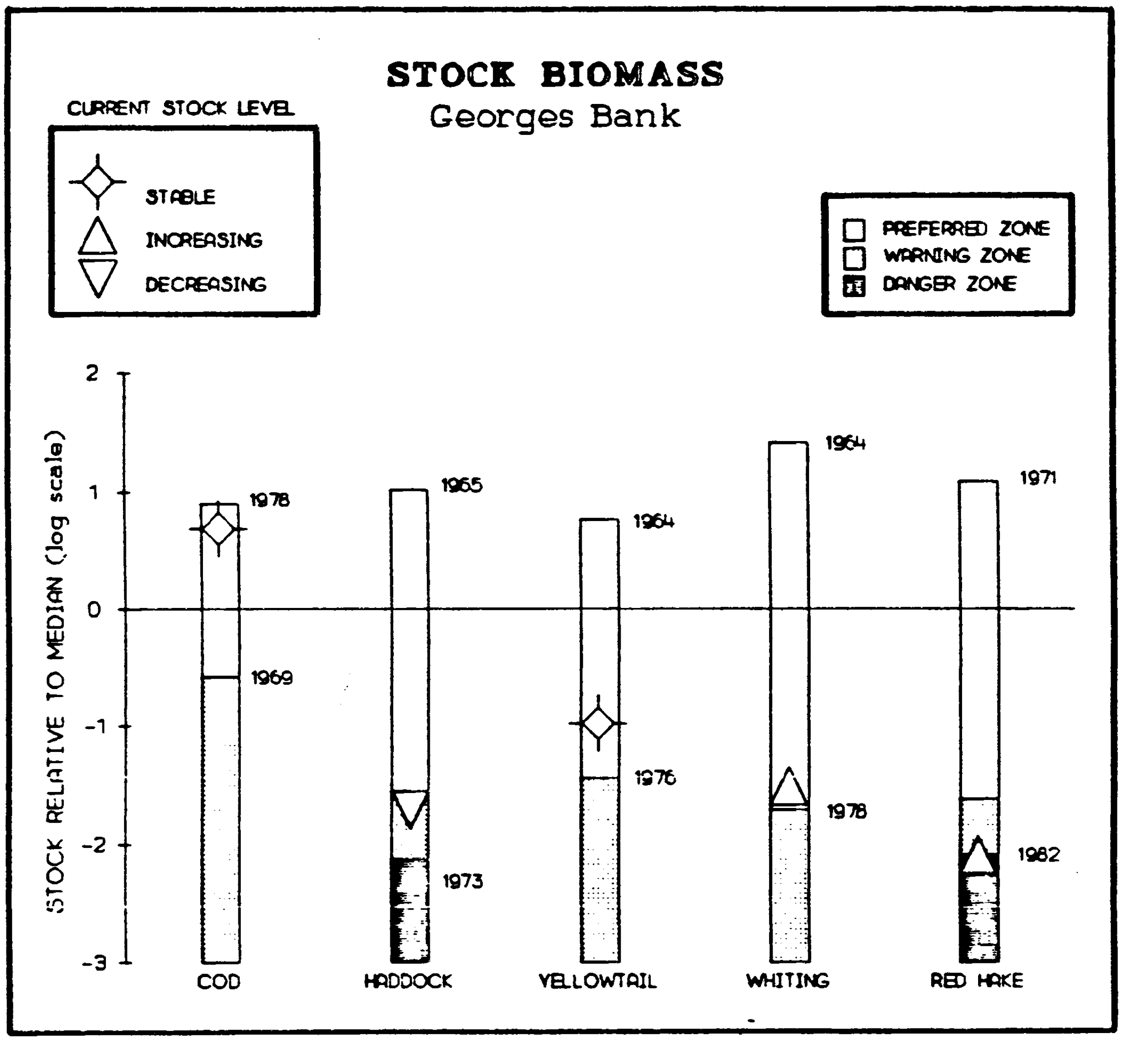


Figure 5.2. Total relative stock biomass for selected Georges Bank species. Explanation same as for Figure 5.1.

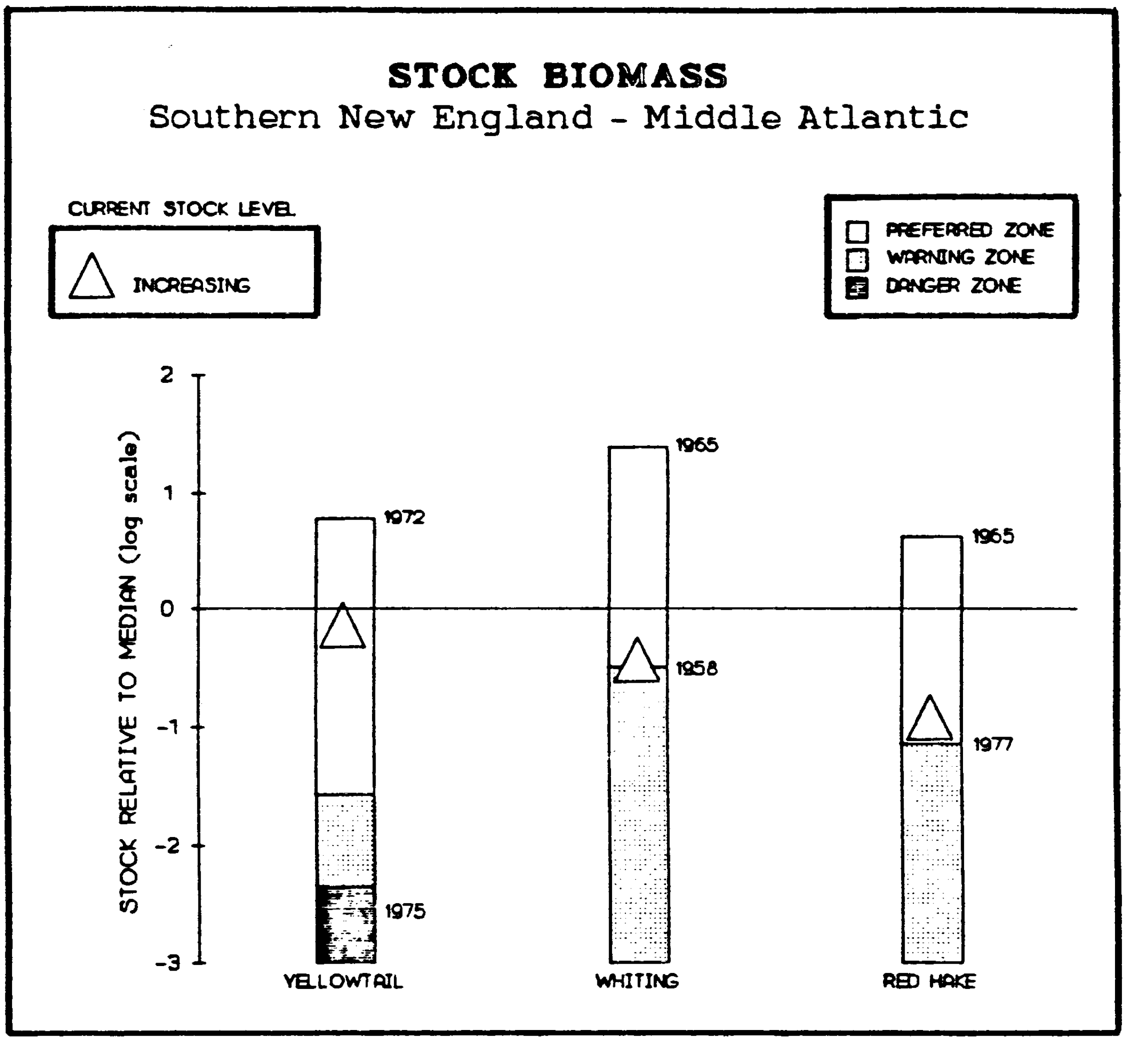


Figure 5.3. Total relative stock biomass for selected Southern New England - Middle Atlantic species. Explanation same as for Figure 5.1.

By contrast, all US stocks of haddock are currently in decline. The Gulf of Maine haddock stock size (Figure 5.1) is currently approaching a level which may incur the risk of recruitment overfishing, particularily with further increases in the fishing mortality which is already too high (higher than F-max). The current level of the Georges Bank haddock stock (Figure 5.2) is also low and continues to decline as a result of insignificant recruitment and high fishing mortality rates. In the short-term, the efficacy of any management action intended to rebuild the Georges Bank stock may be problematic. In the long-term, stock rebuilding will probably be contingent upon the appearance of extraordinarily strong recruitment, an event which has occurred in the past about once in every decade. Given the appearance of strong recruiting year classes, an effective strategy of stock rebuilding should include sharp reductions in mortality of juvenile fish relative to that which was imposed in past such events (for example, the 1975 and 1978 year classes). The probability that future, strong recruiting year classes may occur could be enhanced by conserving the residual spawning stock which still remains.

The Gulf of Maine redfish stock (Figure 5.1) is currently in a seriously depressed condition and is continuing to decline. In contrast to the other economically important species which broadcast millions of eggs into the water column at each spawning beginning at age 2 or 3, redfish require 7-9 years to reach sexual maturity and bear a limited number of their young alive, liberating them as larvae. With such physiological limitations on overall fecundity, the redfish stocks may be expected to require a protracted period of time to rebuild. Moreover, juvenile redfish typically migrate to more shoal waters incurring significant mortality as by-catch in the small mesh shrimp and whiting fisheries.

The 4VWX/SA-5 pollock stock (Figure 5.1) is currently in a very healthy condition by virtue of recruitment from a series of strong year classes (1975, 1976, and 1979) together with fishing mortality rates substantially below F-max, and may be expected to register future increases with growth of fish in the 1979 year class. With the prevailing low fishing mortality rates, a substantial proportion of the total stock reaches sexual maturity under the current mesh sizes used in the fishery. The current and projected state of health of the pollock stock suggests that it may be able to support a modest transfer of fishing effort from currently depressed stocks of other species.

Stocks of whiting in the Gulf of Maine (Figure 5.1), Georges Bank (Figure 5.2), and Southern New England - Middle Atlantic (Figure 5.3) are all near the lower range of historic fluctuations but generally appear to be slowly rebuilding. With current levels of fishing mortality uniformly below the F-0.1 index, it is likely that factors other than the directed fishery may be responsible for the low recruitment indices seen in recent years. For example, it is possible that discarding of juvenile whiting in the Western Gulf of Maine shrimp fishery may have contributed to the relatively depressed condition of the Gulf of Maine whiting stock. Also, the influence of unfavorable environmental conditions should not be discounted.

Among the true hakes, assessment information is available only for red hake. Although registering recent modest increases in stock size, red hake, particularily on Georges Bank (Figure 5.2), is currently exhibiting low stock levels. Despite low levels of fishing mortality, a wide range of age classes in the population, and no apparent significant discarding in the commercial fishery, red hake stocks remain in a depressed condition. It has been suggested that predator-prey interactions may have retarded red hake stock rebuilding following their decimation by the pulse fishing activity of the distant water fleets in the 1960's and early 1970's.

The Georges Bank stock of yellowtail flounder is currently stabilized near the lower range of the historic fluctuations (Figure 5.2), whereas the Southern New England - Middle Atlantic stock (Figure 5.3) is near the long-term median level and is currently exhibiting an increasing trend. Fishing mortality rates, particularily on Georges Bank, for fully recruited fish are in excess of F-max. Mortality among prerecruits through discarding, which may reach substantial proportions with the appearance of strong recruitment (as in the case of the 1980 year class), suggests the need for measures to augment the current mesh size regime. Although the historic record indicates that recruitment is strongly influenced by long-term cycles in water temperature, stability of the fishery could be enhanced by increasing the number of age classes in the population through reductions in mortality from fishing, including discard mortality.

The Gulf of Maine (Figure 5.1) and Georges Bank stocks of American plaice (dab) have benefited from a succession of strong recruiting year classes since the mid-1970's such that current stock sizes are at near record levels. No information exists with respect to fishing mortality rates, but the current mesh size regime appears to be appropriate in consideration of the size (and age) at sexual maturity.

Assessment information for witch flounder (gray sole) indicates that while the stocks are currently in good condition at near the median level (Figure 5.1), the potential exists for declines in abundance in the absence of remedial management action. The recent increased trend in landings to 5-6,000 mt is probably not sustainable in light of events in the historic fishery, particularily in the context of the probable existence of significant discards of juveniles in the small mesh shrimp and whiting fisheries.

§5.3 Stock and Recruitment

Among the population characteristics affecting reproduction and recruitment, abundance of mature spawners is often of sufficient importance to be of value for analysis and prediction. It has already been pointed out that a clear biological relationship exists between the reproductive potential as measured by total fecundity and the number of mature spawners. However, the translation of total fecundity into the number of recruits (ie., net reproduction) on an annual basis is not a straight-forward relationship since year to year differences in environmental characteristics usually cause fluctuations at least as great as those which may be associated with variations in stock size. Sometimes these fluctuations show significant correlations with one or more measured environmental variables (eg., yellowtail flounder, Sissenwine, 1974). Cannibalism of young by adults of the same species may occur in many cases, but the likely effect of parental stock density upon recruitment is probably exerted via the density of the eggs and/or larvae they produce. Survival of the latter is affected by density-dependent competition for food or space, compensatory predation, and density-independent effects (Ricker, 1975). (See §2A3 and §2A5 for additional discussion.)

A graph relating the spawning stock size to subsequent recruitment typically exhibits substantial dispersion of the data because of environmental effects. Consequently, attempts have been made to work out possible interactions between adults and their progeny, deducing average curves describing that interaction. The two most commonly used mathematical models were developed by Ricker and, alternatively, by Beverton and Holt (1957) (see Ricker, 1975). A substantial amount of information exists for some of the more important species within the multi-species complex. However, no attempt will be made to fit these data to such models. It is sufficient for the development of the management program to evaluate the data on the basis of broadly defined zones of risk to aid in establishment of appropriate levels of spawning potential such that the capacity of the resource to recover from unfavorable conditions may not be jeopardized.

Stock-recruitment data for a number of the more important species in the multispecies complex are depicted in Figures 5.4-5.9. Although the data in all cases exhibit considerable scatter, a few general principles are evident. In all cases, recruitment tends to fall towards zero at very low stock levels. In some examples, such as cod, there is an apparent tendency for recruitment to be maximized at some intermediate stock level, not implying that recruitment falls to zero at very high stock sizes. All of the proposed mathematical formulations for describing the stock-recruit relationship assume a curve which begins at the origin, rises rather quickly, but immediately begins to curve downward towards an asymptote such that recruitment never reaches zero at high stock levels. As noted, cod appears to exhibit some sort of dome-shaped distribution which is in accord with characteristics of one or more of the models which have been proposed to describe the relationship. On the other hand, despite the relatively small number of data points, redfish may be tentatively described by a relationship which curves upward over much of the lower range in observed stock sizes. Haddock may exhibit a similar pattern at low stock sizes. Thus, we may conclude that, whereas the commonly used stock-recruit models may be useful in aid of a general understanding of the relationship, their simplicity is inadequate for describing some of the important peculiarities in specific cases.

The stock-recruitment information, as depicted in Figures 5.4-5.9, was examined for the purpose of gaining some insight with respect to that level or range in spawning stock size which, on the basis of the historical perspective, may be expected to generate recruitment levels sufficient to sustain the fishery. For example, in the case of haddock (see Table 5.1) it is seen that when spawning stock sizes were less than 70,000 metric tons, then for 91% of the time, the resulting recruitment was less than 20 million fish at age 2. But when stock sizes were 70,000 tons or greater, recruitment was 20 million fish or higher 34 times out of 40 (85%), and was at least 60 million fish 15 times out of 40 (37% of the time).

The stock-recruit information for the Georges Bank cod stock is not as amenable to this sort of analysis since very few data points are at low stock sizes. The available information suggests, however, the existence of a markedly dome-shaped curve implying the risk of rapid stock collapse at low levels of spawning stock biomass.

