A Population Assessment of the Butterfish *Peprilus triacanthus* in the Northwestern Atlantic Ocean

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ABSTRACT

Nominal landings of butterfish, *Peprilus triacanthus* (Peck), in the Northwest Atlantic increased from 3,209 MT in 1964 to a peak of 19,454 MT in 1973. Most of the catch during this period was taken by Japan, USSR, Poland, and the USA. Unreported butterfish by-catch in the long-finned squid, *Loligo pealei*, fisheries of several nations, particularly Spain and Italy, were probably significant additional sources of mortality. Available scientific evidence indicates that during the period 1968-1976, fishing mortality rates increased, while mean weight of individuals in the exploitable population and average age at capture generally declined. Exploitation rates (E) during 1972-1975 ranged from 0.35-0.42. Yield per recruit studies (M=0.8) suggest that E_{max} and $E_{0.1}$ values are 0.37 and 0.27 for a 30 mm mesh net, and 0.55 and 0.36 for a 60 mm one. Mean weights of fish in the catch, at $E_{0.1}$, would be 66% greater for the larger net (92.128 g), than for the smaller mesh (55.42 g). Equilibrium catches resulting from the average annual recruitment of 1,138.5 x 10^6 fish are 14,540 MT (30 mm mesh) and 18,945 MT (60 mm mesh), assuming $E_{0.1}$. The maximum long term yield from the stock given stable annual recruitment is 21,635 MT, assuming that $F_{0.1}$ is the maximum F that will not adversely effect recruitment.

INTRODUCTION

Landings of butterfish, *Peprilus triacanthus* (Peck), increased significantly off the Northwestern Atlantic coast of the United States with the advent of distant water fleet fishing activity in 1963. Catches reported to the International Commission for the Northwest Atlantic Fisheries (ICNAF) increased from 3,209 metric tons (MT) in 1964 to 19,454 MT by 1973. Nominal landings during this period were primarily by Japan, USSR, Poland, and the USA. A considerable unreported by-catch of butterfish was evident in squid fisheries pursued by several countries, with much of the catch discarded at sea (López-Veiga and Labarta 1975; Nagasaki 1976; Waring 1975). Concern for the status of butterfish in the ICNAF convention area was demonstrated by the recommendation of a total allowable catch (TAC) for 1977 for 18,000 MT (ICNAF 1977; U.S. Dept. Comm. 1976). This figure was judged to be precautionary in nature, since a detailed assessment was not available at the time.

In the present study we have integrated available biological data with USA research vessel survey information and commercial catch statistics to determine the present status of the population, and harvests resulting from varying assumptions of population parameters and size at selection by the fishing gear.

BIOLOGY

Meristic and morphometric studies by Caldwell (1961) and Horn (1970) have established that depth isolated populations of butterfish exist in the Atlantic. Caldwell proposes one population south of Cape Hatteras to Florida, distributed to 22 m, and another group in all waters north of Cape Hatteras and deeper than 22 m to the south. Horn examined specimens from both localities and concluded the two groups were distinct. For the purposes of this study all reported distant water fleet catches, and U.S. landings north of Cape Hatteras are considered to come from the northern stock.

Butterfish north of Cape Hatteras display definite migratory patterns associated with water temperature, and have developed seasonal migrations similar to Atlantic mackerel, *Scomber scombrus*, weakfish, *Cynoscion regalis*, and the long-finned squid, *Loligo pealei*, (Horn 1970; Waring 1975). North of Cape Hatteras summer movements are inshore and northward, however, to the south there is no storng inshore/offshore translocation (Fritz 1965; Caldwell 1961; Horn 1970). The range extends northward to Nova Scotia and Prince Edward Island, although commercial concentrations generally do not occur north of Georges Bank. Butterfish retreat to the edge of the shelf in late autumn as inshore waters cool. The winter distribution in the Middle Atlantic area appears to be at the edge of the continental shelf in waters 200-230 m deep (Heald 1968; Horn 1970).

Spawning occurs once per year, usually from May to July (Hildebrand and Schroeder 1928; Pearson 1941; Bigelow and Schroeder 1953). Seasonal

gonadosomatic indices are unimodal, peaking in June (Wilk et al. 1975; Kawahara 1977). Spent individuals migrate inshore, after spawning a few miles seaward of the coast (Bigelow and Schroeder 1953). DuPaul and McEachran (1973) reported that butterfish in the Chesapeake Bay are fully recruited to the spawning population at the end of their second year, as 37 of 56 age I fish examined were maturing, and all age II individuals were in spent or resting condition. Wilk et al. (1975) reported that from March to June immature or indeterminate specimens comprised 12.5-35.8% of samples in the New York Bight.

Age and growth studies of butterfish using otoliths have been conducted by Draganik and Zukowski (1966), DuPaul and McEachran (1973), Waring (1975), and Kawahara (1977). In the latter three studies the population was composed of four age groups (0+ - III+), while Draganik and Zukowski reported the maximum age as six. Back-calculated lengths at age were significantly smaller within Chesapeake Bay (DuPaul and McEachran 1973) than farther offshore (Kawahara 1977). The von Bertalanffy equation describing growth in length of the population, given by Kawahara (1977) is: $\ell_t = 210.2 \{1-\exp(-0.8618(t + 0.0699)\}$ and the corresponding length/weight equation is: $w = 1.635 \times 10^{-6} L^{3.4920}$ (fork length (L) in mm, total weight (w) in g). According to the von Bertalanffy equation, growth is fastest during the first year and incremental increases in length are smaller as the fish age. The value of K is quite high, characteristic of fast-growing, short-lived fishes. Age data presented by Kawahara (1977) suggest annulus formation in July, and we have adopted this convention in assigning age class designations to cohorts in our analyses.

Butterfish feed on a variety of invertebrates including tunicates, crustaceans, chateognaths, polychaetes, ctenophores and cnidarians (Maurer

and Bowman 1975; Haedrich 1967). In turn they provide a substantial portion of the diet of a number of fishes including haddock, *Melanogrammus aeglefinus*, silver hake, *Merluccius bilinearis*, swordfish, *Xiphias gladius*, bluefish, *Pomatomus saltatrix*, and weakfish (Horn 1970; Bigelow and Schroeder 1953).

DEVELOPMENT OF THE FISHERY

Butterfish off the Northeast coast were landed entirely by U.S. fishermen during the period 1920-1962, with catches averaging 3,500 MT per annum (Waring 1975). From 1963 to 1967 yearly landings fluctuated around 5,000 MT. After 1967, reported landings increased dramatically, peaking in 1969 (17,511 MT) and again in 1973 (19,454 MT) (Table 1). Japan, USSR, Poland and the USA accounted for most of the catches during recent years.

Catches by U.S. fishermen were primarily taken after the spawning season when butterfish are inshore. Seasonal domestic landings were greatest in early autumn (Waring 1975). Landings by the Japanese, coincident with the offshore *Loligo* squid fishery, were taken from November to April with a maximum in November and January (Kawahara 1977). Virtually no butterfish were landed by foreign fleets during the summer when the resource is inshore and available to the domestic fishermen.

By-catch of butterfish during the *Loligo* fishery was considered to be significant. López-Veiga and Labarta (1975) stated that butterfish was the main species in the by-catch of both the Spanish *Loligo* and *Illex illecebrosus* fisheries, although Spain had never reported any butterfish catches (Waring 1975). Data presented by López-Veiga and Labarta indicate that the monthly by-catch

ranged from 3.15% (February) to 38.2% (September) of the entire catch in the directed squid fisheries during 1973 and early 1974. Italy landed significant quantities of squid in the convention area from 1972-1976, however, their butterfish catches have also not been documented (Tibbetts 1977; Waring 1975).

Nagasaki (1976) reported the ability of Japansese fleets to direct effort at either *Loligo* or butterfish, when they inhabit the same gounds, however, the following evidence suggests that the ratio of *Loligo* to butterfish in Japanese catches was generally similar to the annual relative species abundance as determined from research survey information for the period 1969-1975.

The average ratio (kg/tow) of *Loligo* to butterfish was calculated for spring and autumn research vessel bottom trawl surveys from 1969-1975 (Grosslein 1969). Indices were developed for the combined Southern New England and Middle Atlantic strata (Figure 1). Butterfish catches from the spring surveys (in weight) from 1973-1975 were divided by a factor of 1.35 to account for the larger survey net used, however, *Loligo* catches required no adjustment, based on results of gear mensuration studies involving the two survey nets (Sissenwine and Bowman 1977). Spring and autumn survey ratios for the same year were averaged to derive single ratios applicable to the entire year. The ratio of *Loligo*/butterfish landings reported by Japan was plotted against the survey ratio, indicating a general linear correlation (Figure 2). In 1972 there was a much higher ratio of *Loligo* to butterfish in the Japanese commercial catch than in the surveys. However, commercial catch ratios for other countries landing significant amounts of *Loligo* and butterfish in 1972 (e.g. USA, Bulgaria, USSR) more closely

approximated the survey data than the Japanese catches. The implication of the close agreement of survey and commercial landings ratios is that catches (including discards) of butterfish can be approximately determined by knowing the total landings of *Loligo*, and the relative survey abundance of both species. Assuming countries reporting *Loligo* but not butterfish landings did not discard squid, butterfish by-catch was approximated from the survey ratios by multiplying nominal *Loligo* catches by survey ratios to account for butterfish discards of those countries reporting only *Loligo*. If fishing patterns of countries not reporting butterfish are non-random with respect to relative availability *Loligo* and butterfish then these estimates may be inflated. The resulting total catches are listed in Table 1. The most significant change was in 1973, when the total catch increased 71% to 33,236 MT. The adjusted figures must also be regarded as under-estimates of total catch, since there are no data on discards by those countries reporting butterfish landings.

