Gulf of Maine Northern Shrimp - Current Status and Future Outlook

by

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INTRODUCTION

The northern shrimp (*Pandalus borealis* Kroyer) is a circumpolar boreal species which is widely distributed in the northern hemisphere and supports important commercial fisheries in many areas, notably off West Greenland and in the North Pacific. In the Atlantic, populations occur as far north as Lat. 82° N in the Barents Sea and range southward along the coasts of Norway, England, Iceland, Greenland, Canada and the United States as far south as Lat. 41°N (Rasmussen 1953). The Gulf of Maine marks the southernmost extent of its Atlantic range.

Northern shrimp have been fished commercially in the Gulf of Maine since the 1920's (Scattergood 1952). Historically, abundance appears to have fluctuated widely; landings increased from zero in the mid-1950's to an all time high of 12,800 (metric) tons in 1969 before declining drastically to 387 tons in 1977. The fishery has been prosecuted exclusively by Maine, New Hampshire, and Massachusetts, with Maine vessels accounting for the major portion of the catch.

Management of the Gulf of Maine northern shrimp resource has been administered by the Northern Shrimp Sub-Board of the State-Federal Northeast Marine Fisheries Board. Sub-Board membership includes the directors of marine fisheries agencies in Maine, New Hampshire, and Massachusetts and the Director of the National Marine Fisheries Service (NMFS) Northeast Region; the Sub-Board is responsible for making management decisions utilizing information supplied by the State-Federal Northern Shrimp Scientific Committee. The Scientific Committee is composed of representatives from the above three states and NMFS; it is responsible for collecting and analyzing data relative to the northern shrimp resource and for transmitting the results of such analyses to the Sub-Board.

Management of this resource is unique in that the participating member states have designated the Atlantic States Marine Fisheries Commission (ASMFC) as the joint regulatory agency under Amendment 1 of the ASMFC charter. Under this arrangement all regulatory measures are posted and enforced in the name of the Commission; actual law enforcement remains the responsibility of each individual state. To date, regulations have included minimum mesh sizes, seasonal closures, and quota limitations.

The following report briefly reviews the current status of the Gulf of Maine northern shrimp resource and examines prospects for stock recovery vis a vis current management strategies, biological factors, and environmental influences upon recruitment. Detailed assessment information is also presented in recent reports (Northern Shrimp Scientific Committee MS 1978, MS 1979a) and in the Revised Draft Northern Shrimp Management Plan (Northern Shrimp Scientific Committee MS 1979b).

BIOLOGY AND DISTRIBUTION

The northern shrimp is a protandric hermaphrodite, functioning first as a male and later as a female. Some shrimp develop female characteristics directly and are called primary females, but this phenomenon appears to be rare in the Gulf of Maine (Haynes and Wigley 1969).

The life history of northern shrimp in the Gulf of Maine has been extensively studied by Haynes and Wigley (1969) and Apollonio and Dunton (MS 1969). Larval shrimp hatch during winter in inshore areas from eggs attached to the underside of the female's abdomen. Hatching may begin as early as January, but the peak occurs in late February and early March. Larval shrimp spend 1-2 months drifting near the surface and then settle to the bottom in inshore areas, where they remain for over a year as immature shrimp (age groups 0 and 1). With approaching maturation, male shrimp (age group 2) move into deeper offshore areas where they mate with older females in the summer of their third year; they then pass through

several "transitional" stages, becoming females in the summer of their fourth year (age group 3). They then mate with younger males; within a month, fertilized eggs are extruded and the females become "ovigerous" or egg-bearing. Clutch size in the Gulf of Maine ranges from 800 to 3,400 eggs and is positively correlated with size (Haynes and Wigley 1969). Females then move into inshore areas, where the eggs hatch; the females (age group 4) then move offshore. The annual mating cycle may be repeated for 2 or 3 additional years before females die (at ages 6 or 7); however, detailed information on longevity for northern shrimp in the Gulf of Maine area is unavailable at present.