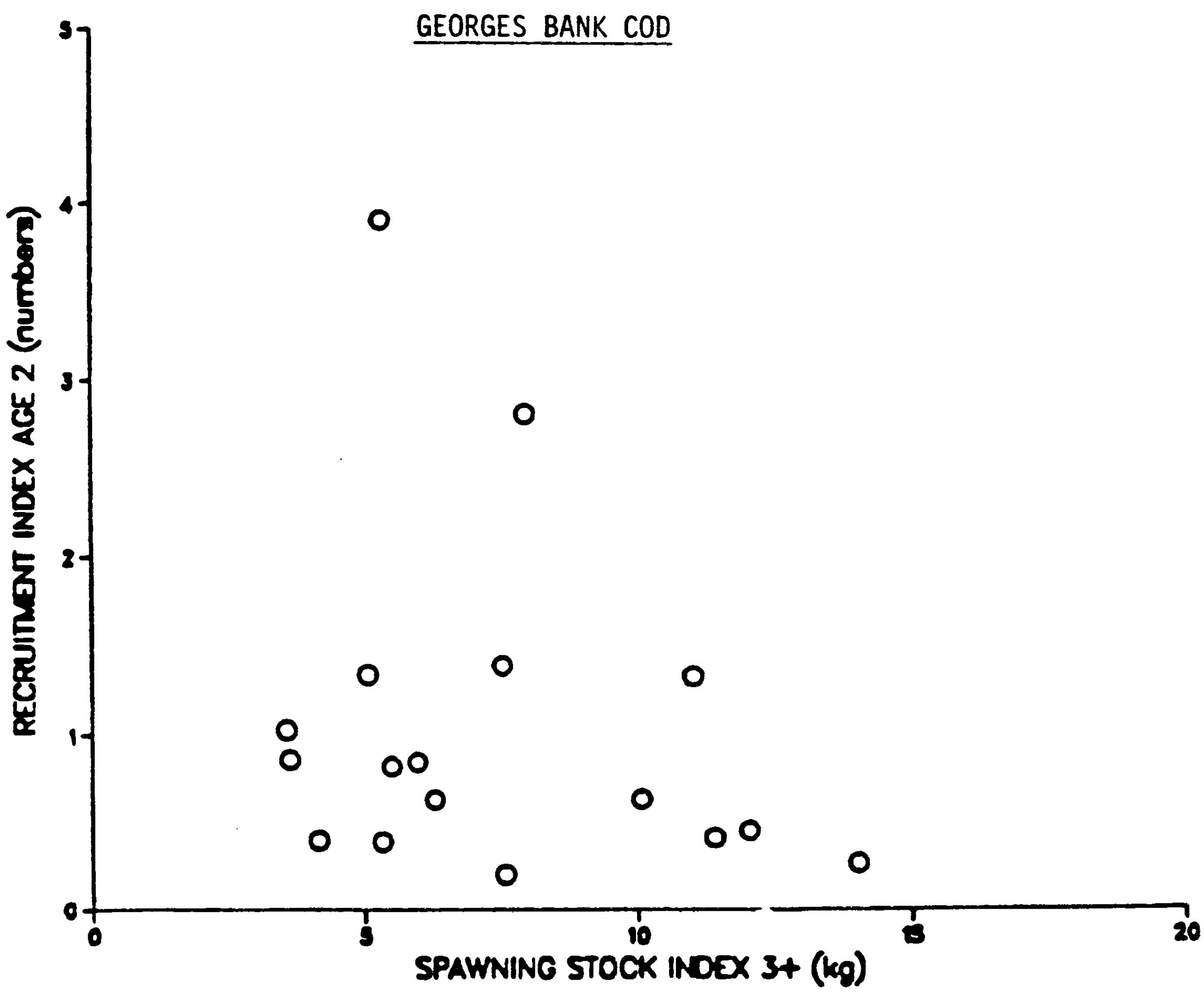


Figure 5.4. Stock-recruitment relationship for Georges Bank cod. Indices of spawning stock size (age 3+) and recruitment (at age 2) are based upon survey data.

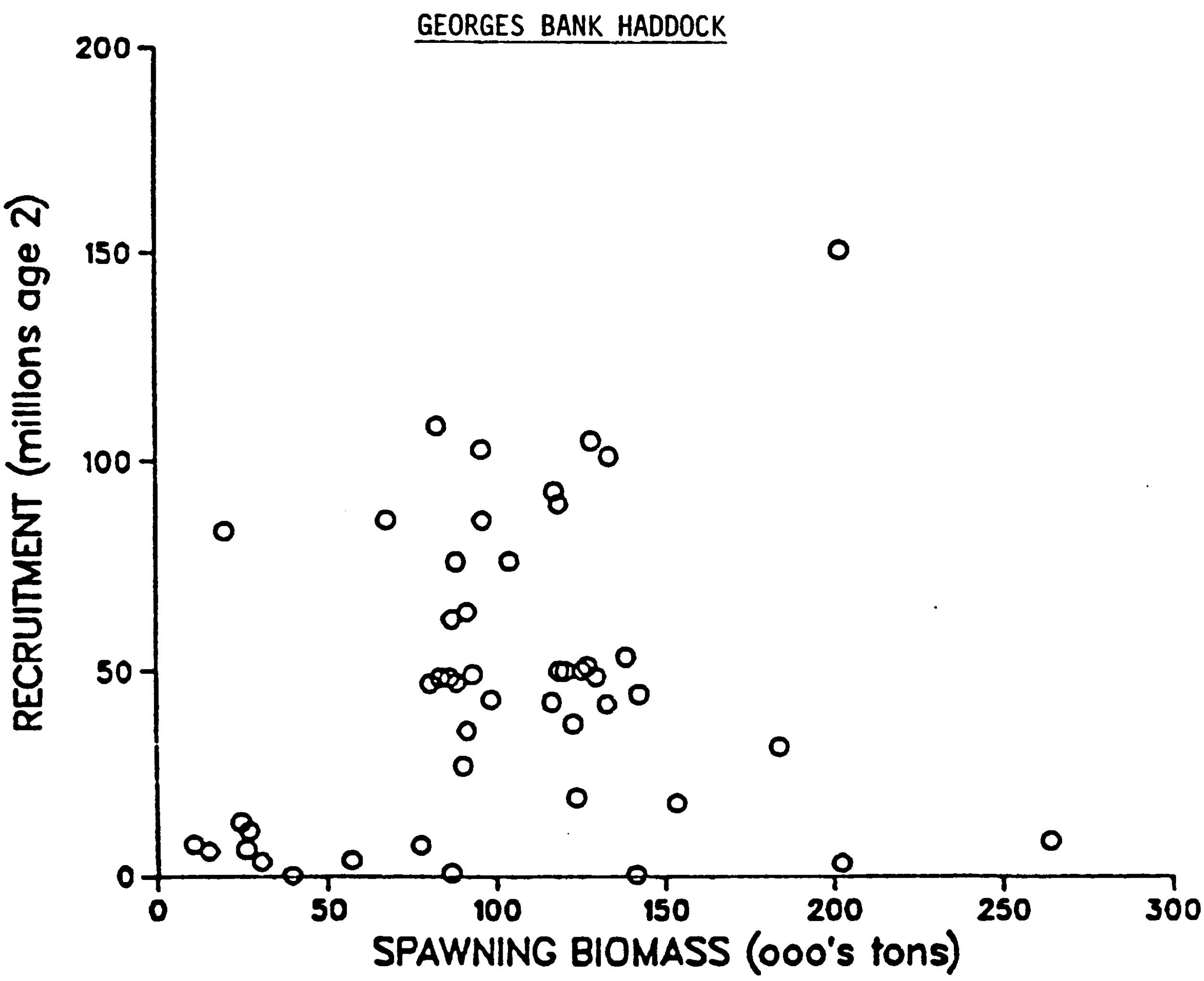


Figure 5.5. Stock-recruitment relationship for Georges Bank haddock. Spawning stock biomass (thousands of metric tons) and subsequent recruitment (millions at age 2) for the period, 1931-1979, based upon VPA. The data point for 1963 (194,700 tons, 368.8 million recruits) is off the scale and has been omitted for clarity.

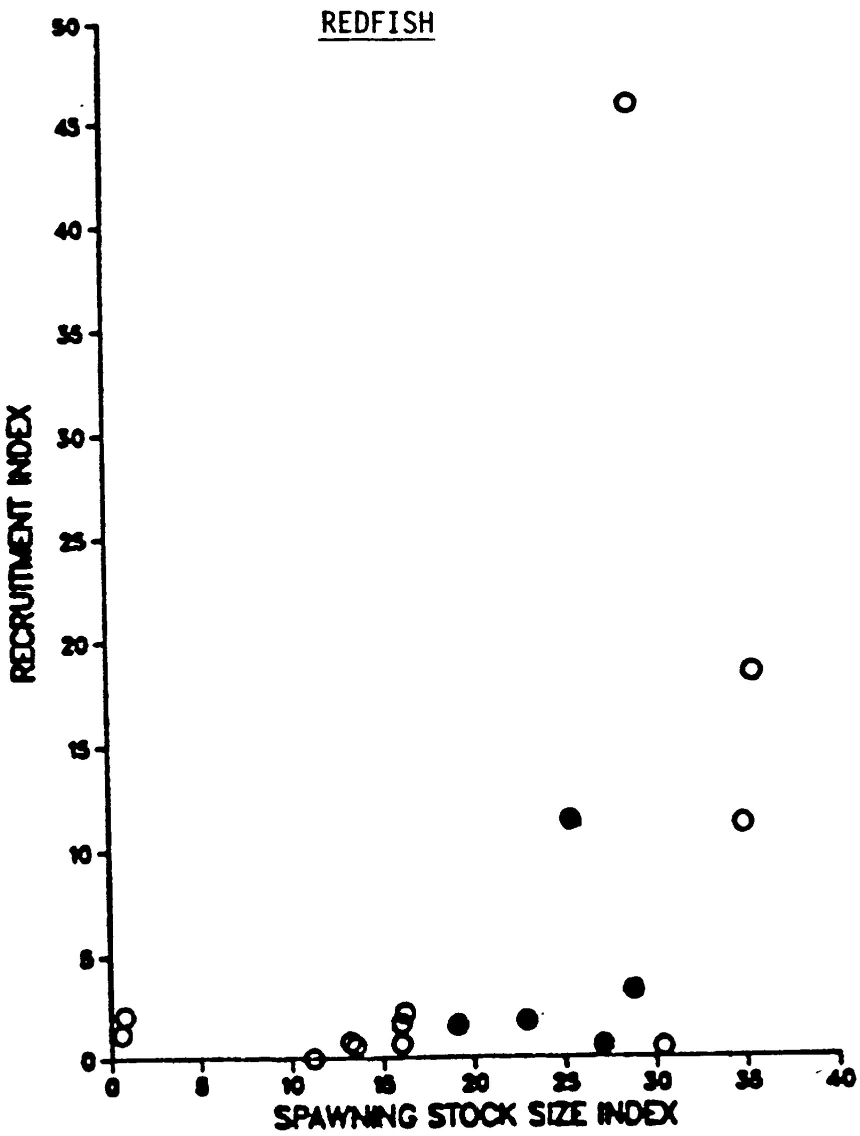


Figure 5.6. Stock-recruitment relationship for Gulf of Maine - Georges Bank redfish. Indices of spawning stock size (age 9+) and recruitment (at age 1) are based upon VPA (solid circles, ●) or linear regression of survey indices on VPA results (open circles, O).

SILVER HAKE

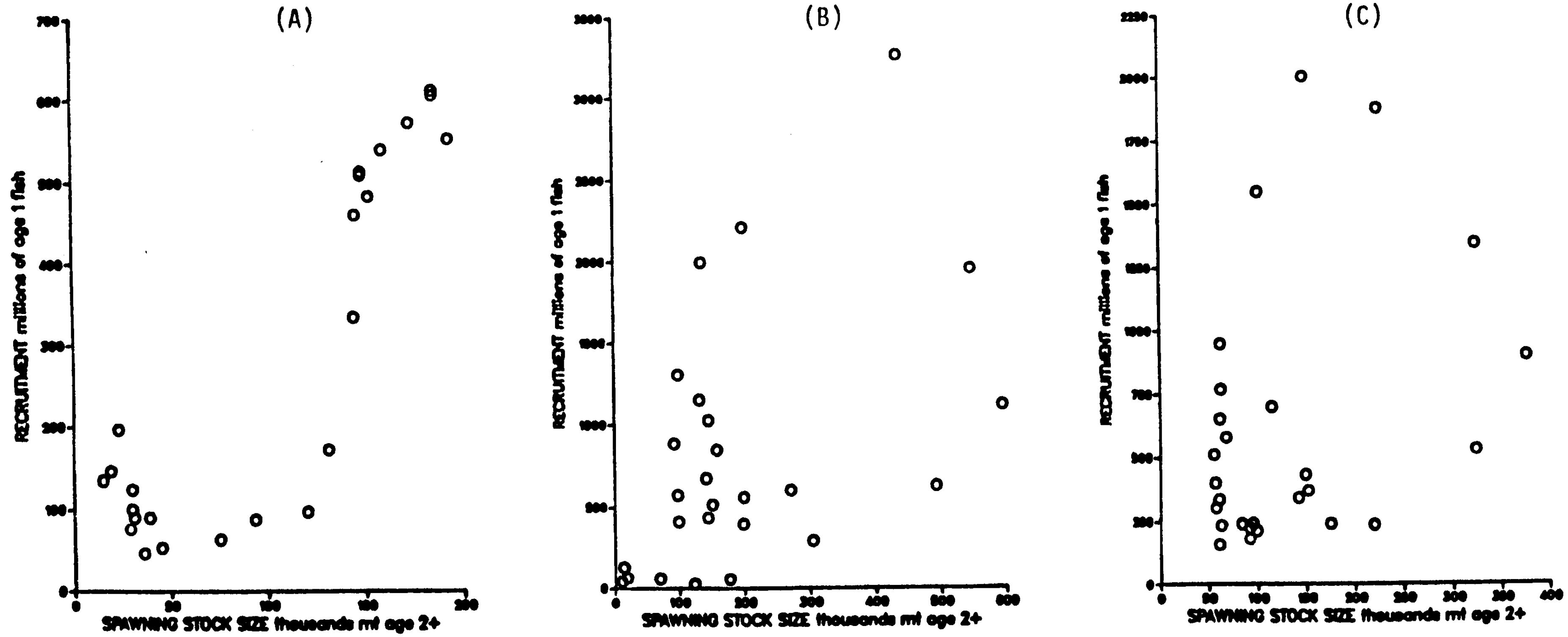


Figure 5.7. Stock-recruitment relationships for whiting (silver hake) by stock; (A) Gulf of Maine, (B) Georges Bank, and (C) Southern New England - Middle Atlantic. Spawning stock size (thousands of metric tons age 2+) and recruits (millions at age 1) are based upon VPA.

RED HAKE

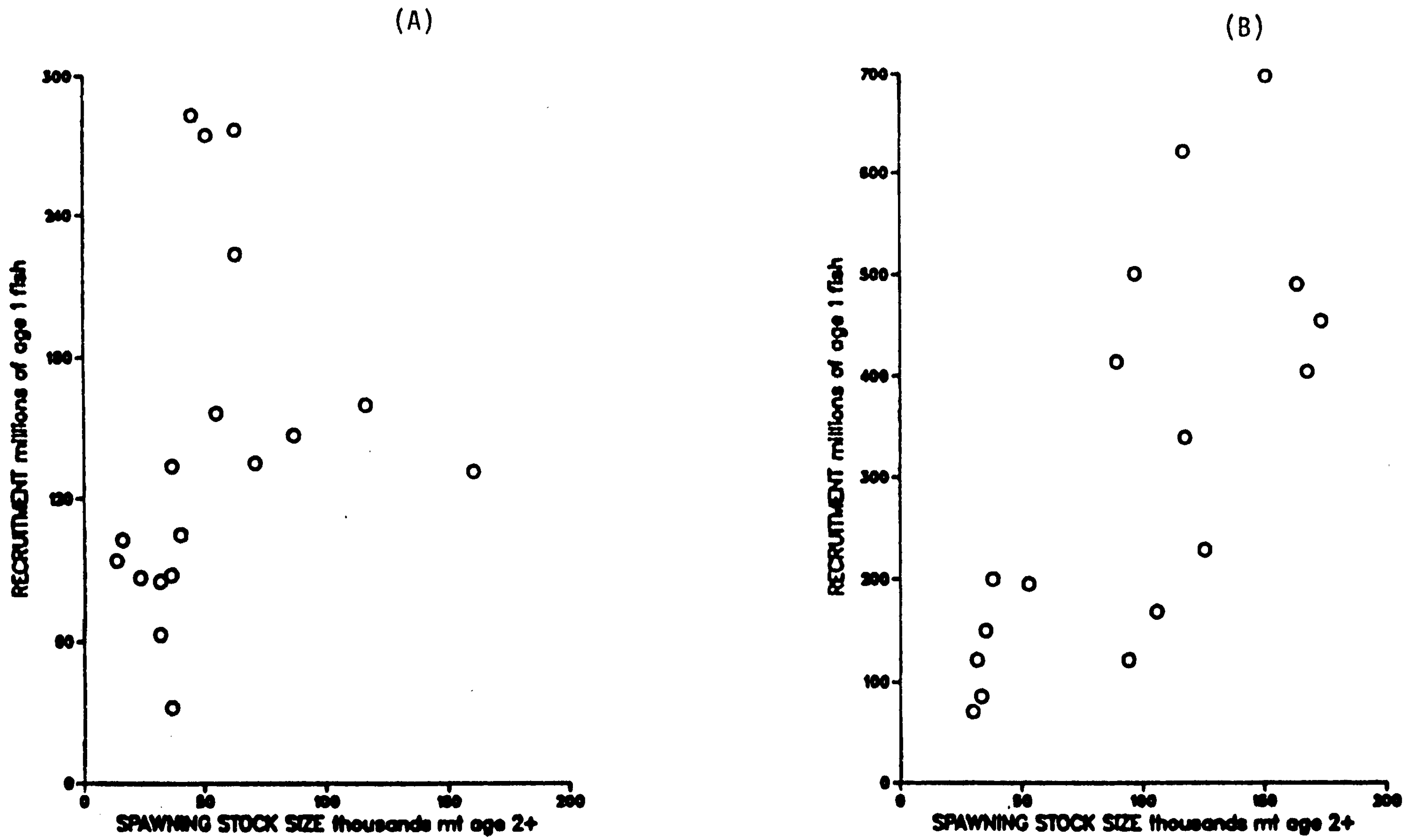


Figure 5.8. Stock-recruitment relationships for red hake by stock; (A) Georges Bank, (B) Southern New England - Middle Atlantic. Spawning stock size (thousands of metric tons age 2+) and recruits (millions at age 1) are based upon VPA.