DYNAMICS OF THE POPULATION

Age Composition of the Catch

Length frequency sampling of butterfish catches by ICNAF member countries has been quite limited. Frequencies have been supplied by Japan, USSR, and the USA. Japan has provided first quarter frequencies since 1970, however, data reported for other quarters, and by the other countries has been intermittent. Since at least one length sample was reported for each quarter, beginning in 1970, all samples within a quarter were combined, weighting by individual sample size, to yield an overall quarterly frequency distribution. The length composition of the catches in 1968 and 1969 were derived from semi-

annual NMFS bottom trawl survey samples. Age frequencies were then calcuated by applying the quarterly age/length keys of Kawahara (1977) to the length frequencies.

Japanese first quarter length and age frequencies from 1970-1976 are presented in Figure 3. The age distribution of the catch remained stable from 1970-1972, with I+ individuals dominating the catch. A considerable proportion of the landings in 1973 were of those fish spawned the previous summer. From 1974-1976 age group 0 and I fish were essentially co-dominant in the samples. Thus, a trend of decreasing age at recruitment to the fishery is notable since 1970.

The annual catch in numbers at age was calculated in the following manner. The age composition in weight of each quarterly sample was derived by multiplying the percent age frequency of numbers by the mean weight at age (Table 2, determined from Kawahara 1977), and dividing the sum of weights over all ages. The proportion at each age (in weight) was then multiplied by the commercial catch, yielding estimates of the total catch by age. Finally, the annual number caught in each year class was calculated by dividing the quarterly catch at age by the average weight, and summing the quarterly estimates.

Table 2 near here

The calculated annual catches (numbers of fish) by year class for the period 1968-1976 are presented in Table 3. Total catches in numbers were greatest in 1973, followed by 1974, 1969, and 1976. The mean weight of fish ($\overline{w}$, g) was calculated by dividing the total catch in weight by the number caught. Mean weights were largest in 1970 and 1974, and relatively small in 1968 and 1973.

Table 3 near here

Survey Abundance Indices

The relative abundance of butterfish was calculated from USA bottom trawl research surveys utilizing data for the Southern New England and Middle Atlantic strata (1-12 and 61-76; Figure 1). Survey catches from the Georges Bank and Gulf of Maine areas were not included in the analysis since catches there were relatively smaller and less consistent than those further to the south. The mean catch per tow of numbers and weight (linear, $\log_e N+1$) were first calculated, then $\log_e$ values were re-transformed according to: $E(\overline{Y}_{st}) = \exp(\overline{Y}_{st} + S^2/2)$ where $E(\overline{Y}_{st})$ is the estimated (re-transformed) stratified mean catch per tow and $\overline{Y}_{st}$ and S^2 represent the stratified mean and estimated population variance (Bliss 1967; Clark and Brown 1977). Estimates of the autumn abundance are given in Table 4. Variations in numbers per tow parallel corresponding calculations in weight. Largest re-transformed catches (in weight) were in 1976, followed by 1973, and 1968, while butterfish catches were smallest in 1970, and 1972. Numbers per tow peaked in 1976, 1973, and 1971, and were low in 1970 and 1972. Autumn survey indices generally correlate well with fluctuations in annual commercial catch (Table 1).

Table 4 near here

The mean weight of individuals caught during the surveys is expressed in Figure 4. Both spring and autumn data show a trend of declining average weights in recent years. This decrease may be attributable to two factors: (1) large year classes dominating the survey catches as juveniles and (2) a decrease in mean weight as fishing becomes more intense and larger individuals are removed. Although differential recruitment between cohorts may play an important role in causing large fluctuations in mean weight, the long-term

trend to smaller fish is probably due to increased fishing pressure. The persistent decline in the catch per tow indices of age I+, and II+ individuals in spring surveys since 1973 (Table 5), notwithstanding the presence of several strong year classes since 1971, clearly demonstrates the importance of increased fishing pressure to the decline in mean weights. The autumn mean weight has averaged 41.43 g since 1972, a figure quite close to the average weight of 0+ individuals in the fourth calender quarter (Table 2). Estimates of average weight in the spring and autumn 1976 samples were nearly identical (41.82, 41.86 g, respectively).

The total instantaneous mortality coefficient (Z) was estimated for each year class from 1968-1975, utilizing the spring survey mean catch per tow in numbers. Autumn data were not useful in this analysis since at this time juveniles are not fully recruited to the offshore survey areas. Spring length frequencies of catch per tow were partitioned into age classes utilizing the appropriate age/length key of Kawahara (1977). Total mortality coefficients of each year class were computed by regressing $\log_e$ number at age on coded age (Table 5). The approximate doubling of total mortality since 1968 has coincided with the tremendous rise in landings associated with the advent of distant water fleet activity.

Population Size Estimates

Stock size estimates at the beginning of each year (1968-1976) were computed by virtual population analysis (VPA, Pope 1972). Calculations of stock size for short-lived fishes utilizing this technique are particularly sensitive to variations in the natural mortality coefficient (M) and related

starting fishing mortalities (F). Since no studies of the natural mortality rate of butterfish have been conducted, we deduced a reasonable estimate of M by comparing total stock size estimates generated by various M values with the VPA, and biomass calculations based on areal expansion of survey catch per tow data for 1969-1973 (Waring 1975). Areal expansion estimates were adjusted to reflect diel changes in the vulnerability of butterfish to bottom trawls. Butterfish apparently undergo vertical migrations; staying relatively close to the bottom during daylight and dispersing upward at night.

Virtual population analyses were conducted with M values of 0.6, 0.8, 1.0, and 1.2, and starting F's for each year class scaled according to Z values from survey data (Table 5).

Biomass estimates from areal expansions of autumn catch per tow data averaged 61,630 MT from 1969-1973 (Waring 1975). Mean stock size from the VPA corresponding to the period of areal expansion estimates (1969-1973) were 40,483 MT, 61,762 MT, 113,162 MT, and 190,571, for M's of 0.6, 0.8, 1.0, and 1.2. Since areal expansion probably results in a minimum estimate, M is apparently at least 0.8. An M of 0.8 implies that the catch efficiency of survey gear (adjusted to daytime catches when butterfish concentrate close to the bottom) is nearly 100%. However, it should be noted that the estimates from expanded catch per tow were also minimum to the extent that a portion of the resource was inshore and/or north of the Southern New England and Middle Atlantic strata.

Stock size estimates (numbers), assuming M=0.8, are presented in Table 6. *Table 6 near her*
Corresponding stock biomass was derived by multiplying numbers at age by the

first quarter mean weights (Table 2), to calculate population size at the beginning of the year. A total stock size estimate for year n was determined by summing stock sizes in weight only for year classes n-1, n-2, n-3, and n-4, since year class n is not spawned until July. Overall stock size (1968-1976) varied from 31,896 (1976) to 70,631 MT (1973), averaging 53,571 MT.

Fishing mortality rates derived from the VPA with M=0.8 are listed in Table 7. Mean mortality rates increased substantially from 1968 (0.213) to 1974 (0.872). Relatively large variations in F's occur among fully recruited cohorts within years, perhaps due to the sensitivity of the analysis to starting F's and/or a violation of the assumption of constant natural mortality for all ages.

Table 7 near here

The apparent discrepancy in the estimates of relative stock size in 1976 between the survey data and the VPA (Table 4; Table 6) is due to a large 1976 cohort that was not reflected in virtual population size calculations at the beginning of the year. The larger year classes indicated by the VPA were in 1972, 1968, 1971, and 1973, while smaller cohorts were 1975, 1969, 1970, and 1974. These data are generally consistent with survey information. A large year class may not be evident in the autumn survey of the year it was spawned since juvenile fish are concentrated inshore during the early autumn. Depending on the timing of the cruise relative to climatic changes, juvenile fish may not be fully available to the offshore survey.

Annual landings during the period 1968-1976 averaged 31% of the initial yearly stock size (Table 6), with the proportion harvested (P) ranging

from 18% (1968) to 50% (1976). Annual exploitation rates (E, calculated from mean F's from the VPA and M=018) parallel the calculations of the portion of initial biomass harvested, even though computations of P and E are based on weights and numbers of fish respectively.