In recent years considerable interest has been expressed in sequential hermaphroditism and its relative advantages compared to other reproductive strategies. Smith (1967) has indicated that protandric hermaphroditism may convey a reproductive advantage over synchronous hermaphroditism and bisexuality through increased production of gametes, provided that development of this strategy results in a relatively longer life span. Also, when reproductive success is related to size or age and/or is most efficient for one sex when small and for another sex when large, successive hermaphroditism may be advantageous (Ghiselin 1969; Warner 1975). Thus, protandric hermaphroditism would appear particularly appropriate for northern shrimp given the above mentioned correlation of fecundity with size. In the Gulf of Maine, the distribution and life cycle of northern shrimp appear to be synchronized with environmental conditions so as to enhance reproductive potential (Apollonio and Dunton MS 1969).

The observed distribution of northern shrimp in the Gulf of Maine during NEFC spring and autumn bottom-trawl surveys from 1974-1976 is given in Figure 1. These data agree with previous studies (Wigley 1960; Haynes and Wigley 1969; Apollonio and Dunton MS 1969) in indicating largest concentrations of northern shrimp to occur in the southwestern Gulf of Maine. Seasonal differences are evident in that the population appears to be more concentrated in the extreme western portion of the Gulf in spring than in autumn; this may relate to migratory movements associated with spawning and hatching as described above. There is no evidence to indicate significant movement into or out of the Gulf of Maine in recent years and abundance in the western Scotian Shelf area appears to be low. Recent exploratory surveys by Canada on the western Scotian Shelf have failed to locate commercially important concentrations of northern shrimp (Labonté pers. comm.).

Distribution in the Gulf of Maine appears to be largely determined by temperature, although other factors may also be of importance. Bottom temperatures observed in NEFC spring and autumn surveys since 1963 have generally been coldest in the western portion of the Gulf (Davis 1978). Apollonio and Dunton (MS 1969) reported heaviest summer concentrations to occur in the southwestern corner of the Gulf of Maine, and observed that "since lowest bottom temperatures in the summer are usually found in the western half of the Gulf .....there is perhaps a causal relation in the occurence of largest numbers of shrimps in those waters". However, Haynes and Wigley (MS 1969) attributed more importance to bottom characteristics, as highest catches were observed to occur in areas of fine-grained sediments, e.g., clay, silt, and silty sand where organic carbon content was moderate to high.

COMMERCIAL FISHERY

Commercial landings of northern shrimp in the western Gulf of Maine have fluctuated widely. Landings increased from 5 tons in 1940 to 264 tons in 1945 before declining to zero in the mid-1950's (Figure 2). Subsequently, total landings again increased from 2 tons in 1958 to a peak of 12,800 tons in 1969, averaged approximately 11,000 tons from 1970-1972, and then declined precipitously to 387 tons in 1977 (Table 1, Figure 2). The fishery was closed in 1978 and reported landings were negligible (3 tons); preliminary data for the 1979 February-March season indicate landings of 439 tons. The Gulf of Maine fishery has been prosecuted exclusively by the USA, although the USSR reported a catch of 7 tons from Georges Bank in 1975 and Canada has taken minor quantities in the Fundian Channel area off eastern Georges Bank in 1972, 1976, and 1977.

Since the mid-1960's, Maine and Massachusetts have accounted for nearly all of the Gulf of Maine landings; New Hampshire landings were less than 1% of the total since 1969. Prior to seasonal restrictions imposed in 1975, the Maine and Massachusetts fisheries were somewhat different in character; the Maine fishery was directed predominantly towards mature (age 4+) females migrating into inshore areas in wintertime (often within the territorial sea) while Massachusetts vessels exploited both mature females in inshore situations in wintertime and shrimp of all age classes in offshore areas throughout the year. (A number of Portland, Maine vessels have also traditionally fished in offshore areas southeast of Cape Elizabeth). Since 1975 the fishery has been prosecuted almost exclusively during the winter months. The relative proportion of the total catch landed in Massachusetts has increased from an average of 24% during 1969-1972 to 78% during 1977-1979. In 1979, 406 tons (92% of the total catch) was taken by Gloucester, Massachusetts vessels fishing primarily in Scantum and Jeffreys Basins (near Gloucester).

There is little information on shrimp taken incidentally in other fisheries and discarded (or retained and sold) during closures imposed beginning in 1975. Previous analyses have indicated little potential for incidental catch of shrimp in groundfish fisheries although a potential by-catch of 136 tons was estimated for the 1977 summer and autumn whiting fishery (Northern Shrimp Scientific Committee MS 1977). Reports from industry sources indicate this figure to have been reasonable.