YELLOWTAIL FLOUNDER

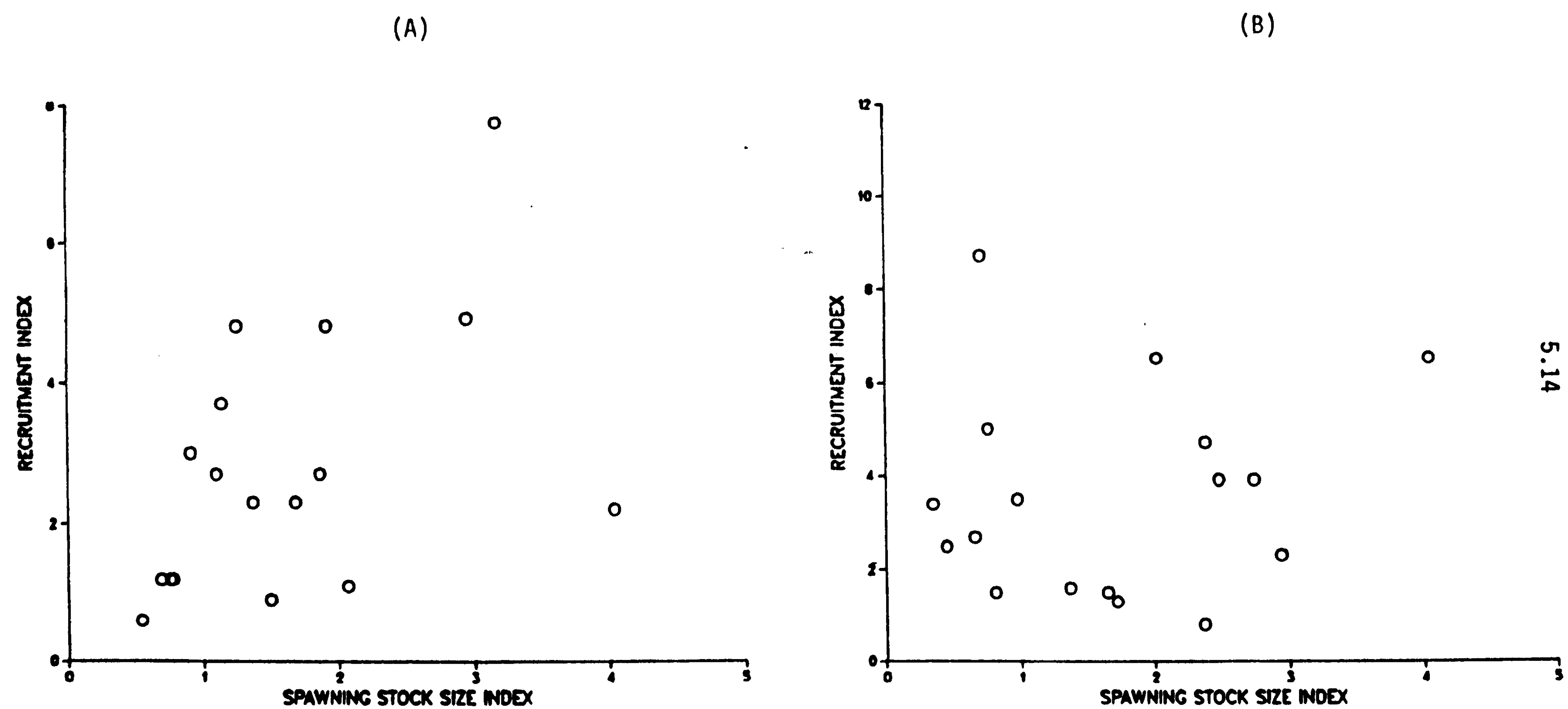


Figure 5.9. Stock-recruitment relationships for yellowtail flounder by stock area; (A) Georges Bank, and (B) Southern New England. Indices of spawning stock size (catch per unit of effort of age 3+ fish) and recruitment (catch per unit of effort of age 2 fish) are based upon commercial catch and effort data.

Gulf of Maine - Georges Bank redfish is another stock identified in §5.2 as currently being in a depressed condition. The available stock-recruit data indicate that at spawning stock sizes less than 200,000 fish, recruitment is uniformly low (less than 10,000 fish at age 1). At stock sizes greater than 200,000 fish, recruitment has exceeded 10,000 fish, 56% of the time, averaging about three times that level.

A stock-recruitment contingency tabulation for stocks of whiting (silver hake) is shown in Table 5.2. Referring to Figure 5.7, it is seen that recruitment has consistently remained relatively low when spawning stocks were at less than 30% of the highest observed level. More variability is evident when spawning stocks were high.

The stock-recruitment relationship for red hake also exhibits relatively low recruitment at stock sizes less than 30% of the highest observed. At spawning stocks less than 45,000 metric tons of age 2+ fish, recruitment to the Georges Bank stock was less than 100 million fish at age 1, 80% of the time. At stock levels greater than 45,000 tons, recruitment was high 100% of the time. In the Southern New England - Middle Atlantic stock, recruitment was always low when stocks were less than 60,000 tons.

Recruitment levels in yellowtail flounder have been shown to be significantly correlated with temperature (Sissenwine, 1974). The stock-recruitment relationships shown in Figure 5.9 (for all years' data combined) are based on commercial CPUE data. The stock-recruitment contingency tabulation for yellowtail shown in Table 5.3 combines indices based upon commercial CPUE and survey catch data, and has been categorized according to whether bottom water temperatures were cooler or warmer than the long-term average. In general, for both the Georges Bank and Southern New England stocks, low stock sizes generate low recruitment and high stock levels generate high recruitment, <u>when water temperatures were higher than average</u>. When water temperatures were cooler than average, there is much less consistency with the usual stock-recruit relationship.

Table 5.1

Stock-recruit contingency table for Georges Bank haddock.

	SPAWNING STOCK1/	
RECRUITMENT2/	LOW (0-70)	HIGH (70+)
Low (less than 20)	91%	15%
Intermediate (20-60)	0%	48%
High (greater than 60)	9%	37%

1/ Spawning stock biomass in thousands of metric tons.

2/ Recruitment in millions of fish at age 2.

Table 5.2

Stock-recruit contingency table for whiting (silver hake) stocks.

	SPAWNING STOCK[1/] LOW	SPAWNING STOCK[1/] HIGH
RECRUITMENT[2/]		
Gulf of Maine	(1-60)	(60+)
Low (1-250)	100%	29%
High (250+)	0%	71%
Georges Bank	(1-180)	(180+)
Low (1-1500)	94%	56%
High (1500+)	6%	44%
So. New England/Mid-Atlantic	(1-140)	(140+)
Low (1-800)	88%	60%
High (800+)	12%	40%

1/ Spawning stock biomass in thousands of metric tons age 2+.

2/ Recruitment in millions of fish at age 1.

Table 5.3

Stock-recruit contingency table for yellowtail flounder.

RECRUITMENT	SPAWNING STOCK LOW	SPAWNING STOCK HIGH
Georges Bank		
Cool Temperatures		
Low Recruitment	17%	43%
High Recruitment	83%	57%
Warm Temperatures		
Low Recruitment	71%	17%
High Recruitment	29%	83%
Southern New England		
Cool Temperatures		
Low Recruitment	60%	45%
High Recruitment	40%	55%
Warm Temperatures		
Low Recruitment	64%	0%
High Recruitment	36%	100%

Note: Data in each cell are based upon summed frequency occurrances of indices from survey results and from commercial CPUE.

§5.4 Year Class Replacement Analysis

The policy describes the minimum acceptable spawning stock size as that level of abundance which provides a long-term average level of recruitment just adequate to avoid an unacceptably high risk of recruitment failure. As discussed in §5.1, there are certain conceptual flaws associated with any possible definition of minimum acceptable stock abundances in this context. Translated into practical biological terms, however, the minimum acceptable spawning stock size may be thought of as that level of biomass which, on a long-term average basis, may be expected to continue to replace itself. Thus, if the stock is able to continue to replace itself, its capacity to quickly recover from unfavorable circumstances will not be in jeopardy.

The stock replacement linkage is through egg production by the spawners and the subsequent survival to new recruits, and thence to the new generation of mature fish. That linkage may be examined using stock-recruit data. Figure 5.10 illustrates the stock-recruit relationship for Georges Bank haddock. Superimposed on the scatter of stock-recruit data points are a number of straight lines drawn through the origin which are labeled "10%", "20%", etc., through "100%". These curves describe lines of constant relative potential egg production by the spawning stock to produce one unit of recruitment. For instance, the line labeled 10% results in all combinations of fishing mortality and age-at-entry which will result in 10% of potential egg production of any cohort entering the fishery. In analytical terms, the total potential egg production is assumed to be a direct function of the spawning stock size. Therefore, the exploited stock biomass per recruit may be calculated as a surrogate of egg production per recruit using yield per recruit analysis with appropriate specification of the parameters. The curve labeled "100%" represents the condition at zero fishing mortality. The remaining curves with increasing slope are consistent with conditions of increasing fishing mortality.

The value of the straight-line curves depicted in Figure 5.10 is their position relative to the scatter of points describing the stock recruitment relationship. Thus, considering all such points at stock sizes greater than 70,000 metric tons, it is seen that 18 points (including the point off scale at 194,700 tons and 368.8 million recruits estimated for 1963) lie above the 20% line and 20 points are below the line. Any point above the line has resulted from recruitment greater than that specified by the line. Such greater recruitment will tend to drive the stock to higher levels provided that the stock was at the 20% level. Conversely, with recruitment lower than that specified by the line, the stock will tend to be driven lower. The fact that the 20% line about evenly bisects the historical data at stock sizes above 70,000 tons indicates that such a level of potential egg production is an appropriate long-range goal for management of the Georges Bank haddock stock (after stock sizes have been rebuilt to 70,000+ tons).

Assuming that compensatory mortality is significant at high stock levels in haddock, the 20% level becomes even more appropriate. At stock sizes greater than 70,000 tons but less than 150,000 tons, it is seen that 16 points lie above the 20% line and 16 points are below the line. Thus, given a continuation of the historic variability of recruitment, the probability that the stock may increase would be equal to the probability that it may decrease, indicating that over the long-term it would tend to remain constant.

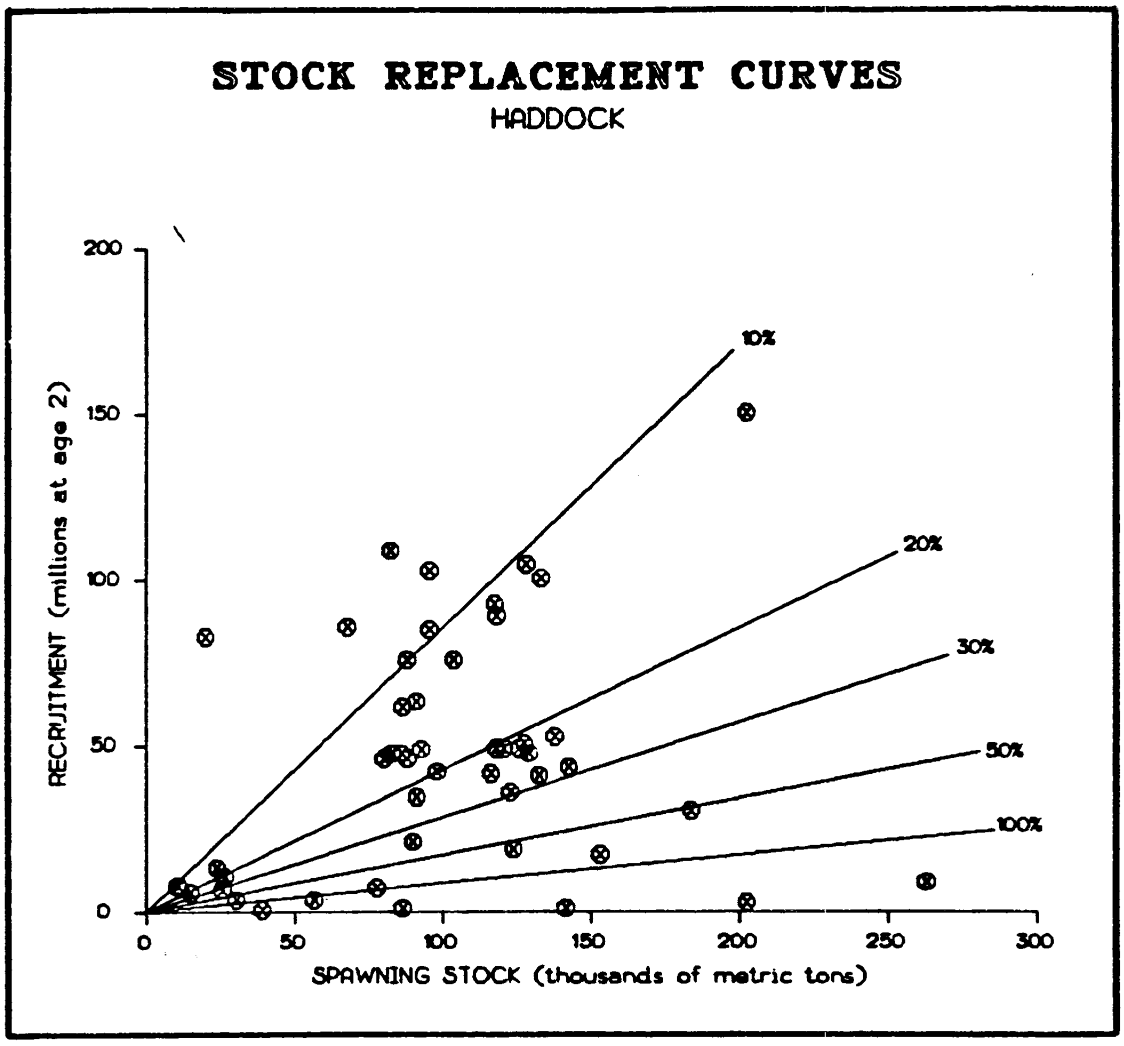


Figure 5.10. Lines of equal potential egg production per recruit superimposed on the stock recruitment relationship for Georges Bank haddock. The curves indicate that at intermediate stock levels, haddock may be most appropriately managed such that the spawning stock has 20% of the potential egg productivity of the unexploited (virgin) stock. At current low stock levels, the 30% level is most appropriate.

The current stock size of Georges Bank haddock is substantially less than 70,000 metric tons. Examining the distribution of data points in the lower range of stock sizes it is seen that the 30% curve is appropriate under current conditions.

This discussion of the replacement concept has been exemplified by the case of haddock. In a similar manner, the 20% level of potential egg production has been found to be most appropriate for management of most other stocks within the overall multispecies complex. In the case of Gulf of Maine-Georges Bank redfish, however, a similar situation exists as was found in the case of haddock. Thus, until stocks of redfish have been rebuilt to about 100,000 metric tons, the 30% level of potential egg production is the most appropriate basis for management.

The potential egg production of a stock of fish is maximized under conditions of zero exploitation. The maximum possible reproductive capacity is embodied in the virgin stock where the only source of mortality is from natural causes. The potential egg production, along with the stock size, is reduced with the introduction of fishing mortality (F), and at any given level of F, egg production is relatively lower (higher) as the age at entry to the fishery is reduced (increased). This relationship provides the operational link for effecting a desired level of potential egg production as a goal of management.

The relationship between the potential egg production, and the fishing mortality rate and age at entry (age at 50% selection) is illustrated for a number of important species in Figures 5.11-5.16. Where estimates are available, the current level of fishing mortality has been indicated. In addition, vertical accent lines have been included in each graph to denote the age (and average fish size) at 50% selection for a series of alternative cod end mesh sizes for trawl nets.

The two primary dimensions to the problem of achieving a desired level of total reproductive potential for the important stocks within the multispecies complex are the fishing mortality rates and the ages at 50% selection. Both have important ramifications with respect to the management program and are treated in the following sections. As noted above, the most appropriate level of total reproductive potential for haddock and redfish in the short-term is at the 30% benchmark and for all stocks in the long-term is 20%. The task of management of the multispecies resource will be to manipulate the fishing mortality rate and age at 50% selection such that those benchmarks will be achieved for the important stocks, thus implementing the overall policy guidance.