YIELD ANALYSIS

Yield Per Recruit

Yield per recruit (Y/R) analyses were conducted for butterfish with the model of Paulik and Gales (1964), since an isometric length/weight relation could not be assumed. Fork Lengths at 50% selection (ℓ_c) were calculated utilizing Meyer and Merriner's (1976) empirical selection factor of 1.8. Analyses were conducted for stretched mesh sizes of 30 mm (ℓ_c=54 mm) 60 mm (ℓ_c=108 mm), 80 mm (ℓ_c=144 mm), and 100 mm(ℓ_c=180 mm). Various values of M, ranging from 0.6 - 1.2 were also included. The following data were used as input parameters to the model:

L_∞ = 210.2 mm	β = 3.4920
W_∞ = 210.9 g	M = 0.6 - 1.2
K = 0.8618	F = 0.01 - 2.50
t_o = -0.0699 yrs	t_λ = 6.0 yrs
t_r = 0.25 yrs	t_c = 0.275, 0.767, 1.271, 2.182 yrs

Values of $F_{0.1}$ (Gulland and Boerema 1973) were determined to be the point at which the marginal increase yield per recruit was 10% of the yield at F = 0.01. Exploitation rates corresponding to F_{max} and $F_{0.1}$ were computed from:

$$E = \frac{F\ (1 - \exp\ (-Z))}{Z}$$

Calculations of yields, fishing mortalities, and exploitation rates for various combinations of mesh size and natural mortality rate are listed in Table 8. Transverse isopleth sections for M = 0.8 are presented in Figure 7. If M = 0.8, maximum yield per recruit (>26.48 g) occurs with the 80 mm mesh, at F>2.50. If a 60 mm mesh net is used, a maximum yield of 22.07 g could be harvested with an F of 1.33. Utilizing $F_{0.1}$ computations 23.04 g can be derived with F = 0.96 and a mesh of 80 mm, however, with a 60 mm mesh, 20.32 g can be taken at an F of only 0.69 (Figure 5, Table 8).

Table 8 near here

Exploitation rates (E_{max}, $E_{0.1}$) are only slightly different among M values within mesh size categories (Table 8). Thus, these calculations are not highly sensitive to the absolute value of the natural mortality coefficient. Figure 6 summarizes the relations between stretched mesh size (mm) and $E_{0.1}$. The calculated regression equations describe more than 99% of the variation about the lines for all M values, therefore, $E_{0.1}$ for a particular mesh size within the range 30 to 100 mm (assuming a selection factor of 1.8) can be accurately computed.

The theoretical mean weight of individuals in the catch was estimated for several exploitation rates by dividing yield (in weight) per recruitment by the number of fish harvested from that cohort over its life span. Curves of the mean weight vs. exploitation rate for the 30 mm and 60 mm mesh sizes are presented in Figure 7. Assuming the average exploitation rate from 1974-1976 was 0.43 (Table 6), then average weight in the catch should have equalled 40.73 g if a 30 mm mesh was used, and 87.99 g if the net was 60 mm. The Japanese have traditionally used a 30 mm mesh inside a 60 mm one in their

squid-butterfish fisheries, however, trawls used by US fishermen averaged 66 mm in the industrial fishery and 114 mm for the food fishery (Waring 1975). Mean weights of fish in the US. survey catches in 1976 (spring and autumn average = 41.84 g) are quite close to those predicted with the 30 mm mesh. However, mean weights in the fishery (Table 3, 1976 average 92.82 g) more closely approximate those derived with the larger net. The apparent discrepancy may reflect culling of small butterfish (<15 cm, FL) taken with the small mesh nets. The relative proximity of estimates from yield per recruit analyses to data from the fishery and surveys tends to validate our assumptions of population parameters.

Equilibrium Yield

The total harvest of butterfish is a function of the number of recruits entering the population, fishing mortality, and the age at entry to the fishery. If the 30 mm mesh is used (ℓ_c = 54 mm, FL) a considerable portion of the stock will be harvested prior to initial spawning since effort is concentrated in the late autumn and winter months, and butterfish are only partially recruited to the spawning population at age I. However, if age at selection is prolonged, harvest rates resulting in maximum yield increase to the point that very little of the adult stock survives the fishery, even though large increases in fishing rate result in only marginal gains in yield (Figure 5). Although arbitrary, values of $F_{0.1}$ are preferable to those resulting in maximum Y/R (F_{max}) when stock-recruitment relationships are considered. The reduction in fishing mortality rate from F_{max} to $F_{0.1}$ results in only minor

decreases in Y/R, while preserving a larger portion of the spawning stock. A positive stock-recruitment relationship has not been conclusively demonstrated for butterfish but it is clear that more progeny will be generated by fishing at $F_{0.1}$ than at F_{max}.

The total catch from a given number of recruits can be simulated utilizing the yield per recruit model. The mean number of fish entering the population from 1968-1975 was $1{,}138.5 \times 10^6$ (Table 6). Assuming ages at selection for the 30 mm and 60 mm meshes are 0.275 and 0.767 yrs, then the average numbers of recruits alive at t_c are:

$$1{,}138.5 \times 10^6 \cdot \exp-(0.8)(0.275) = 913.7 \times 10^6$$

and

$$1{,}138.5 \times 10^6 \cdot \exp-(0.8)(0.767) = 616.4 \times 10^6$$

Yields associated with $E_{0.1}$ ($F_{0.1}$(30 mm) = 0.47; $F_{0.1}$ (60 mm) = 0.69) are:

30 mm mesh (t_c = 0.275 yrs) = 14,540 MT

60 mm mesh (t_c = 0.767 yrs) = 18,945 MT

Thus yield at $F_{0.1}$ from the average recruitment for 1968-1975 ranges from 14,540 MT to 18,945 MT, depending which mesh size is used. Average nominal landings during the period were 11,685 MT per year, with an adjusted mean catch of 16,123 MT. Since both mesh sizes were used at the time, the fact that the total adjusted catch was between our yield calculations indicates the population was utilized near $E_{0.1}$. Maximum yield at $F_{0.1}$ was computed by iterating Y/R calculations with respect to mesh size (1 mm increments). Maximum catch at $F_{0.1}$ given constant recruitment was 21,635 MT at a mesh size of 82 mm and $F_{0.1}$ = 1.01.

CONCLUSIONS

Total mortality rates derived from survey numbers per tow at age, fishing mortality rates from virtual population analysis, and mean weights in the survey and landings indicate that exploitation of Northwest Atlantic butterfish increased rapidly from 1968-1976. Juvenile fish have comprised a considerable portion of the catch since 1973. Calculated exploitation rates from 1974-1976 (0.40 - 0.46) were slightly greater than the values of $E_{0.1}$ for 30 mm and 60 mm mesh sizes of 0.27 and 0.36. Survey data for 1976 indicate an autumn stock size equivalent to the peak in 1973. If average recruitment is maintained, then equilibrium total catches associated with $E_{0.1}$ range from 14,540 to 18,945 MT depending on if 30 or 60 mm mesh is in use. Predicted mean weights of fish in the catch are 66% larger for the 60 mm mesh net (92.23 g) than for the 30 mm net (55.42 g). If $F_{0.1}$ is assumed to be the maximum F that will not adversely effect recruitment, the maximum long term yield from the stock, assuming constant annual recruitment is 21,635 MT.

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REFERENCES

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish. Wildl. Serv. Fish. Bull. 53(74): 577 p.

Bliss, C.I. 1967. Statistics in biology; statistical methods for research in the natural sciences, Vol. I, 558 p. McGraw-Hill, N.Y.

Caldwell, D.K. 1961. Populations of the butterfish, *Poronotus triacanthus* Peck), with systematic comments. Bull. South. Calif. Acad. Sci. 60(1): 19-31.

Clark, S.H., and B.E. Brown. 1977. Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras 1963-1974, as determined from research vessel survey data. U.S. Nat. Mar. Fish. Serv. Fish. Bull. 77(1): 1-21.

Draganik, B., and Cz. Zukowski. 1966. The rate of growth of butterfish (*Poronotus triacanthus* (Peck)) and ocean pout (*Macrozarces americanus* (Schneider)) from the region of Georges Bank. ICNAF Res. Doc. 66-42. 3 p.

DuPaul, W.D., and J.D. McEachran. 1973. Age and growth of the butterfish, *Peprilus triacanthus*, in the lower York River. Ches. Sci. (14)3: 205-207.

Fritz, R.L. 1965. Autumn distribution of groundfish species in the Gulf of Maine and adjacent waters, 1955-1961. Am. Geol. Soc., Ser. Atlas. Mar. Environ., Folio 10: 48 p.

Grosslein, M.D. 1969. Groundfish survey program at BCF Woods Hole. Comm. Fish. Rev. 31(8-9): 22-35.