§5.5 <u>Age at Entry to the Fishery</u>

The policy guidance of this FMP is concerned that there be a continuation of adequate spawning potential in the multi-species fishery. One of the dimensions for accomplishing this is to control the age at which the fish enter the fishery. The age at entry varies with individual species (see Table 2A6) and may be manipulated both directly and indirectly. A direct means of affecting age at entry is to set minimum sizes for species in the fishery. This would take into consideration important factors such as the size at sexual maturity and the most appropriate market size as a basis for

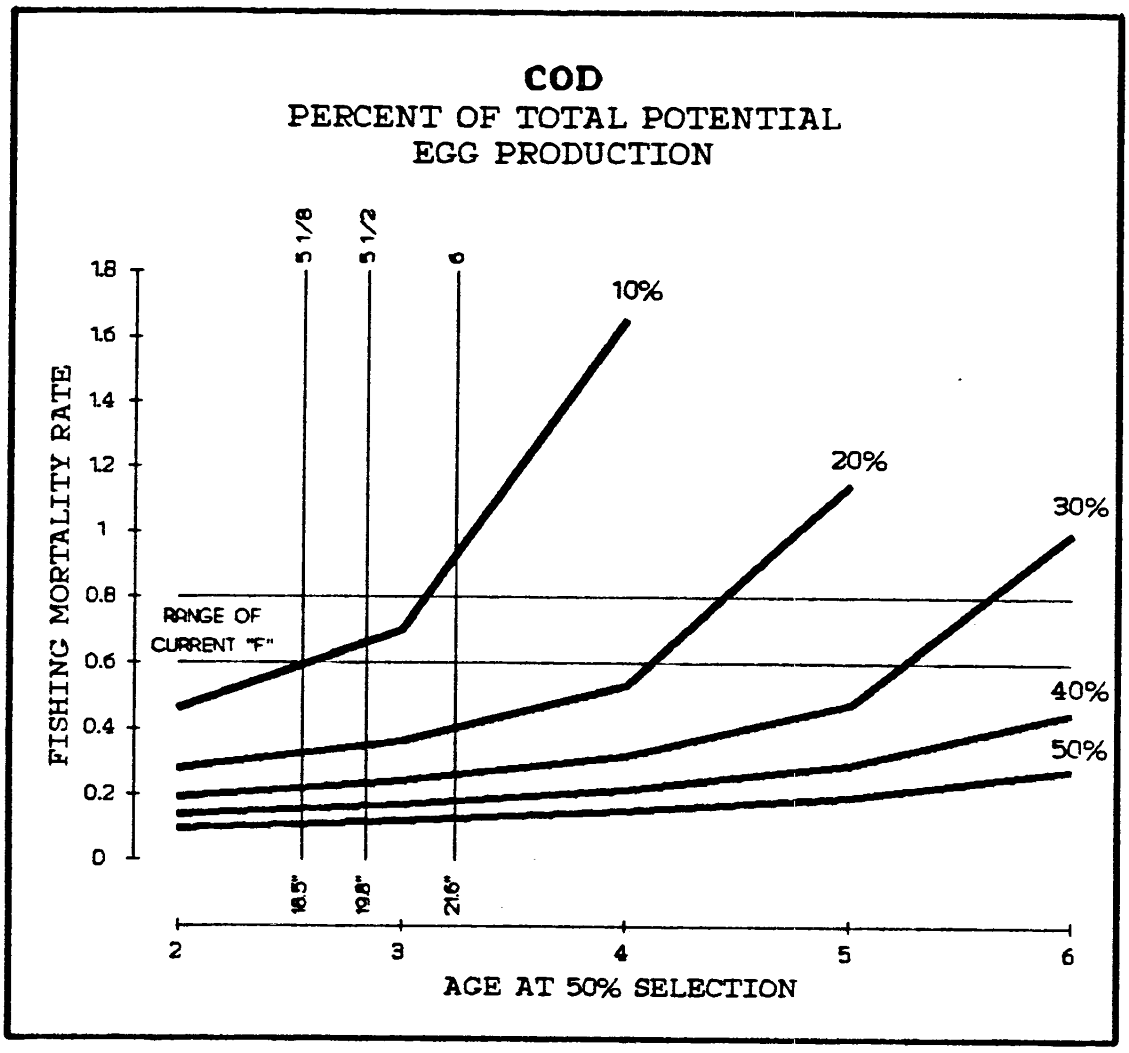


Figure 5.11. Isopleths of total potential egg production for cod. Horizonal accent line(s) indicate the estimated current level of fishing mortality, where available. Vertical accent lines indicate the age (and fish length) at 50% selection for a range of cod-end mesh sizes.

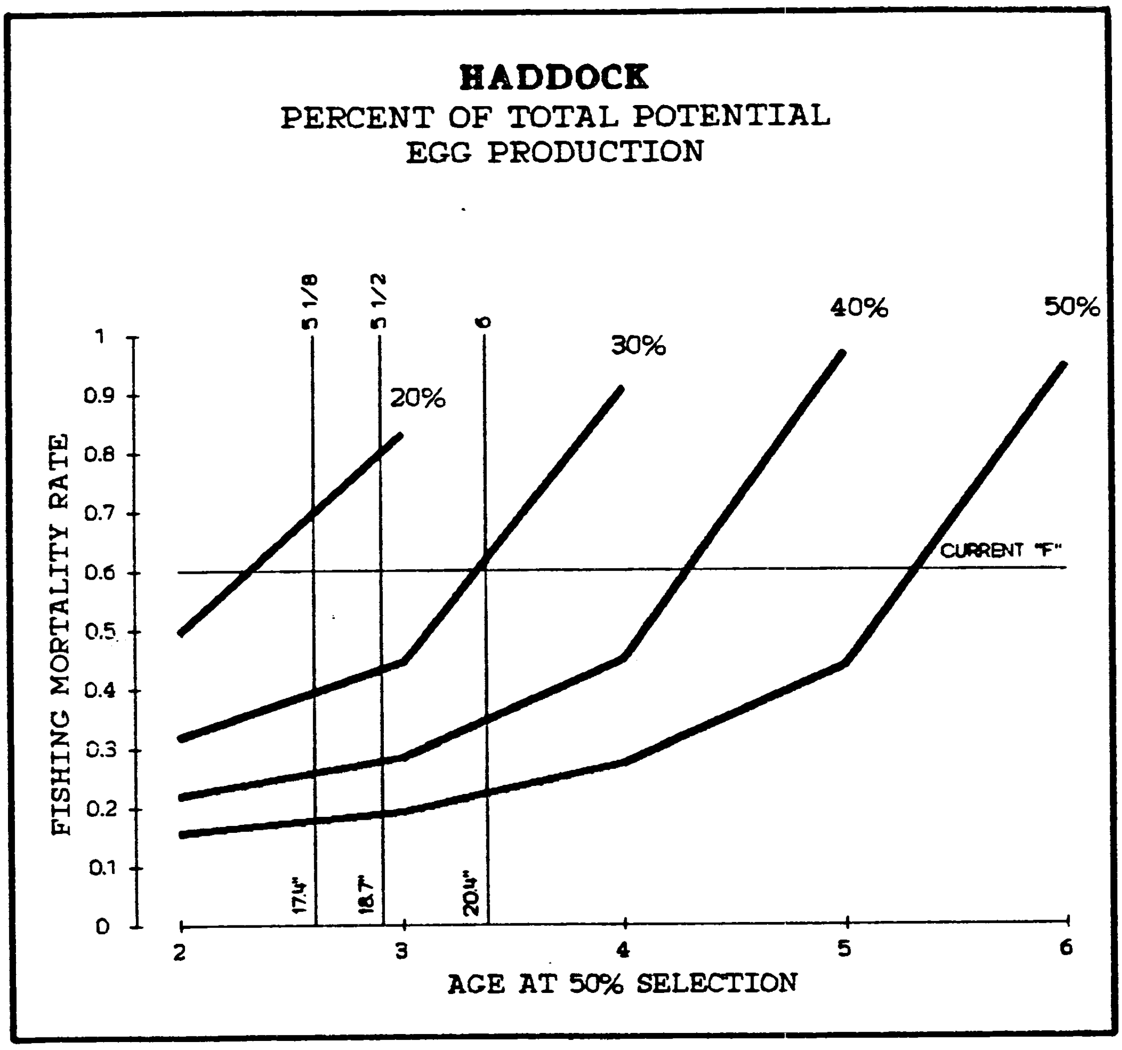


Figure 5.12. Isopleths of total potential egg production for haddock. Explanation same as for Figure 5.11.

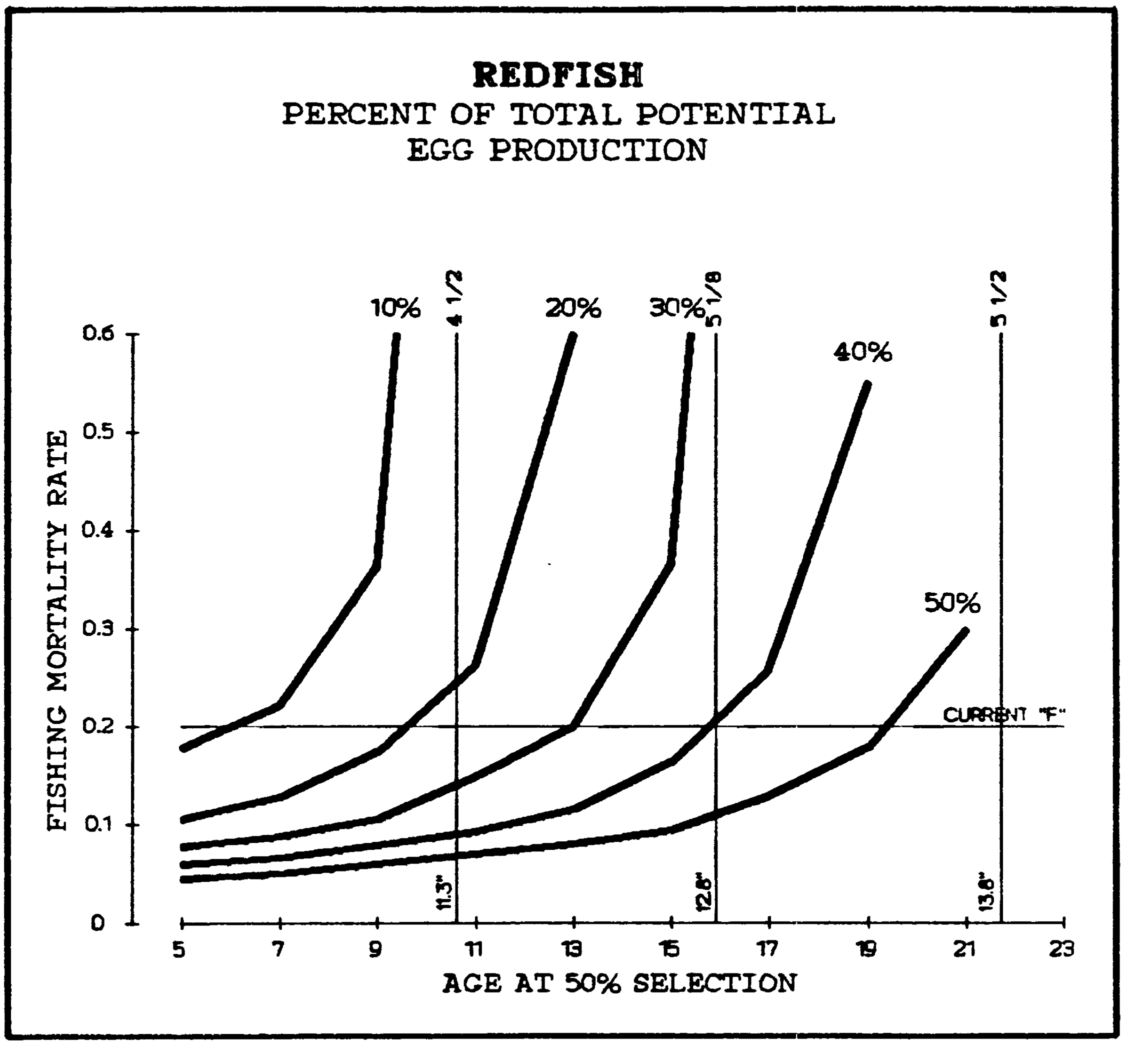


Figure 5.13. Isopleths of total potential egg production for redfish. Explanation same as for Figure 5.11.

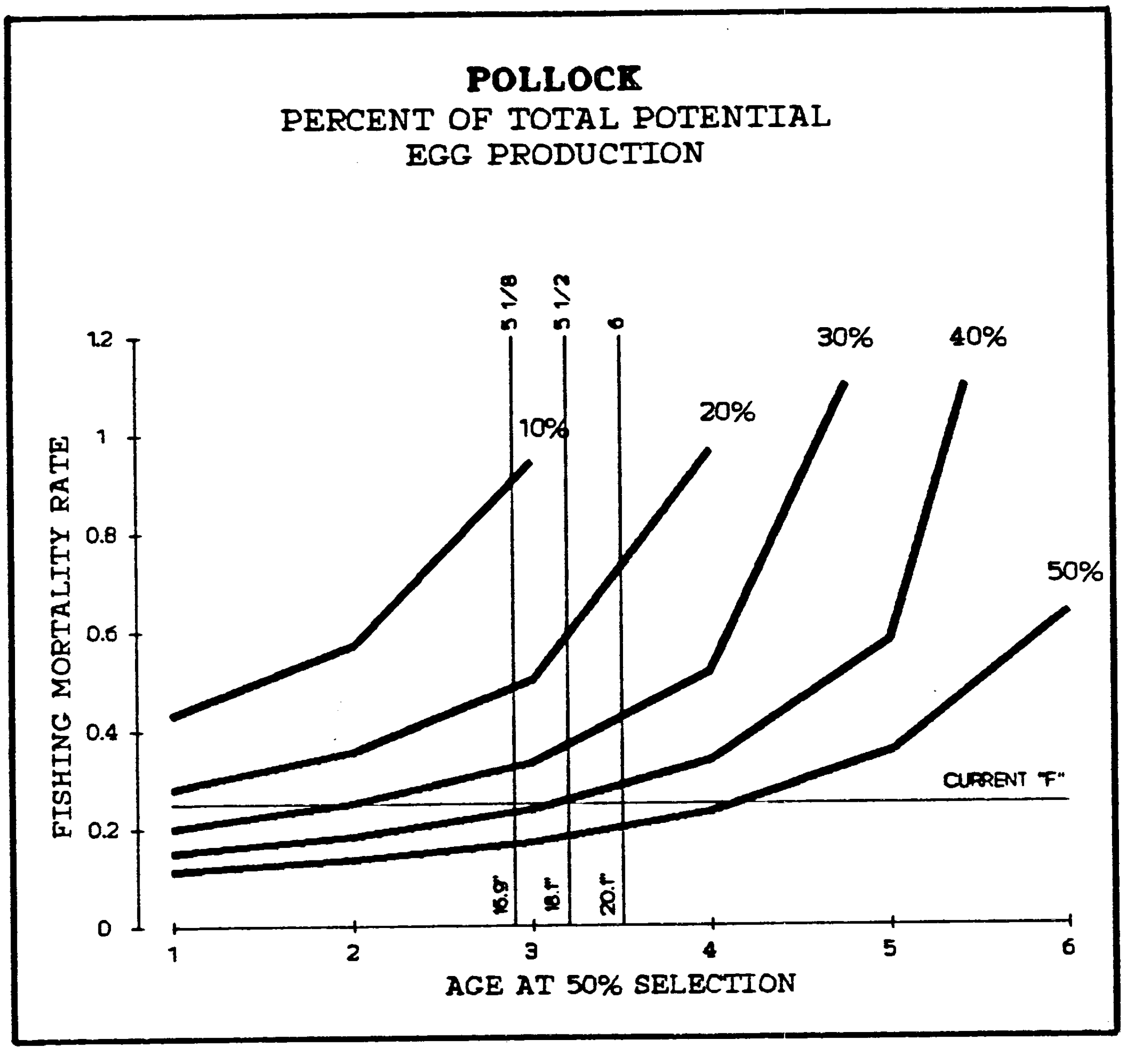


Figure 5.14. Isopleths of total potential egg production for pollock. Explanation same as for Figure 5.11.

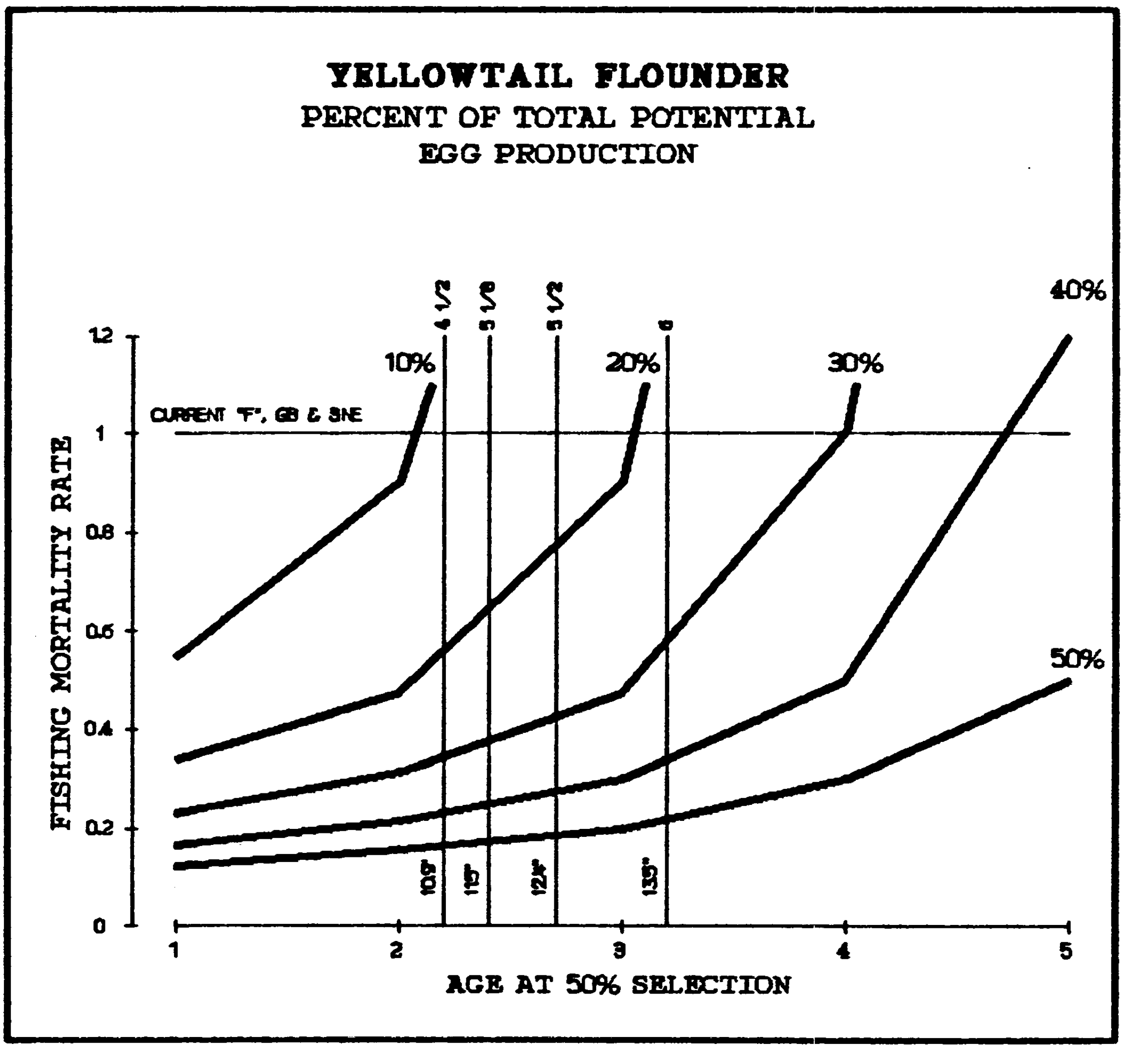


Figure 5.15. Isopleths of total potential egg production for yellowtail flounder. Explanation same as for Figure 5.11.

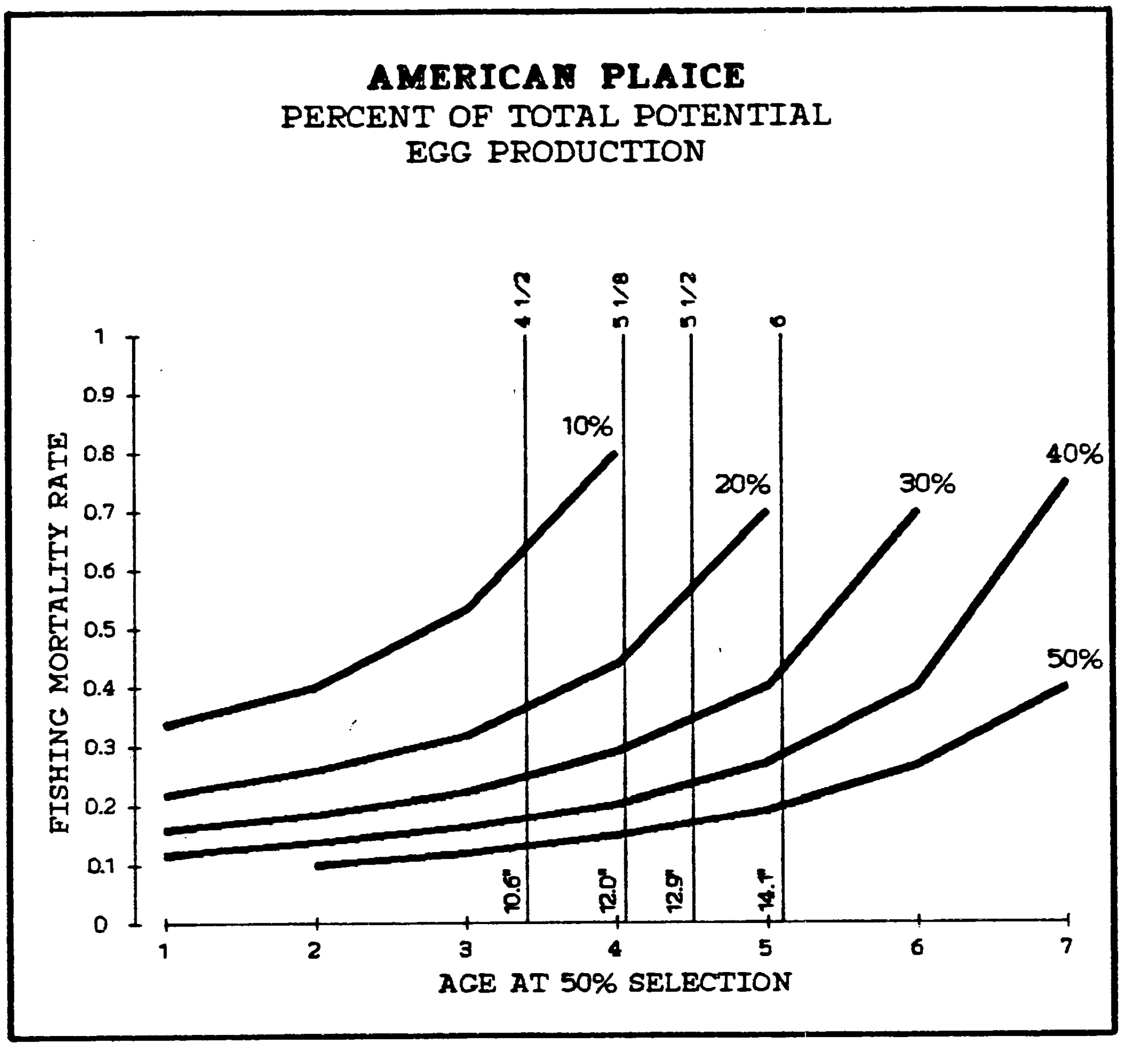


Figure 5.16. Isopleths of total potential egg production for American plaice (dab). Explanation same as for Figure 5.11.

determination of the minimum fish size for each species. An indirect means of controlling age at entry is through selection of an appropriate mesh size which targets fish of designated lengths. Controlling age at entry by manipulating the mesh size has certain advantages but may suffer inefficiencies depending upon fishing conditions.

Direct Methods - Minimum Size. Appropriate minimum sizes may be established based on the average length of fish at sexual maturity and other factors which may include commercial considerations. The size at 50% maturity of the mix of species in the Northwest Atlantic groundfish fishery varies with each species and stock. Control of age at entry by use of a minimum size has certain limitations. When catchs are culled aboard a fishing vessel, significant mortality may occur among undersized fish before they are discarded. This method for controlling age at entry is highly successful for crustaceans (eg., lobster) and shellfish (eg., sea scallops) but has limited usefulness, as a single measure, in most fisheries for finfish except in the case of the recreational fisheries.

Indirect Methods - Gear Control. The selection characteristics of fishing gear may be used to control the age at entry to the fishery. The three main types of gear used in the multi-species fishery include mobile trawls, gill nets, and long-lines (hooks). The selection characteristics of these types of gear depend upon the mesh size (trawls and gill nets) and the hook size.

Gillnets are known to be size selective. Depending upon the size range of available fish, gill nets usually select a relatively narrow range in fish lengths. Small fish avoid gilling in the meshes and may swim right through the net, whereas very large fish are unable to penetrate the net far enough to be caught. Hooks are also selective. Large hooks will not be swallowed by small fish, and small hooks will unlikely snag large fish.

Historically, the most significant type of gear used in the multi-species fishery is the mobile trawl. When fish enter the trawl net they are selected by size according to the measurement of the cod end mesh. Modification of mesh size is a relatively simple means of effecting a change in the size selection of fish. The use of mesh size as a management tool has been demonstrated to play a significant role in the goal of reducing discards of undersized fish. As the size of mesh increases, escapement of undersized fish increases, discard of undersized fish decreases and yield of the fishery may be maximized.

In the multi-species fishery, use of cod-end mesh size to select for age at entry has inherent limitations. While a specific mesh size may be appropriate for one species, it may not produce the results desired for other species in the combined catch. There are some additional problems of applying mesh size controls. Deformation of the geometry of ordinary diamond mesh in the extension piece ahead of the cod-end may occur when the trawl bag is full. This may have the effect of retaining more small fish.

Mesh Selectivity and Selection Factors. Mesh selection is a process which distinguishes a part of a larger population. Since populations of fish are heterogeneous in size, age, behavior, etc., they are not equally vulnerable to any specific mode of capture. Selection is a process which attempts to increase the chances of capturing fish of a specific characteristic, e.g. age or size. The expression "selectivity" is a qualitative expression of selection, and is usually a relative, not an absolute term.

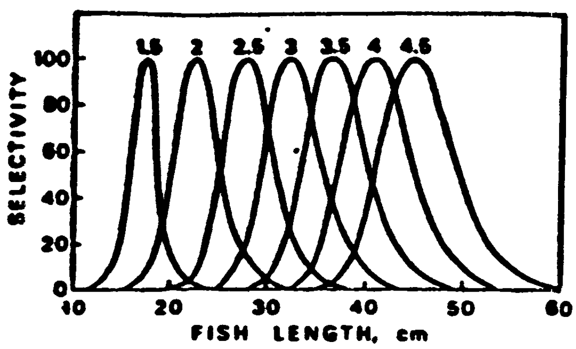
Gillnet selectivity exhibits a different pattern than trawl mesh selectivity. Normal probability curves may be used to describe the selectivity of gillnets (Figure 5.17). As mesh size increases, the curve becomes displaced such that the modal point corresponds to a longer length fish. The shape of the curve indicates that fish larger or smaller than the average sized fish sought are not likely to be caught. While it is known that gillnets are more selective with regards to size than mobile trawl nets, they are not selective with regards to species.

Selectivity in mobile trawl nets is quite different. The 50% retention point is commonly used to describe selectivity in such gear. This is the point at which half of the fish of a particular length are retained by a certain mesh size and the other half escape. The 50% point increases in direct proportion to the mesh size. There is a straight line relationship between the 50% release (retention) length (L) and the stretched length of the mesh (m), such that the selection factor, $C = L/m$. While in the past it has been termed the relative releasing effect, today we call it the selection factor (Smolowitz, 1983). This selection factor describes the capacity of fish to escape and varies from species to species and with the conditions of capture.

It may be demonstrated that the 50% retention length increases as the mesh size increases. Table 5.4 shows, for example, that 5-1/2 inch mesh retains 19.8 inch cod at the 50% point, while 6 inch mesh will retain 21.6 inch cod at the 50% point. The idealized nature of the change in selection which occurs through trawl mesh size changes is demonstrated through typical sigmoid selection curves illustrated in Figure 5.18 for cod with two different sized cod-end meshes. As shown, the 50% retention length increases with the larger mesh.

Smolowitz (1978) has suggested that increases in cod end mesh size may result in concurrent increases in trawl efficiency. When larger mesh sizes are employed large fish are often caught in greater numbers. But, not withstanding the possibly controversial nature of that claim, the relationship between the size and shape of the mesh and the shape of the fish affects the escapement rate, as does the behavioral response of fish species. Selection is largely determined by the physical feature of the fishing gear. Different types of gear, or modification in gear may produce catches of different species composition and affect the size composition of the catch of particular species.

(A)



(B)

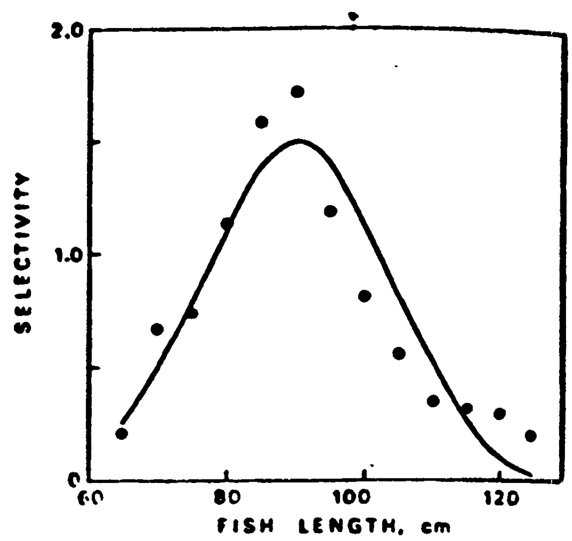


Figure 5.17. Selection curves for gill nets, based upon, (A) lake whitefish, and (B) cod.

SOURCE: Hamley, J.M., Review of gillnet selectivity. J. Fish. Res. Board Can. 32(11). 1975.

Table 5.4

Calculated rates of retension and escapement for selected species at two mesh sizes.

COD (selection factor = 3.6)

Length (in.)	5 1/2" Mesh Retain (%)	5 1/2" Mesh Escape (%)	6" Mesh Retain (%)	6" Mesh Escape (%)
27	99.4	0.6	97	3
26	98.4	1.6	94	6
25	96.5	3.5	88	12
24	93	7	80	20
23	87	13	69	31
22	78	22	56	44
21.6	74	26	50	50
21	66	34	42	58
20	53	47	29	71
19.8	50	50	27	73
19	39	61	19	81
18	27	73	11	89
17	16	84	6	94
16	9	91	3	97
15	5	95	1	99
14	2	98	0.5	99.5

HADDOCK (selection factor = 3.4)

Length (in.)	5 1/2" Mesh Retain (%)	5 1/2" Mesh Escape (%)	6" Mesh Retain (%)	6" Mesh Escape (%)
26	99.7	0.3	98.3	1.7
25	99.2	0.8	96	4
24	98	2	92	8
23	95	5	84	16
22	90	10	73	27
21	81	19	59	41
20.4	74	26	50	50
20	69	31	44	56
19	55	45	30	70
18.7	50	50	26	74
18	40	60	18	82
17	26	74	10	90
16	15	85	5	95
15	8	92	2	98
14	4	96	0.8	99.2
13	1.6	98.4	0.3	99.7

REDFISH (selection factor = 2.5)

Length (in.)	5 1/2" Mesh Retain (%)	5 1/2" Mesh Escape (%)	6" Mesh Retain (%)	6" Mesh Escape (%)
17	99.9	0.1	98	2
16	98.8	1.2	84	16
15	90	10	50	50
14	60	40	16	84
13.8	50	50	11	89
13	22	78	2	98
12	4	96	0.1	99.9

POLLOCK (selection factor = 3.3)

Length (in.)	5 1/2" Mesh Retain (%)	5 1/2" Mesh Escape (%)	6" Mesh Retain (%)	6" Mesh Escape (%)
25	99.1	0.9	96.5	3.5
24	98	2	93	7
23	95	5	87	13
22	91	9	78	22
21	84	16	66	34
20	74	26	53	47
19.8	72	28	50	50
19	62	38	39	61
18.2	50	50	28	72
18	48	52	27	73
17	34	66	16	84
16	23	77	9	91
15	14	86	5	95
14	8	92	2	98
13	4	96	0.1	99.9

Table 5.4

(Continued)

YELLOWTAIL FLOUNDER (selection = 2.25)

Length (in.)	5 1/2" Mesh Retain (%)	5 1/2" Mesh Escape (%)	6" Mesh Retain (%)	6" Mesh Escape (%)
16	99.9	0.1	98.4	1.6
15	98.8	1.2	90	10
14	92	8	67	33
13.5	84	16	50	50
13	71	29	33	67
12.4	50	50	17	83
12	38	62	10	90
11	12	88	1.6	98.4
10	2	98		

AMERICAN PLAICE (selection = 2.35)