Gulland, J.A., and L.K. Boerema. 1973. Scientific advice on catch levels. U.S. Nat. Mar. Fish. Serv. Fish. Bull. 71(2): 325-335.

Haedrich, R.L. 1967. The stromateoid fishes: systematics and a classification. Bull. Mus. Comp. Zool. 135(2): 31-139.

Heald, E.J. 1968. Atlas of the principal fishery resources on the continental shelf from New York to Florida. Inst. Mar. Sci. Univ. Miami, 225 p.

Hildebrand, S.F., and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. Bull. U.S. Bur. Fish. 43(pt.1): 388 p.

Horn, M.H. 1970. Systematics and biology of the stromateid fishes of the genus *Peprilus*. Bull. Mus. Comp. Zool. 140(5): 165-261.

ICNAF. 1977. Proceedings of the Ninth Special Meeting, December 1976, 27th Annual Meeting, June 1977. 172 p.

Kawahara, S. 1977. Age and growth of butterfish, *Poronotus triacanthus* (Peck) in ICNAF Subarea 5 and Statistical Area 6. ICNAF Res. Doc. 77/VI/27. 13 p.

López-Veiga, E.C. and E. Labarta. 1975. Some observations on the Spanish squid (*Illex* and *Loligo*) fishery in Subarea 5 and Statistical Area 6 of the ICNAF. ICNAF Working Paper No. 3. 16 p.

Maurer, R.O., Jr., and R.E. Bowman. 1975. Food habits of marine fishes of the northwest Atlantic - data report. U.S. Nat. Mar. Fish. Serv., Northeast Fish. Center, Woods Hole Lab. Ref. 75-3: 90 p.

Meyer, H.L. and J.V. Merriner. 1976. Retention and escapement characteristics of pound nets as a function of pound-head mesh size. Trans. Am. Fish. Soc. 105(3): 370-379.

Nagasaki, F. 1976. By-catch in Japanese squid-butterfish fisheries of Subarea 5 and Statistical Area 6. ICNAF Working Paper No. 76/XII/158. 7 p.

Paulik, G.J. and L.E. Gales. 1964. Allometric growth and the Beverton-Holt yield equation. Trans. Am. Fish. Soc. 93(4): 369-381.

Pearson, J.D. 1941. The young of some marine fishes taken in lower Chesapeake Bay, Virginia, with special reference to the gray sea trout, *Cynoscion regalis* (Bloch). U.S. Fish. Wildl. Serv. Fish. Bull. 50(36): 79-101.

Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. ICNAF Res. Bull. 9: 65-74.

Sissenwine, M.P. and E.W. Bowman. 1977. Fishing power of two bottom trawls towed by research vessels off the Northeast Coast of the USA during day and night. ICES Gear and Behavior Comm. C.M. 1977/B:30. 12 p.

Tibbetts, A.M. 1977. Squid fisheries (*Loligo pealei* and *Illex illecebrosus*) off the Northeastern Coast of the United States of America, 1963-1974. ICNAF Selected Pap. No. 2: 85-109.

U.S. Dept. Comm. 1976. Draft environmental impact statement/preliminary fishery management plan for other finfish. U.S. Dept. Comm. NOAA, NMFS. 85 p.

Waring, G. 1975. A preliminary analysis of the status of butterfish in ICNAF Subarea 5 and Statistical Area 6. ICNAF Res. Doc. 75/74 32 p.

Wilk, S.J., W.W. Morse, D.E. Ralph, and E.J. Steady. 1975. Life history aspects of New York Bight finfishes. Unpubl. Rpt. Nat. Mar. Fish. Serv., Sandy Hook Lab. 265 p.

Table 1. Nominal landings (MT, ICNAF SA 4-6) by country, and adjusted total catches[a], 1963-1976.

Year	USA	Japan	USSR	Poland	Bulgaria	GDR	Romania	Ireland	Nominal Total	Adjusted catch
1963	4513		2285						6798	6798
1964	2461		748						3209	3209
1965	3340		749						4089	4089
1966	2615		3865						6480	6480
1967	2452	146	2170						4768	4768
1968	1804	3526	1911						7241	7241
1969	2438	3930	11107		36				17511	17816
1970	1869	8624	404						10897	14319
1971	1570	5771	486		26				7853	10483
1972	819	3675	1848		114	34			6490	13040
1973	1557	12172	2334	2804	239	196	152		19454	33236
1974	2528	5457	1372	3508					12865	17993
1975	2088	3624	789	3754	298	1		612	11166	14852
1976	1528	7884	420	1518	4	3	62		11419	15837

[a]Adjusted to account for discards of countries not reporting butterfish catches from the *Loligo* fishery.

Table 2. Mean butterfish weight (kg) by calendar quarter, adapted from Kawahara (1977).

Age	July-Sept.	Oct.-Dec.	Jan.-Mar.	Apr.-Jun.
0+	--	0.040	0.047	0.055
1+	0.056	0.101	0.104	0.104
2+	0.099	0.153	0.163	0.152
3+	0.150[a]	0.222	0.219	0.183

[a]Adjusted from 0.111 kg

Table 3. Butterfish catch ($x10^{-6}$ fish), ICNAF SA 4-6, 1968-1976.

Year Class	YEAR 1968	1969	1970	1971	1972	1973	1974	1975	1976
1964	0.02								
1965	3.94	0.03							
1966	19.80	8.05	1.45						
1967	68.11	51.03	23.97	2.31					
1968	10.90	109.81	58.95	19.45	4.47				
1969		9.51	39.86	43.88	25.30	0.21			
1970			13.89	27.27	44.57	7.06	3.03		
1971				10.55	25.60	87.90	30.87	1.43	
1972					39.09	309.84	74.87	18.35	3.26
1973						55.04	65.76	67.67	17.49
1974							21.66	63.32	74.08
1975								5.30	75.09
1976									0.71
Σ[a]	102.77	178.44	138.12	103.46	139.02	460.05	196.19	156.06	170.62
$\overline{w}$ (g)	70.46	99.85	103.68	101.32	93.80	72.24	103.09	95.17	92.82

[a]Totals may not equal Σ due to rounding error.

Table 4. Autumn USA survey butterfish catch per tow, Strata 1-12, 61-76, 1968-1975 76

	Catch per tow in Numbers			Catch per tow in Weight (kg)		
Year	linear	$\log_e$	re-transformed	linear	$\log_e$	re-transformed
1968	121.09	1.99	47.28	10.44	0.66	2.91
1969	76.93	2.16	57.25	5.32	0.66	2.72
1970	48.29	1.13	10.74	3.07	0.34	1.06
1971	242.17	2.19	112.00	5.45	0.58	2.29
1972	86.67	1.36	20.11	3.21	0.36	1.16
1973	178.03	2.35	124.08	8.39	0.75	3.70
1974	116.32	1.95	77.52	5.12	0.66	2.66
1975	52.47	1.69	36.19	2.94	0.58	1.80
1976	160.31	2.32	156.60	6.71	0.86	4.15

Table 5. Calculation of total instantaneous mortality (Z) utilizing number-per tow by age for NMFS spring surveys, 1968-1977.

Year Class	Stratified Number per tow at Age				Regression Coefficients for $\log_e$ No./Tow vs. coded Age[a]		
	0+	1+	2+	3+	r^2	a	b(= -Z)
1968	11.66	2.96	1.30	0.01[b]	0.980	3.462	-1.097
1969	10.04	2.36	1.24	0.31	0.981	3.322	-1.108
1970	26.36	4.22	8.00	0.33	0.768	4.546	-1.250
1971	313.31	40.17	3.68[b]	0.17[b]	1.000	7.801	-2.054
1972	44.09	9.05	1.89	0.18	0.989	5.745	-1.807
1973	22.12	6.88	1.82	0.18	0.972	4.918	-1.576
1974	162.24	5.12	1.04	--	0.957	7.304	-2.524
1975	36.40	4.39	--	--	1.000	5.710	-2.115
1976	4.21	--	--	--	--	--	--

[a]Coded Ages A_i = 1, 2, 3.....n for Ages 0+, 1+, 2+.....N+

[b]Not included in regression

Table 6. Butterfish stock size (x 10^{-6} fish), calculated from virtual population analysis (M = 0.8).