Length (in.)	5 1/2" Mesh Retain (%)	5 1/2" Mesh Escape (%)	6" Mesh Retain (%)	6" Mesh Escape (%)
18	99.9	0.1	99.3	0.7
17	99.5	0.5	96.5	3.5
16	97.5	2.5	89	11
15	91	9	72	28
14.1	77	23	50	50
14	75	25	47	53
13	52	48	24	76
12.9	50	50	23	77
12	28	72	9	91
11	11	89	2.5	97.5
10	3	97	0.5	99.5

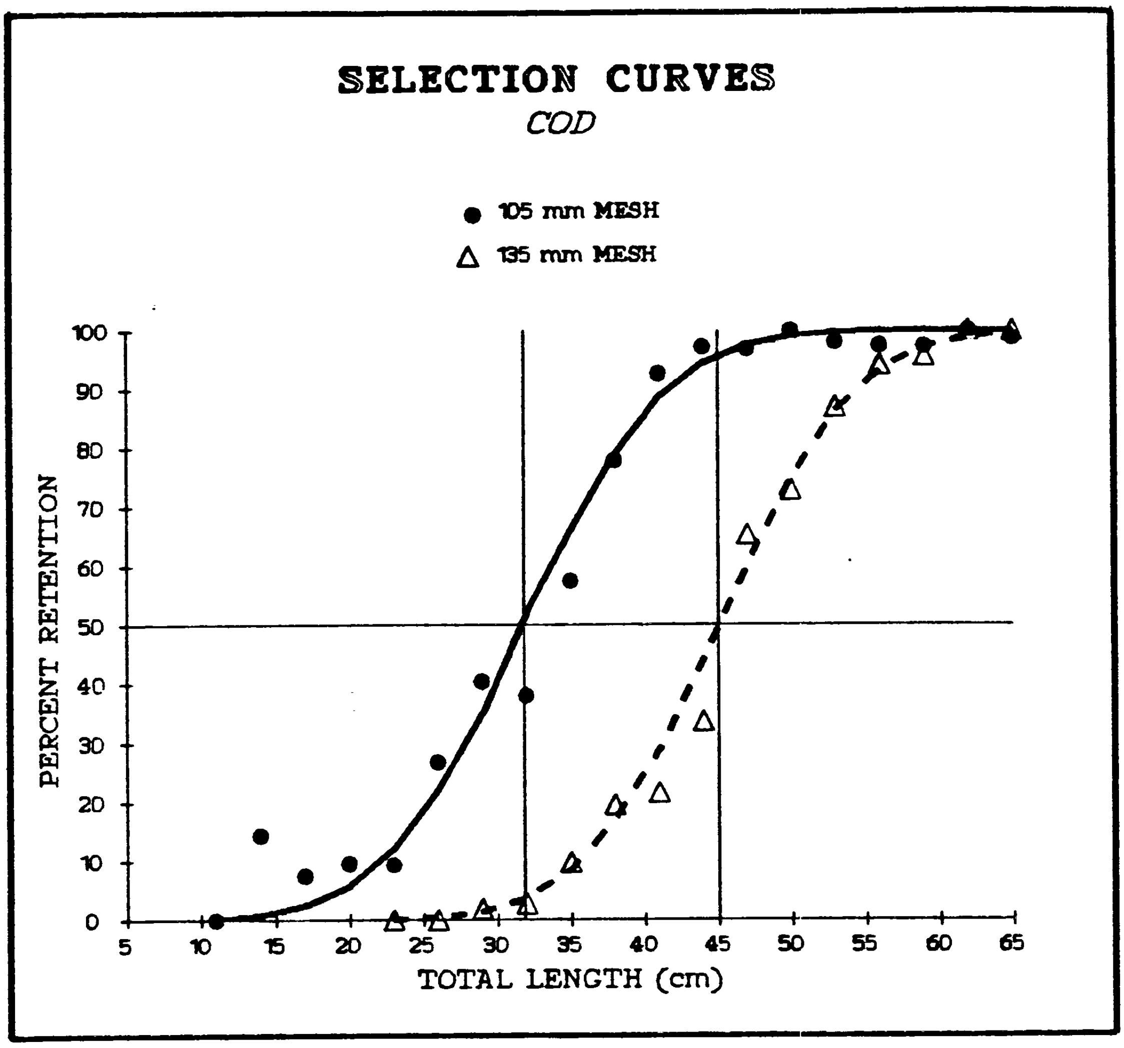


Figure 5.18. Selection curves for cod at two different cod-end mesh sizes.

Mesh Selection and Maturity

The classical approach to the problem of determining the most appropriate mesh size to be used in a commercial fishery, using biological criteria, has been to choose that mesh size which has a 50% selection length corresponding to or slightly longer than the fish size at 50% maturity. The conventional wisdom has been that, in the absence of a method for quantifying the minimum necessary number of spawners to assure continued recruitment, such a strategy assures that at least half of newly maturing fish will survive to spawn at least once thus providing a hedge against recruitment overfishing. The major weakness of the approach is that fishing mortality is not considered. Nevertheless, it has been valuable to fishery management and is useful for consideration here. As discussed in §5.5, minimum size may be an appropriate management measure in combination with mesh size (especially when applied to all segments of the fishing industry) if it discourages fishermen from setting on schools of predominantly small fish.

Illustrated in Figures 5.19-5.24 for a number of important species within the multispecies complex are curves describing the relative proportion of fish at size and age which have attained sexual maturity plus selection curves for a range of cod end mesh sizes. In addition, the selection curves indicate the relative proportion of the catch which is comprised of fish which are smaller than existing and/or proposed minimum sizes, thus representing the potential discard.

In the case of Georges Bank cod (Figure 5.19), it is seen that fish reach 50% maturity at a total length of 20-21 inches. With a 5 1/8 inch mesh (which may approximate the current operative mesh size), the 50% retention length is only about 18-19 inches when fish are less than 40% mature. Moreover, about 30% of the fish just below the current minimum size for cod (17 inches) are discarded. A cod end mesh of 5 1/2 inches has a 50% retention length of about 20 inches, near the size at 50% maturity, but a minimum size of 19 inches implies a substantial amount of discard. The 6 inch cod end mesh would result in a low discard level with the same minimum size, but a 50% retention length of 21-22 inches implies the greatest loss of marketable fish among the three alternatives.

For Georges Bank haddock (Figure 5.20), all three cod end mesh sizes examined (the 5 1/8 inch mesh approximates the current operative mesh) have 50% selection lengths which are greater than the size at 50% maturity (16-17 inches). However, the current seriously depressed haddock stocks indicate the need for a strategy of stock rebuilding rather than one of stock maintenance, implying the inadequacy of matching the 50% retention length with the size at 50% maturity. Consistent with that philosophy, the current 17 inch minimum size is also inadequate. But, of the mesh sizes examined, only the 6 inch mesh would <u>not</u> result in a substantial amount of discard.

GEORGES BANK COD

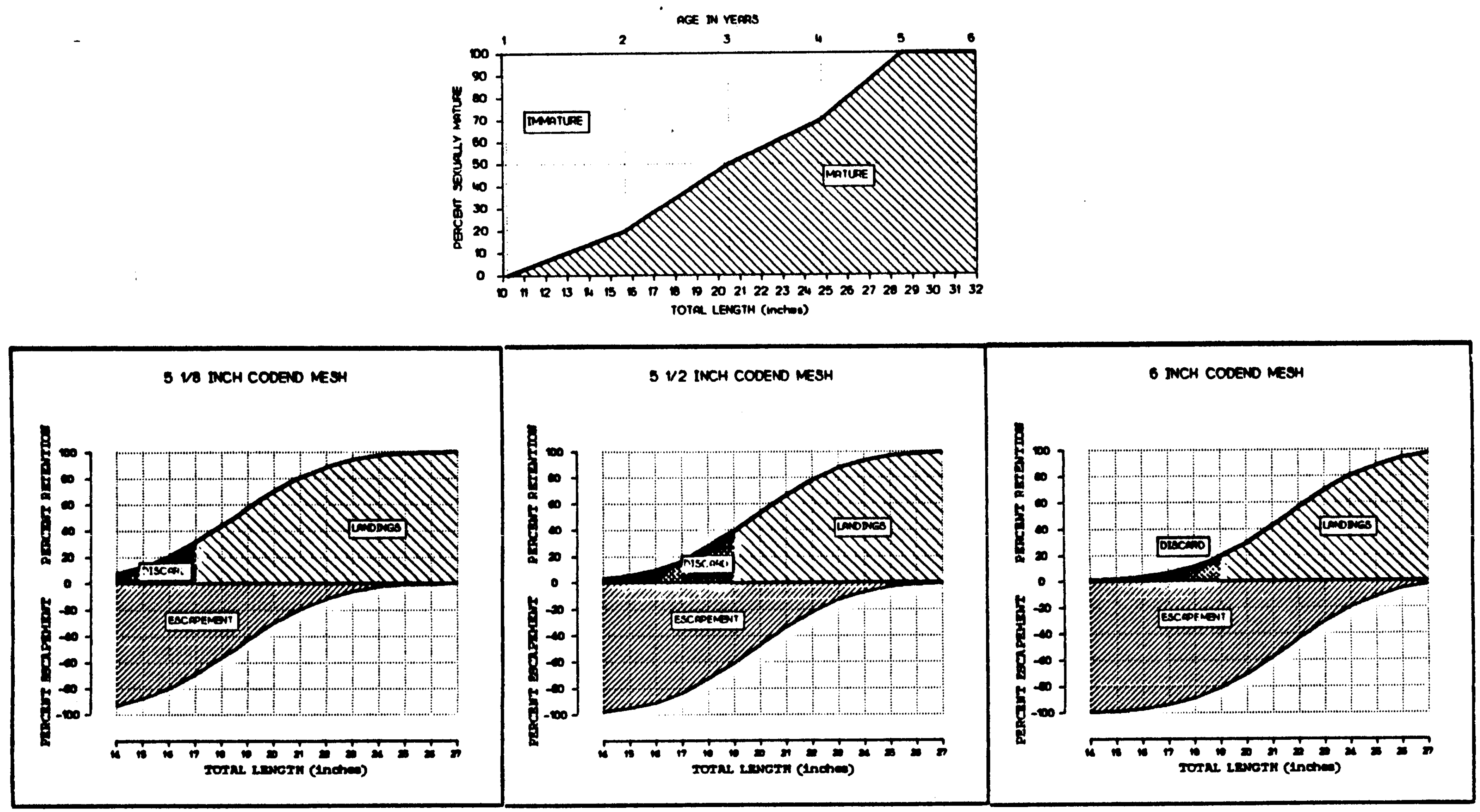


Figure 5.19. Selection and maturity in Georges Bank cod. The first selection curve represents the current operative mesh and the current minimum size. The other two panels indicate alternative meshes and minimum sizes.

GEORGES BANK HADDOCK

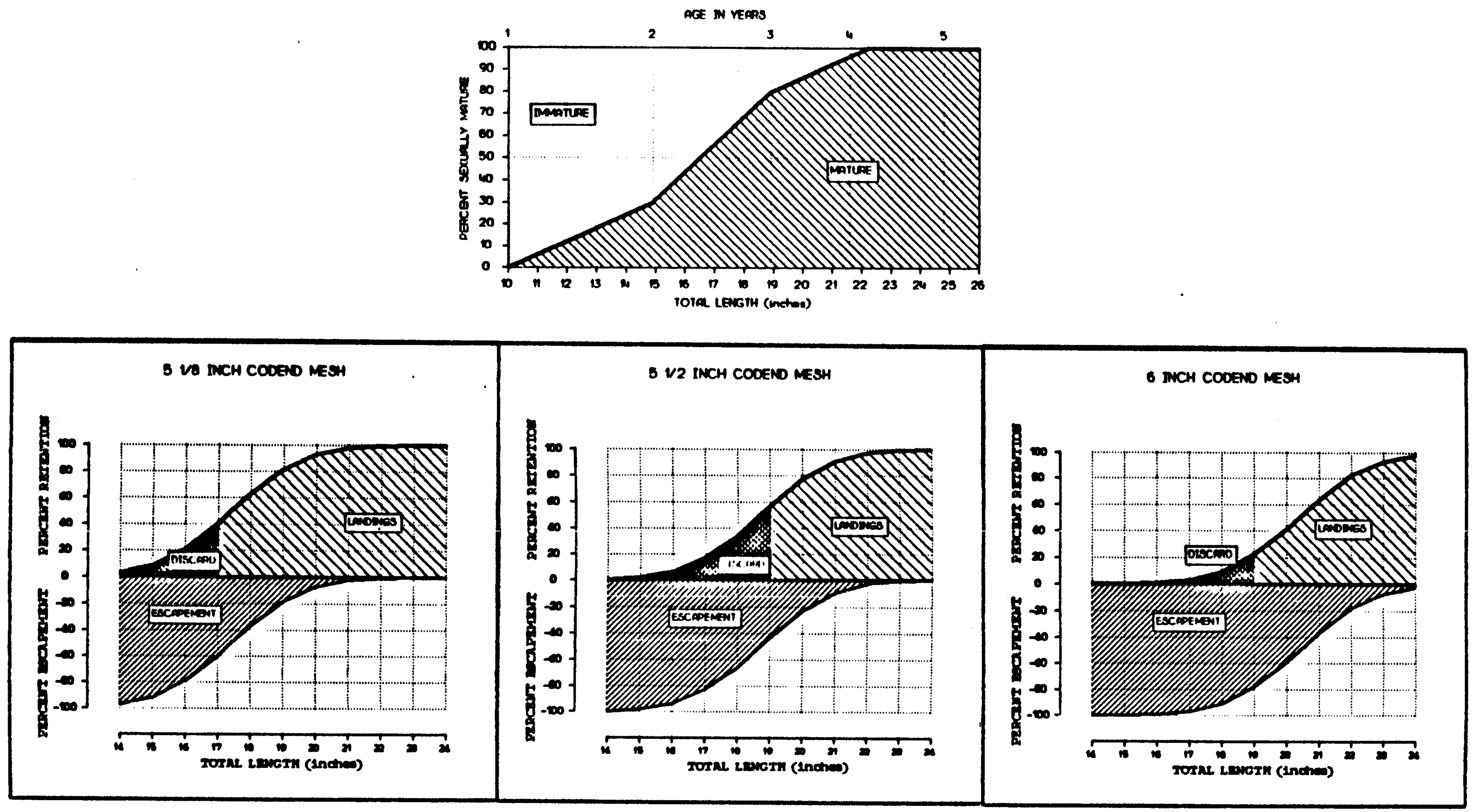


Figure 5.20. Selection and maturity in Georges Bank haddock. Explanation same as Figure 5.19.

With the exception of the current operative mesh size (approx. 5-1/8 inches), a similar relationship between the important parameters exists with respect to pollock as was the case with haddock. The 50% selection lengths for both of the larger meshes examined are larger than the size at 50% maturity (see Figure 5.21), but with a minimum size appropriate to the size at maturity, the discard level associated with 5-1/2 inch mesh is prohibitively high. these findings suggest the appropriateness of the 6 inch mesh.

Georges Bank yellowtail flounder (Figure 5.22) reaches 50% sexual maturity at age 2 (10-11 inches). All three mesh sizes examined have 50% retention lengths which are substantially larger. Therefore, the most appropriate mesh size is that which minimizes discards in consideration of an acceptable minimum size.

A virtually identical situation exists in the case of American plaice. As seen in Figure 5.23, the 50% selection length varies from 12 to 14 inches, uniformly at or above the size at 50% maturity (11-12 inches). Thus, the most appropriate mesh size is that which implies an acceptable level of discard given a minimum size which approximates the size at 50% maturity (i.e., about 12 inches).

On the basis of the size at 50% maturity for Georges Bank winter flounder (Figure 5.24), 12-13 inches, the most appropriate mesh size is between 5-1/2 and 6 inches. In consideration of coastal stocks of winter flounder which reach sexual maturity at smaller sizes and for economic reasons, a somewhat smaller minimum size may be appropriate (i.e., 11 inches). As in the case of the other flounders considered, the most appropriate mesh (in the range of 5-1/2 to 6 inches) is that which results in an acceptable level of discard.

<u>Square Mesh</u>. The closest approximation of a sharp cut off in the selection of fish below a certain size in a trawl catch would likely be accomplished through the use of square mesh cod ends. Comparison of retention curves for haddock and whiting using conventional diamond mesh vs. square mesh codends based upon Aberdeen, Scotland mesh selectivity studies demonstrate that retention curves for square mesh codends more closely approximate vertical "knife-edge" selection than do those for diamond mesh (Figure 5.25).

The geometric configuration of the square mesh allows for escapement of more juvenile round fish than the conventional diamond mesh. This has been documented through the above cited experimental work on whiting cod-end selectivity in Aberdeen (Robertson, 1983). Work is currently underway in the North Atlantic groundfish fishery comparing selectivity of square mesh cod ends with the conventional diamond mesh cod ends. Results, while preliminary, demonstrate the same conclusions as did the Aberdeen study.