Year Class	YEAR 1968	1969	1970	1971	1972	1973	1974	1975	1976	
1964	1.9[a]									
1965	5.6	0.2								
1966	92.7	29.0	8.0							
1967	562.1	208.7	61.4	12.7						
1968	1684.2	750.3	266.6	82.2	24.6					
1969		823.3	363.7	137.7	34.3	1.2				
1970			847.5	371.8	149.4	39.0	13.0			
1971				1215.3	539.4	225.7	46.8	3.1		
1972					1976.8	862.5	194.1	40.7	7.0	
1973						1168.8	489.4	177.6	37.7	
1974							1024.0	446.1	159.7	
1975								368.1	161.9	
Stock size (S, MT) at beginning of year	41,022	61,740	56,580	67,976	51,884	70,631	53,663	46,750	31,896	$\bar{S}$ 53,571
Total catch (C, MT)	7,241	17,816	14,319	10,483	13,040	33,236	17,993	14,852	15,837	$\bar{C}$ 16,091
Portion of initial stock harvested (P)	0.18	0.29	0.25	0.22	0.25	0.47	0.34	0.32	0.50	$\bar{P}$ 0.31
Exploitation Rate (E)[b]	0.13	0.17	0.18	0.28	0.35	0.36	0.42	0.40	0.46[c]	$\bar{E}$ 0.31

[a]Calculated from 5.57 x exp (-1.1)

[b]$E = \frac{F(1 - \exp(-Z))}{Z}$

[c]Assumed

Table 7. Fishing mortality rates (F) for butterfish, calculated from virtual population analysis (M = 0.8).

Year Class	YEAR 1968	1969	1970	1971	1972	1973	1974	1975
1966	0.361	0.494	0.300					
1967	0.191	0.424	0.776	0.300				
1968	0.009	0.235	0.376	0.407	0.300			
1969		0.017	0.171	0.590	2.582	0.300		
1970			0.024	0.112	0.542	0.298	0.400	
1971				0.013	0.071	0.773	1.920	1.000
1972					0.029	0.691	0.762	0.957
1973						0.071	0.214	0.750
1974							0.031	0.227
1975								0.021
$\overline{F}$[a]	0.213	0.279	0.290	0.504	0.660	0.690	0.872	0.788
Ages[b]	1-2	1-3	1-3	2-4	2-4	1-4	2-4	2-4

[a]Mean F for fully recruited ages, weighted by stock size in numbers (Table 6).

[b]Ages included in the calculation of $\overline{F}$

Table 8. Yield per recruit calculations for butterfish.

Mesh Size	M	Y/R_{max} (g)	F_{max}	$Y/R_{0.1}$ (g)	$F_{0.1}$	E_{max}	$E_{0.1}$
30 mm	0.6	22.45	0.59	21.38	0.39	0.35	0.25
	0.8	16.44	0.71	15.60	0.47	0.37	0.27
	1.0	12.65	0.84	11.99	0.55	0.38	0.28
	1.2	10.11	0.98	9.55	0.63	0.40	0.29
60 mm	0.6	29.14	0.99	27.08	0.55	0.50	0.33
	0.8	22.07	1.33	20.32	0.69	0.55	0.36
	1.0	17.48	1.78	15.95	0.84	0.60	0.38
	1.2	14.29	2.35	12.92	1.03	0.64	0.41
80 mm	0.6	35.25	2.05	31.39	0.75	0.72	0.41
	0.8	>26.48	>2.50	23.04	0.96	>0.73	0.45
	1.0	>20.04	>2.50	17.56	1.22	>0.69	0.49
	1.2	>15.24	>2.50	13.62	1.49	>0.66	0.52
100 mm	0.6	>35.32	>2.50	30.23	1.09	>0.77	0.53
	0.8	>22.41	>2.50	19.57	1.38	>0.73	0.56
	1.0	>14.28	>2.50	13.01	1.74	>0.69	0.59
	1.2	> 9.13	>2.50	8.67	2.08	>0.66	0.61

LIST OF FIGURES

Figure 1. International Commission for the Northwest Atlantic Fisheries (ICNAF) Subareas 4W-5Zw; and Statistical Areas 6A-6C, with USA bottom trawl survey strata (A); and regional designations of strata sets (B).

Figure 2. Ratio of *Loligo* to butterfish in USA research vessel surveys vs. Japanese landings (⊙), and 1972 catch ratios for Bulgaria (□), USSR (■), and the USA (○).

Figure 3. Length and age composition of Japanese first-quarter butterfish samples, 1970-1976.

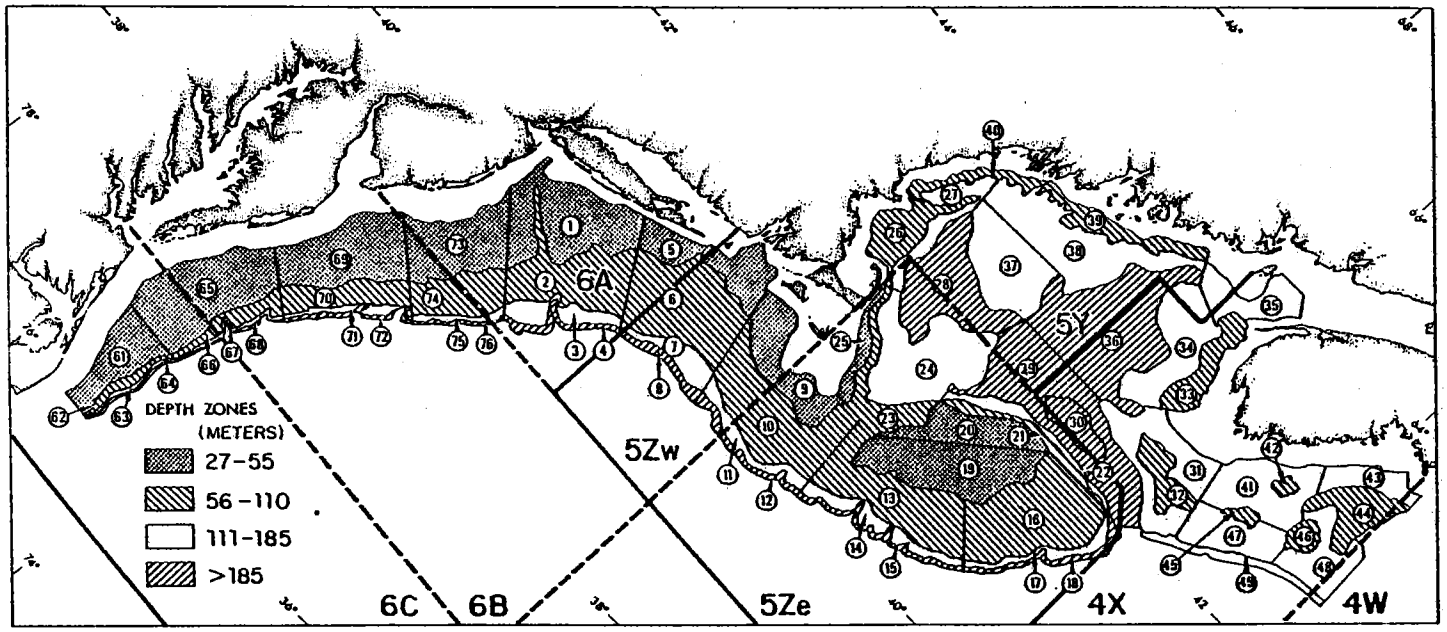
Figure 4. Mean weight of butterfish (g) taken from the Southern New England and Middle Atlantic areas during USA research vessel surveys, 1968-1976.

Figure 5. Yield per recruit of butterfish with various mesh sizes (M = 0.8).

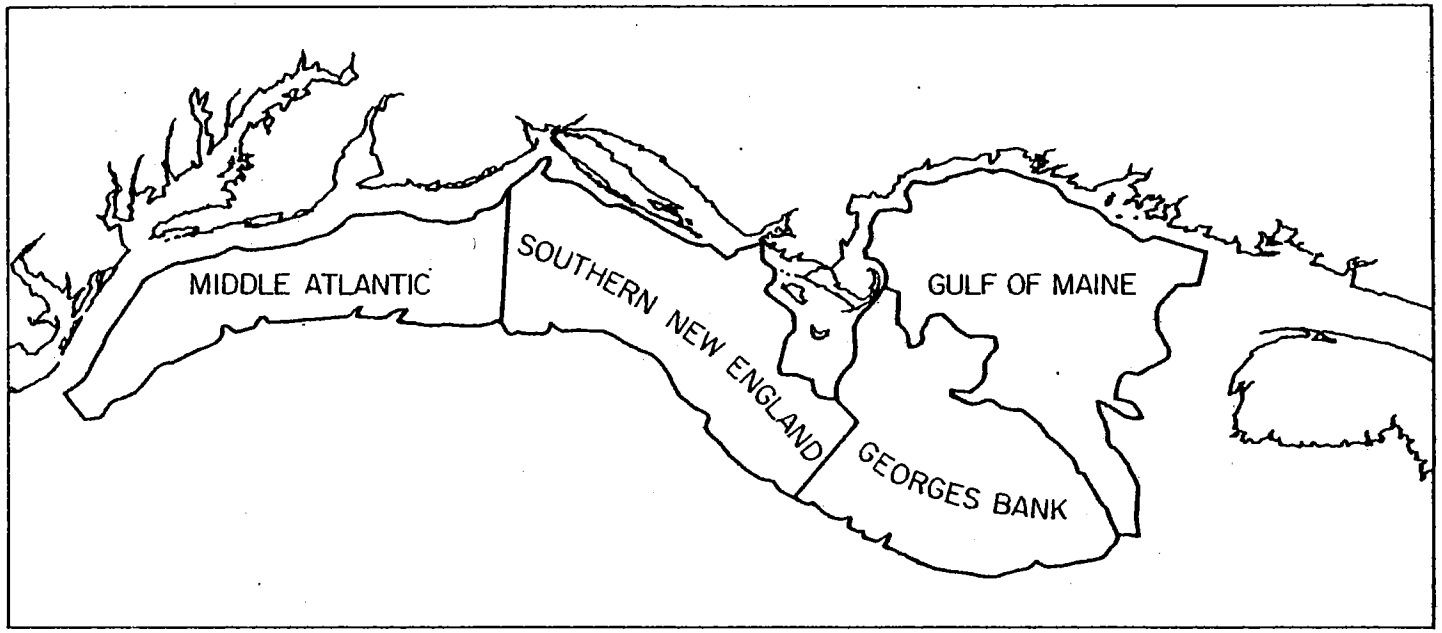
Figure 6. Relation between stretched mesh size (mm) and exploitation rate ($E_{0.1}$) for several assumptions of the instantaneous natural mortality rate (M).