Square mesh cod ends have a smaller selection range than conventional diamond mesh (Figure 5.25). The square mesh with the same 50% retention length as the conventional mesh retains fewer small fish and more large fish and the quality of fish caught in the square mesh cod-ends is likely to be superior to that caught by conventional mesh. In addition, less sorting time is required on deck, the workload may be considerably reduced, and less debris is retained by the square mesh cod-ends than with conventional diamond mesh. This may result in reduced costs in time, and effort, and lead to increased revenues.

POLLOCK

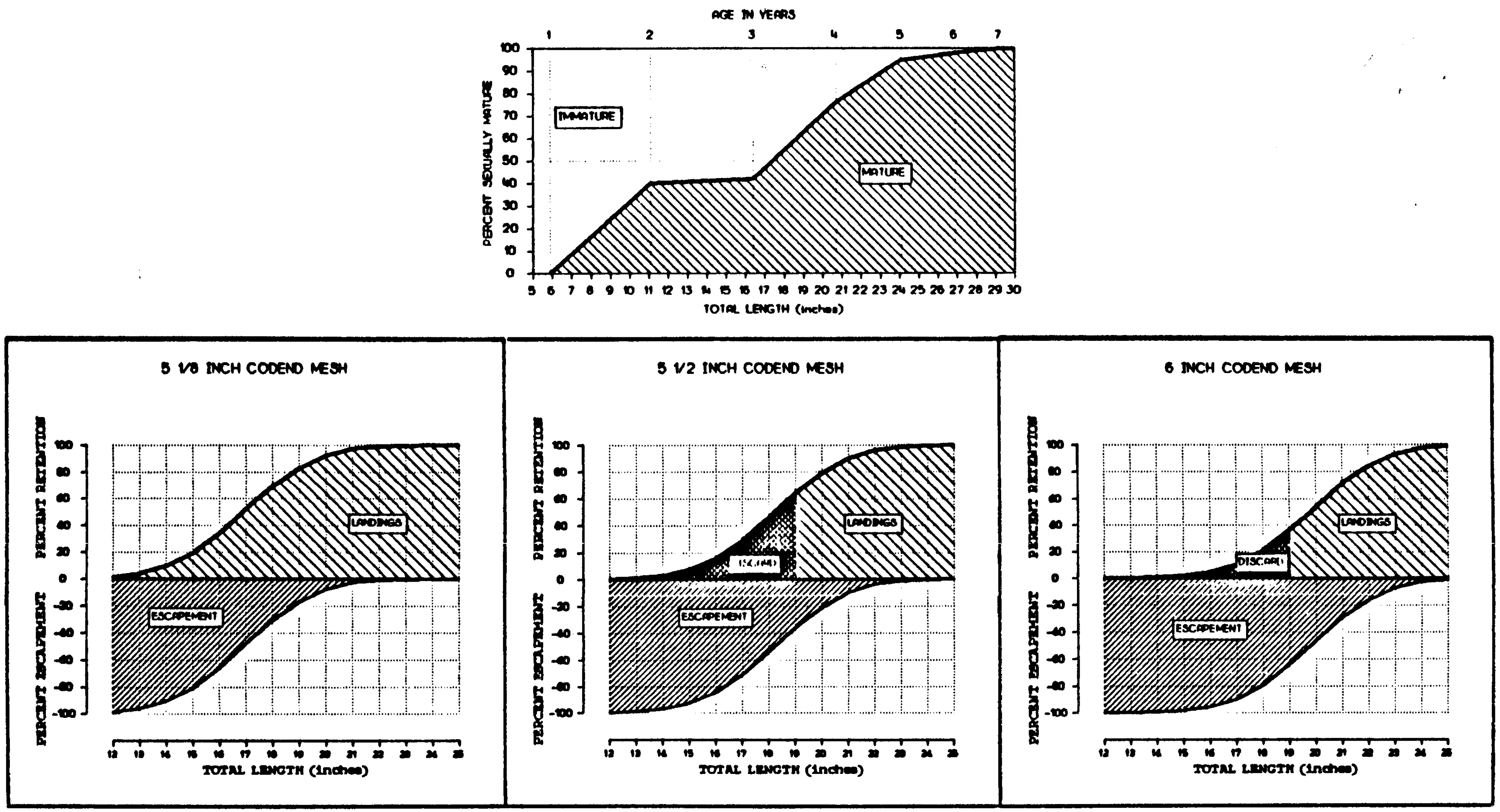


Figure 5.21. Selection and maturity in pollock. Explanation same as Figure 5.19.

GEORGES BANK YELLOWTAIL FLOUNDER

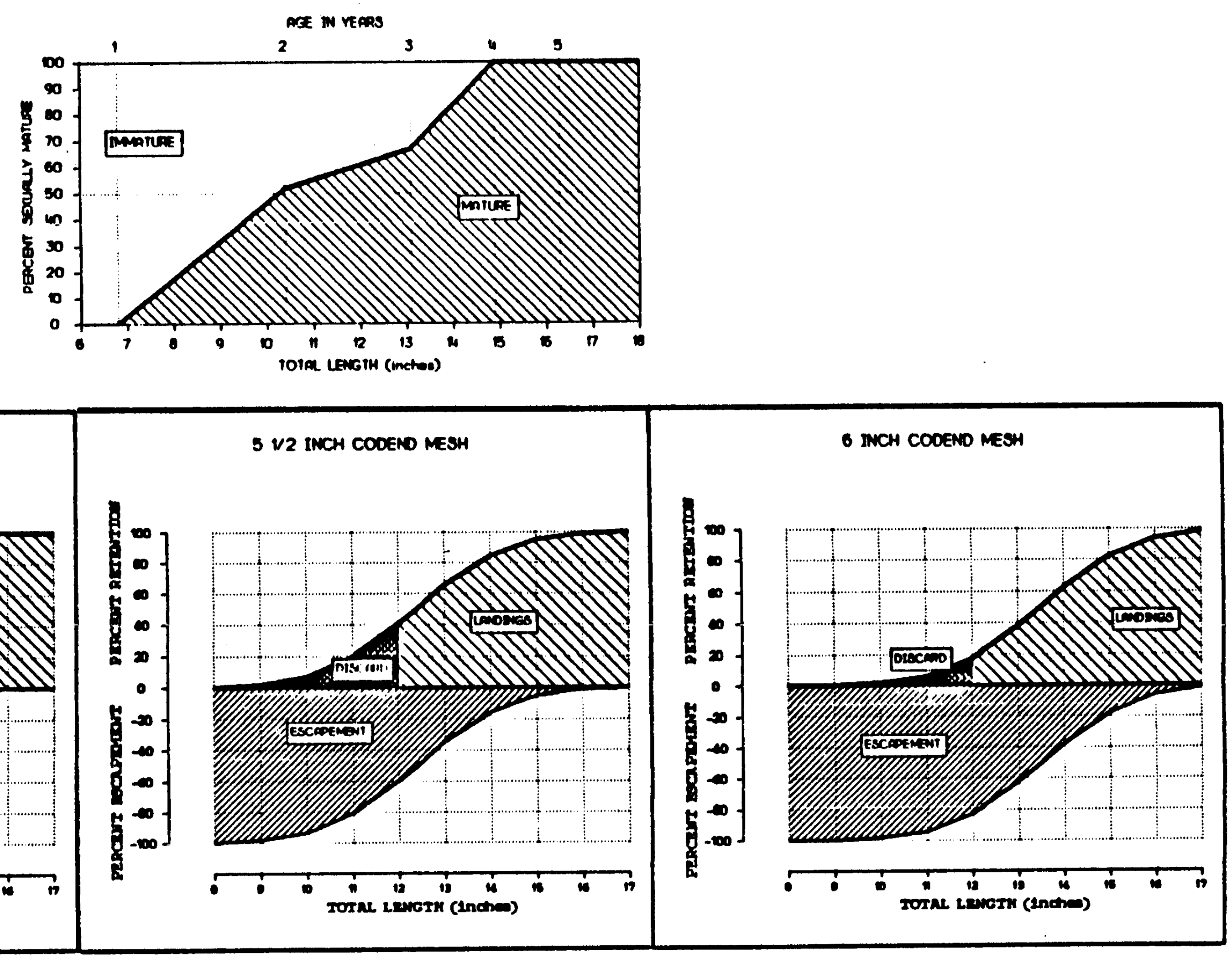


Figure 5.22. Selection and maturity in Georges Bank yellowtail flounder. Explanation same as Figure 5.19.

AMERICAN PLAICE

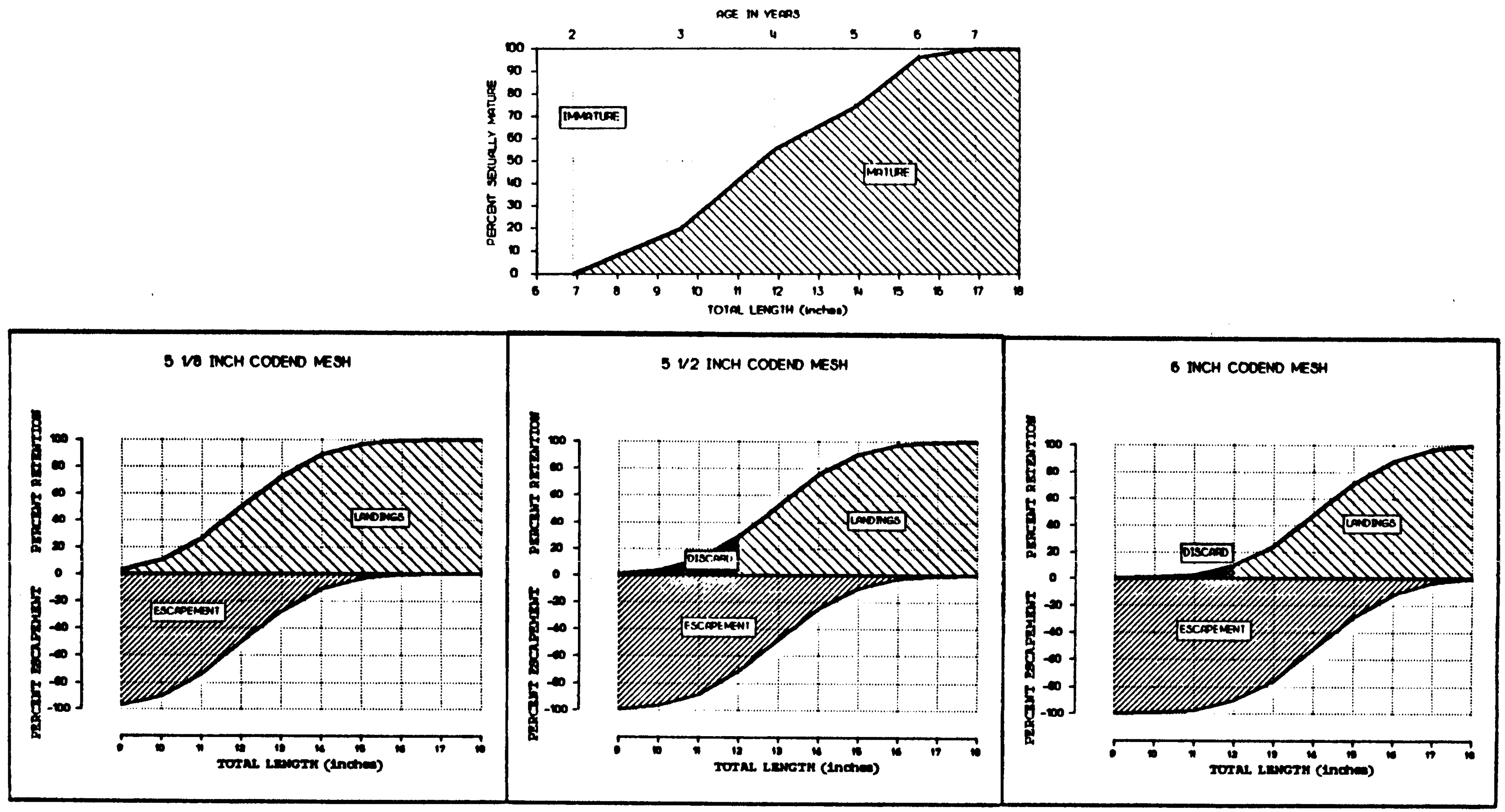


Figure 5.23. Selection and maturity in American plaice. Explanation same as Figure 5.19.

GEORGES BANK WINTER FLOUNDER

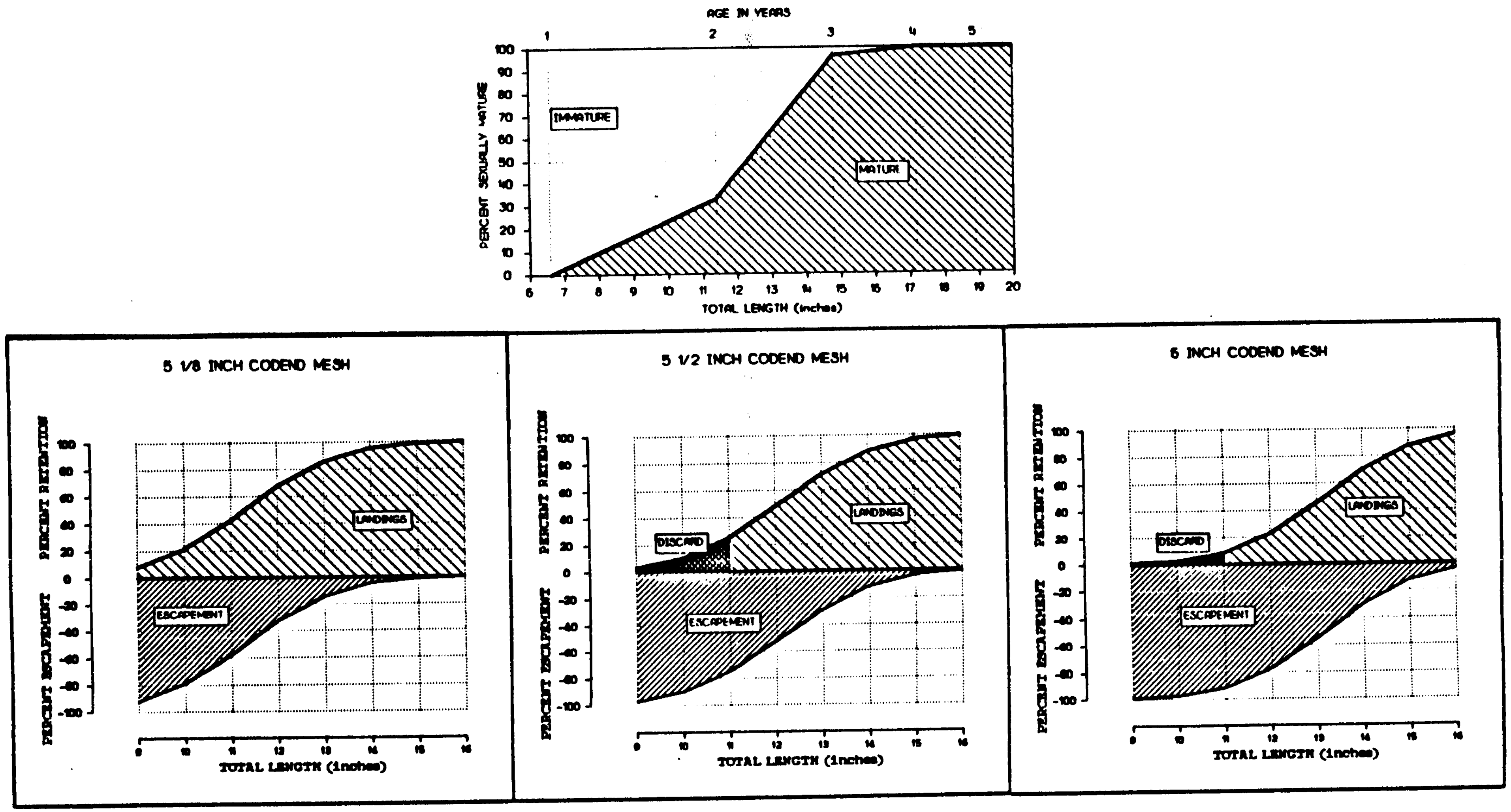


Figure 5.24. Selection and maturity in Georges Bank winter flounder. Explanation same as Figure 5.19.

Use of square mesh cod-ends allows for a greater escapement of juvenile roundfish, thus reducing the discard level. As illustrated in Figure 5.26, the square mesh allows for passage of a given sized roundfish at a slightly smaller mesh size than the diamond mesh. When the diamond mesh is contorted, as when added tension is placed on the mesh from the weight of a full bag, only small roundfish are able to escape through the mesh. By contrast, square mesh is not so distorted when under load. Thus, the retention characteristics of square mesh remains much more consistent. Preliminary results of experiments conducted by MIT Sea Grant indicate that conventional diamond mesh "necks down" in the wing and forward sections as well as the cod end when it is loaded with fish. Square mesh demonstrates less "necking down". An additional important feature of square mesh is that it will retain relatively smaller flatfish than similar sized diamond mesh (Figure 5.26).