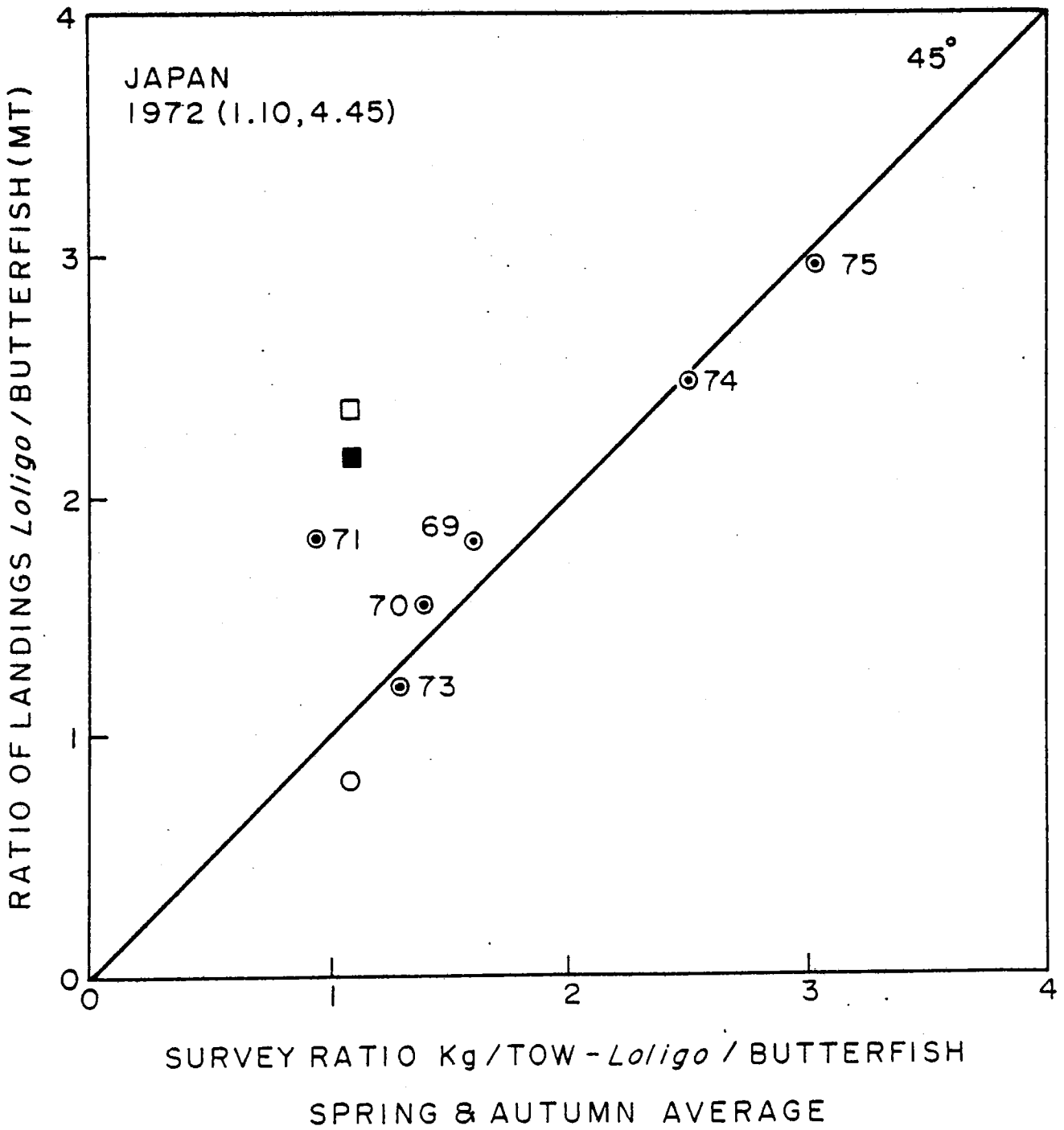
Figure 7. Relations between exploitation rate and simulated mean weights of butterfish in the catch with 30 mm and 60 mm nets.