It would appear, therefore, that use of square mesh similar in size to conventional diamond mesh may be very beneficial in reducing juvenile roundfish mortality in the fishery. However, the specification of an appropriate square mesh in regulating the fishery is premature at this time since comparative studies with conventional diamond mesh need to be done in local waters. Additionally, there is a need to complete data analysis for the retention of small flatfish in square mesh nets.

§5.6 Fishing Mortality

As discussed in §5.4, the two dimensions to the overall problem of achieving a desired level of total reproductive potential are fishing mortality rate and age at entry to the fishery. These two factors must be simultaneously considered in developing the management program. The concept of age at entry and the means by which it may be manipulated were discussed in §5.5. The following is a discussion of various aspects of fishing mortality.

The concept of fishing mortality rate, as used in this document, is the instantaneous rate of change in the size of the population as the result of fishing. The instantaneous fishing mortality rate (F) is a logarithmic function, but at low rates of F (ie., F = 0-0.3) it approximates the fraction of the fish population which is annually removed by fishing. Of course, not all deaths among fish populations are due to fishing activity. Death caused by predation, disease, accident, senility, etc., collectively comprises the natural mortality rate (M). As in the case of fishing mortality, M is calculated as an instantaneous rate using a logarithmic function. The sum of the two, F and M, is the total mortality rate (Z).

Robertson, J.H.B. Square mesh cod-end selectivity experiments on whiting (*Merlangius merlangus* (L)) and haddock (*Melanogrammus aeglefinus* (L)). ICES Fish Capture Committee, Working Group Meeting, Ijmuiden 1983.

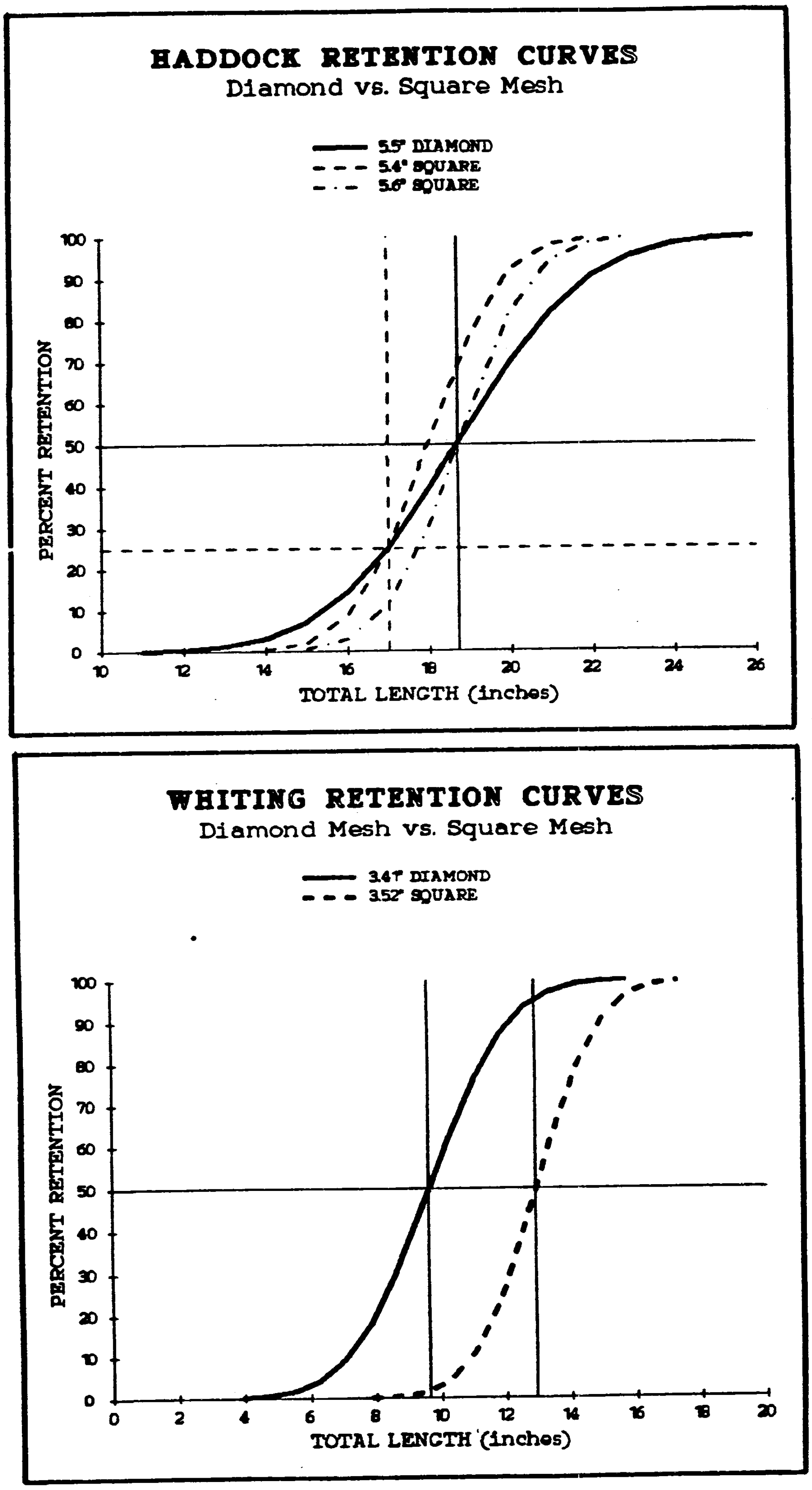


Figure 5.25. Comparative retention curves for haddock and whiting using square mesh versus diamond mesh cod-ends.

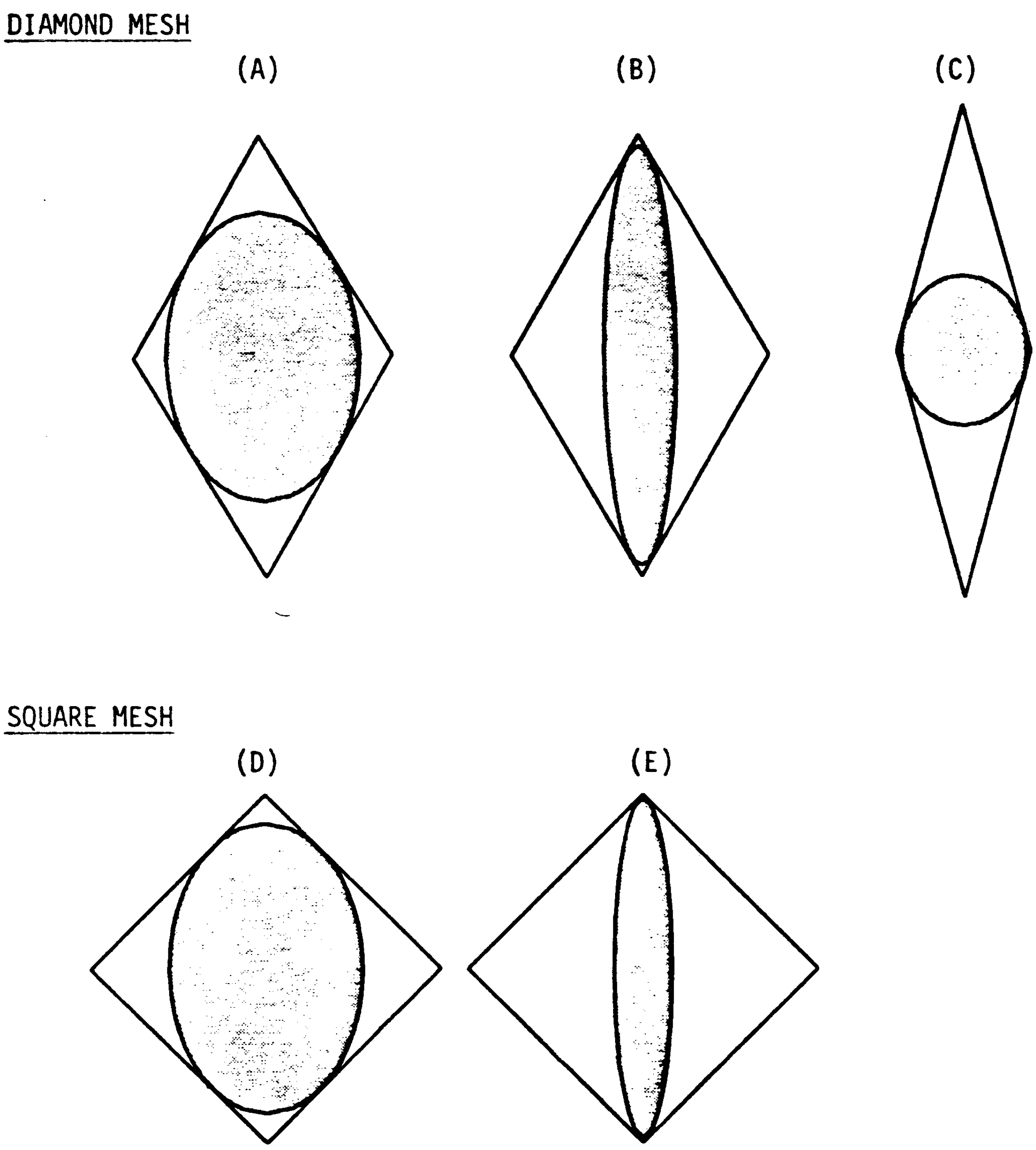


Figure 5.26. **Diagrammatic representation of cross-sections of fish able to pass through diamond mesh and square mesh.**
Diamond mesh: (A) roundfish, and (B) flatfish, (C) distortion of diamond mesh under heavily loaded conditions causes it to select for much smaller roundfish.
Square mesh: (D) same sized roundfish as in (A), and (E) flatfish. Note that the mesh bar is slightly shorter than that for the diamond mesh which will select for the same sized roundfish. Also note that the square mesh will retain smaller flatfish.

Sources of Fishing Mortality It is understood that fishing mortality is that portion of total mortality which is ascribable to fishing activity, but how does such activity translate to the observed level of F? The most obvious source of fishing mortality is from the operation of fishing gear with the intent to capture a specific species of fish. Such is a directed fishery which will exert a certain directed mortality. Only in very rare instances does fishing gear capture only those species which are specifically targetted. In the usual situation, other species of fish, not specifically sought, may also be captured. In such cases, the fishing mortality exerted on those other species comprises the incidental mortality. The fish captured in this fashion are often called "by-catch". In the "real world" operational sense, these two categories of fishing mortality may be interchangable with respect to a particular species, depending upon the specific intentions of the fisherman at any moment in time. In the ideal case, from the energetic standpoint of population dynamics, the only sources of fishing mortality would be directed and incidental, and in combination would be held constant at the optimum level which maximizes fish production. Various ramifications of that relationship may be examined using yield-per-recruit analysis.

Ordinarily, among those species of fish which have a commercial value and generate revenue in commercial enterprises, there is a minimum size for those fish of a particular species which enter into such commerce. Minimum sizes may be explicitly levied through regulations or they may be implicit in the size having acceptance by the fish processing industry. We have seen in §5.5 that fishing gear may be modified with the intent to target on specific sizes of fish, but the gear has inherent limitations in that regard. As a consequence, fish smaller than any specified minimum standard will be caught. In the case of the more hearty species, crustaceans and shellfish in particular, the undersize individuals taken in the catch may survive being culled out and returned to the sea. Among nearly all of the commercially important finfish, however, the discarded individuals do not survive. This exerts a certain discard mortality. Fish may be discarded from directed or incidental catches of important species or simply because they may be species with little or no economic importance. In the long-range perspective, it makes little sense to waste undersized individuals of the important species. Thus, again from that perspective, it is appropriate to reduce discards of such species to the maximum extent possible.

Options for Limiting Fishing Mortality A wide range of possible options are available for limiting the fishing mortality rate. Generally, these range from the more direct controls on total fishing effort, which are potentially the most intrusive in the conduct of fishing enterprises, to more benign measures which act in an indirect manner to effect changes in fishing mortality. The measures chosen should give fishermen the greatest possible freedom of action in conducting business and pursuing recreational opportunities while remaining consistent with ensuring wise use of the resource.

Direct methods for limiting the fishing mortality rate generally include any means for controlling the total amount of applied fishing effort. In operational terms, this means controlling the total number of fishing days at sea (or some other appropriate unit of fishing effort) by limiting the number of vessels which may participate in the fishery or the number of units of effort each vessel may be permitted to exert or a combination of both. Any predetermined level of fishing mortality (arrived at, for example, by yield-per-recruit analysis) may conceptually result from application of these types of measures. However, embedded within such an approach are certain disadvantages. The quantitative relationship between fishing effort and fishing mortality is well understood in only rare instances. Thus, only an approximation of the desired level of fishing mortality may ordinarily be achieved. Moreover, that relationship is subject to continuous change from technological improvements in gear and techniques. From an industry perspective a significant disadvantage may be that the benefits of unusually high levels of resource abundance cannot be fully captured as they occur.

Another direct method for limiting fishing mortality is the use of a regulated minimum size. In this case, the intent is to limit fishing mortality on a particular segment of the population, the juveniles and prerecruits. Such a measure may be very effective in limiting deaths from fishing among undersized individuals, particularily in the case of the heartier species which are able to survive being caught. In most finfish taken in commercial operations, however, such is not the case. If the minimum size measure is applied to all segments of the industry, then a certain benefit may result from an incentive to avoid concentrations of small fish when found.

Perhaps the most commonly used indirect method for limiting fishing mortality is through the imposition of catch quotas. For any given level of resource abundance, there is a calculable relationship between total catch and the fishing mortality rate. Given an adequate assessment of resource abundance, then an appropriate level of fishing mortality (in the context of the goals of management) may be achieved through proper specification of the total catch quota. This approach avoids many of the pitfalls of setting a direct cap on fishing mortality described above, but in operation is subject to two major disadvantages. Traditionally, there has been a dichotomy of interest between the fishing community and the management agency with regard to management goals in the short-term context. Management goals appropriate to quota management are typically oriented towards maintenance of spawning stocks. During periods of low resource abundance, the fishing community has an interest in exploiting those abundances at a level sufficient to preserve the integrity of the community. But that interest conflicts with the perceived responsibility of the management agency to maintain a long-term perspective in its approach to those management goals. The other major disadvantage to quota management is due to its reliance on quantitative stock assessments. The quantitative assessment of a stock of fish is not and never will be an exact science. Therefore, there will always be differing perceptions of resource abundance by the fishing community versus the assessment scientists such that the latter will be unable to categorically answer many of the objections raised by the former.

Another indirect approach to limiting the fishing mortality rate is through the use of closed seasons and/or areas. Such an approach may be effective provided that the availability of the resource or a segment thereof may be definable in terms of a specifiable time or space. Of course, it should be recognized that the overall impact upon fishing mortality will depend on the availability of fish at other times and in other areas. For example, the intent may be to reduce the fishing mortality on juveniles. Provided that certain areas may be definable as nursery areas, then those areas could be closed to fishing during the period of the year that concentrations of juveniles are in residence. The same approach could be applied in the case of known spawning areas with the intent of avoiding disruption of spawning activity. However, to the extent that a spawning closure corresponds in time and place to dense concentrations of spawners, it may represent to the industry a foregone opportunity to efficiently make good catches of fish.

Finally, it is possible to effect indirect limitations of the fishing mortality rate by controlling the kinds of fishing gear which may be employed. One approach is to specify certain types of gear which have inherent limitations in efficiency. A good example was the requirement, for many years, to use only sailing vessels in the Chesapeake oyster dredge fishery.

The more general approach, which has been applied in a wide variety of fisheries, is to specify certain minimum dimensions in the construction of the gear such that smaller individuals are less likely to be captured. A detailed discussion of the role that mesh size plays in the multispecies fishery appears in §5.5 of this document. A minimum mesh size may be specified with the intent to limit fishing mortality on juveniles and prerecruits within the multispecies resource. To the extent that the mesh size chosen is appropriate to a given species and, in fishing operations, is efficient in making a distinction between adults and undersized fish, this approach will meet that intention. It has been pointed out, however, that mesh size (particularily the commonly employed diamond mesh) has inherent limitations in making that distinction. The greatest difficulty in applying mesh size to the multispecies fishery with the intent to limit fishing mortality on undersized fish is the fact that each of the component species within that fishery may have its own unique (most appropriate) mesh size. This difficulty may be minimized if we consider only the most important species within the overall mixture. That compromise is a necessary precursor to the choice of standard mesh sizes, but it should be accompanied with the recognition that certain minor component species may be exploited at less than optimum conditions. A close examination of the important component species within the multispecies resource reveals that many of those species may appropriately be harvested with standardized, relatively large sized mesh, whereas a limited number of other important species require use of smaller sized mesh. Additional compromises are necessary to resolve these conflicting imperatives. Nevertheless, if mesh size is to be used as a management measure in the multispecies fishery to limit the fishing mortality on juvenile fish, then the small-mesh fisheries must be strictly limited in time and space to the minimum absolutely necessary to successfully prosecute those fisheries. The alternative is that mesh-size will be an ineffective measure in the prevention of recruitment overfishing.