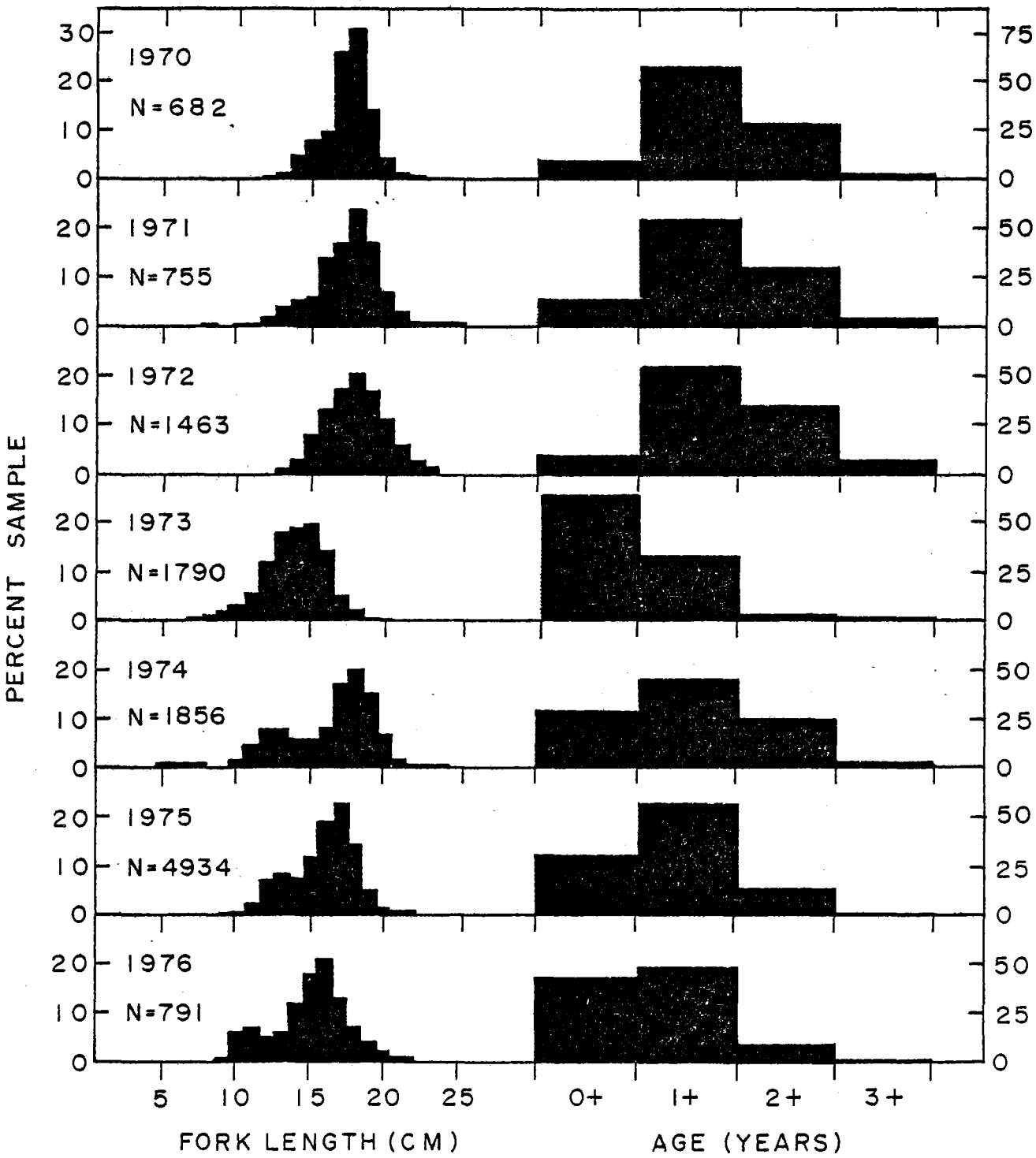
A

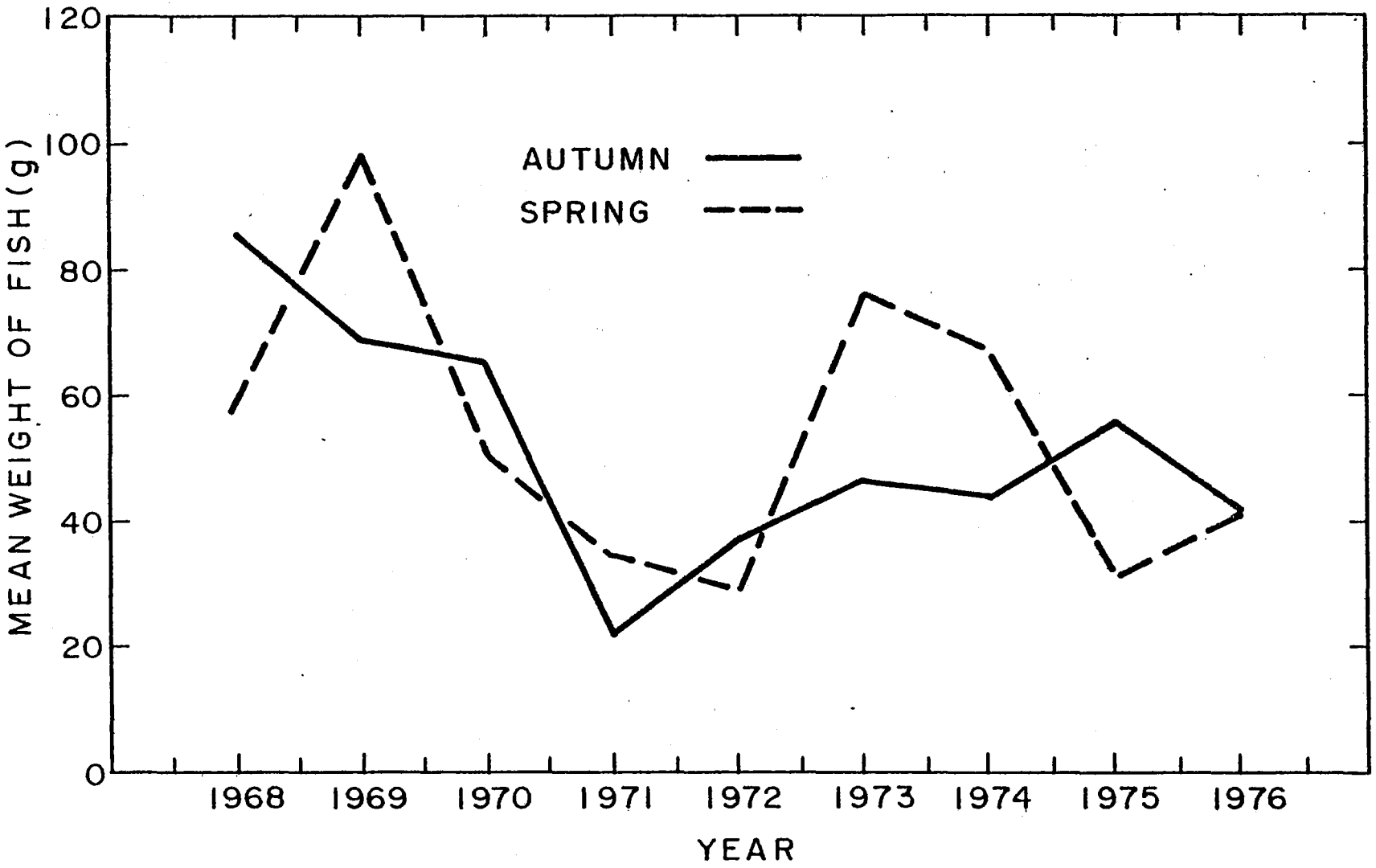

DEPTH ZONES
(METERS)
27-55
56-110
111-185
>185
6C
6B
6A
5Zw
5Y
5Ze
4X
4W

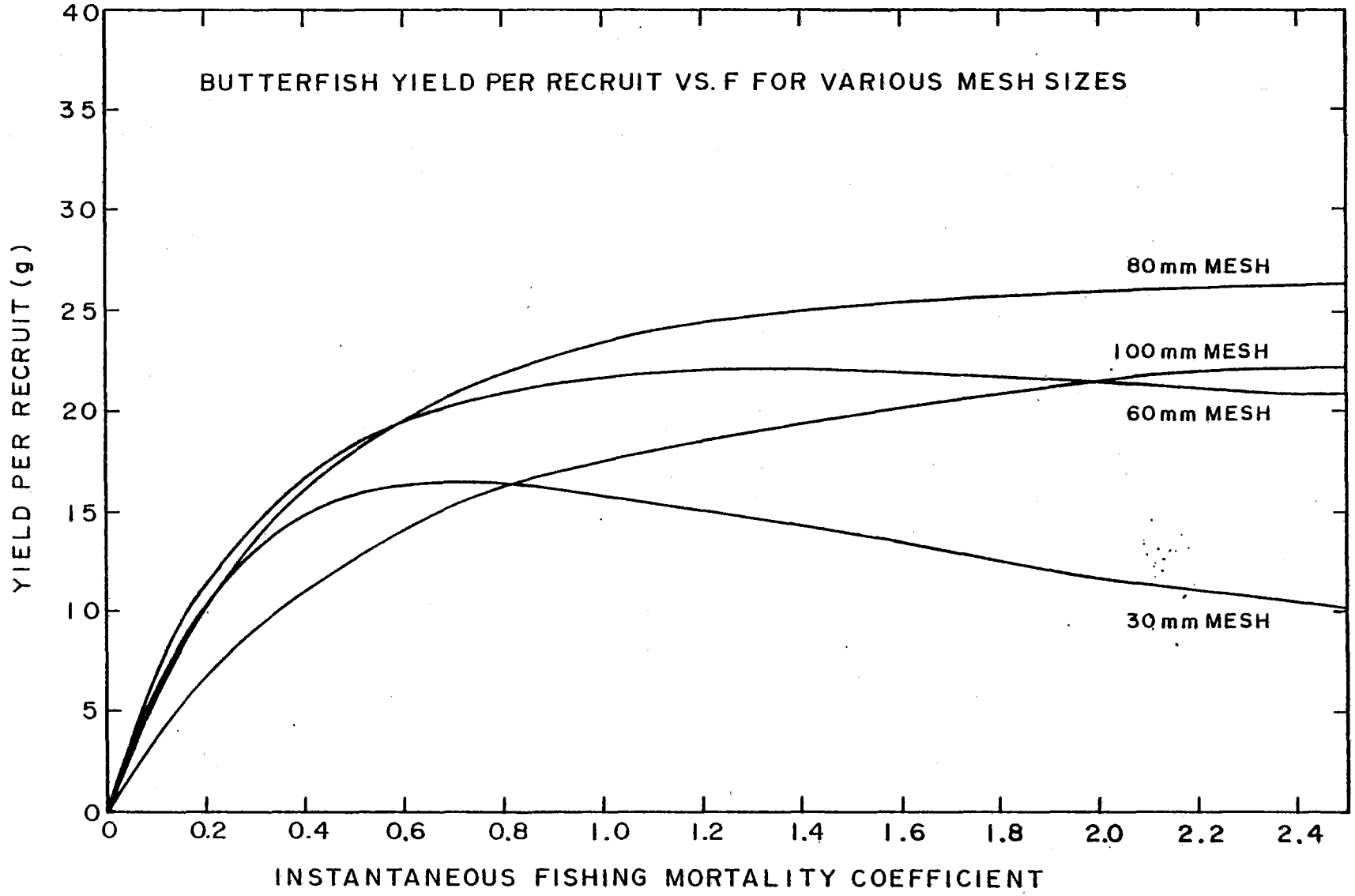
B

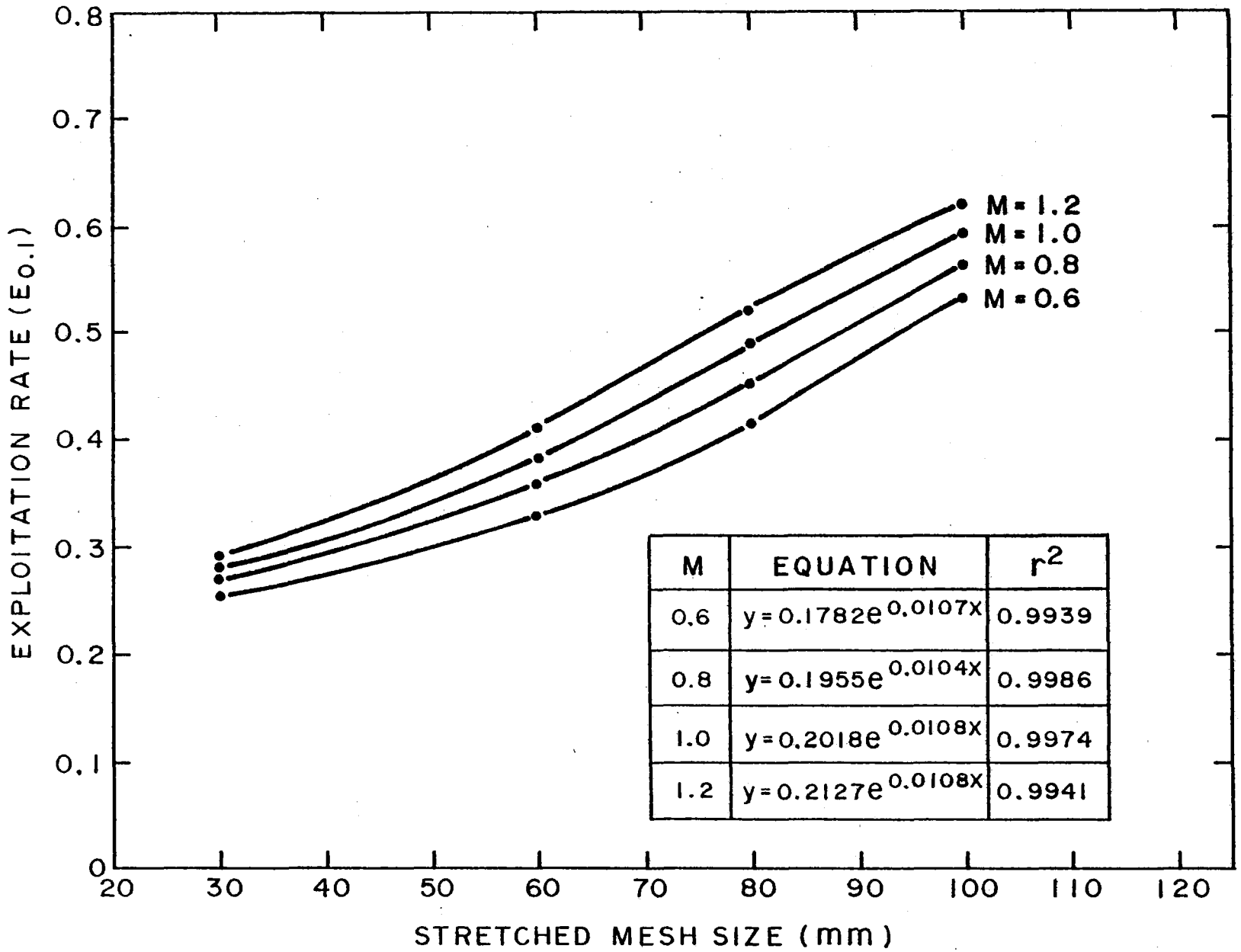

MIDDLE ATLANTIC
SOUTHERN NEW ENGLAND
GULF OF MAINE
GEORGES BANK


JAPAN
1972 (1.10, 4.45)
45°
75
74
71
69
70
73
RATIO OF LANDINGS Loligo / BUTTERFISH (MT)
SURVEY RATIO Kg / TOW - Loligo / BUTTERFISH
SPRING & AUTUMN AVERAGE
0
1
2
3
4

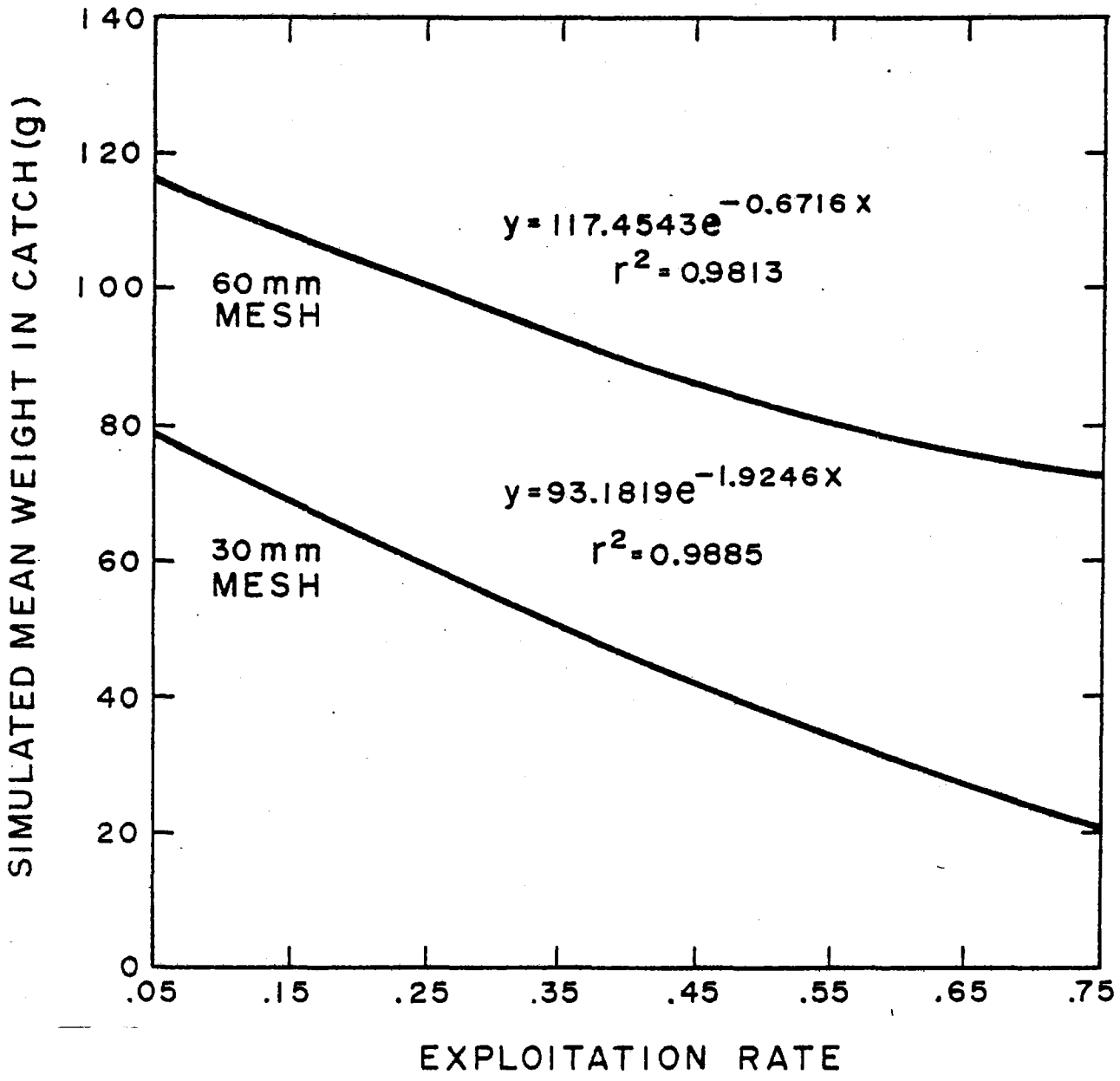

1970
N=682
1971
N=755
1972
N=1463
1973
N=1790
1974
N=1856
1975
N=4934
1976
N=791
PERCENT SAMPLE
FORK LENGTH (CM)
AGE (YEARS)
0+
1+
2+
3+


120
100
80
60
40
20
0
MEAN WEIGHT OF FISH (g)
AUTUMN
SPRING
1968
1969
1970
1971
1972
1973
1974
1975
1976
YEAR


BUTTERFISH YIELD PER RECRUIT VS. F FOR VARIOUS MESH SIZES
80 mm MESH
100 mm MESH
60 mm MESH
30 mm MESH
YIELD PER RECRUIT (g)
INSTANTANEOUS FISHING MORTALITY COEFFICIENT
0
5
10
15
20
25
30
35
40
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4



M	EQUATION	r^2
0.6	$y = 0.1782e^{0.0107X}$	0.9939
0.8	$y = 0.1955e^{0.0104X}$	0.9986
1.0	$y = 0.2018e^{0.0108X}$	0.9974
1.2	$y = 0.2127e^{0.0108X}$	0.9941


SIMULATED MEAN WEIGHT IN CATCH (g)
140
120
100
80
60
40
20
0
.05
.15
.25
.35
.45
.55
.65
.75
EXPLOITATION RATE
60 mm MESH
y = 117.4543e^-0.6716 X
r^2 = 0.9813
30 mm MESH
y = 93.1819e^-1.9246X
r^2 = 0.9885