Commercial landings have been sampled at Gloucester and Portland by state and NMFS personnel since 1973. Age groups have been identified by examination of sexual characteristics (Allen 1959) and polymodal curve dissection (Cassie 1954); percentage age composition of the landings (numbers) by quarter for 1973-1979 is given in Figure 3. Considerable seasonal variability is evident; winter catches have been dominated by transitionals and females (age groups 3+), but in spring, summer, and autumn younger shrimp have been taken in larger quantities, e.g. in 1974 over 60% of the summer catch consisted of age group 1 shrimp (Figure 3). High catches of older age groups in winter reflect inshore migration of ovigerous females, while high catches of younger shrimp during the remaining seasons reflect distribution of effort in offshore situations where shrimp of all age classes are taken. Yield per recruit analyses (discussed below) indicate potential losses of 40% or more associated with harvesting age group 1 shrimp as opposed to delaying harvest until age 4.

The relatively high percentage of age groups 1 and 2 observed in 1979 landings reflects sampling bias to some degree in that only Gloucester landings were represented; Maine landings (which typically contain higher percentages of older shrimp) were not sampled. However, the observed percentage for these age groups (59%) was also unusually high compared

to the 1973-1977 Gloucester average (37%). This increase may result both from use of illegal gear and from distribution of fishing effort, as proportionally more effort appears to have been directed towards concentrations in deeper areas in 1979 (Northern Shrimp Scientific Committee MS 1979).

Small amounts of other pandalid species, e.g. *P. montagui* and *Dichelopandalus leptoceras*, are occasionally taken with *P. borealis;* however, catches appear to have comprised less than 5% of the total (by weight) during 1973-1977. Approximately 7% of the 1979 Gloucester landings consisted of *P. montagui*, the only other species observed (Diodati MS 1979).

CURRENT ASSESSMENT

Commercial Index

Trends in abundance for the 1964-1977 period were examined using catch-effort data from NMFS weighout and interview record files. To adjust for changes in fleet composition, effort data were standardized by vessel class using trip data for 34-50 GT vessels as standard; data for trips in which 50% or more of the total catch consisted of shrimp were used so as to reflect "directed" effort. Total standardized effort data were then divided into summarized catch data for all vessel classes to obtain an index (catch in tons per standard day fished, considering a fishing day as 24 hours of actual fishing time, Figure 4).

Calculated index values increased from 1.6 tons in 1964 to 4.2 tons in 1969, followed by a more or less continual decline to 1.5 tons in 1976 (Northern Shrimp Scientific Committee MS 1979b; Figure 4). The index appears to reflect an actual increase in abundance for 1964-1969 resulting from optimal environmental conditions for recruitment; the subsequent decline (65% from 1969 to 1976) is corroborated by research vessel survey data. Rinaldo (MS 1976)

reported an 80% decline in catch rates for selected Maine study vessels from 1969-1974, when these vessels stopped fishing. The lower rate evidenced by the index may reflect changes in vessel efficiency, data base limitations, redirection of fishing effort or other factors (Northern Shrimp Scientific Committee MS 1979b).

Research Vessel Survey Indices

The State of Maine has sampled standard locations in the western Gulf of Maine each August since 1967 using a shrimp research trawl; the Northeast Fisheries Center (NEFC) of NMFS has conducted stratified random bottom trawl surveys in the Gulf of Maine in autumn (beginning in 1963) and in spring (beginning in 1968) and also initiated a summer survey in 1977. Information concerning survey procedures, gear used, and application of resulting data to assessment of the Gulf of Maine northern shrimp stock is given elsewhere (Apollonio and Dunton MS 1969; Northern Shrimp Scientific Committee MS 1979a, MS 1979b).

The Maine survey index (catch per tow at standard stations) declined from 56.9 kg in 1968 to 1.6 kg in 1977 before increasing to 3.2 kg in 1978 and 4.4 kg in 1979 (Table 2, Figure 5). The NEFC spring survey index (stratified mean catch per tow) has declined more or less steadily from 10.82 kg in 1968 to 0.13 kg in 1979, while the autumn survey index declined from 4.14 kg in 1969 to 0.01 kg in 1976 before increasing in 1977-1978 (Table 2, Figure 5). The NEFC summer survey index declined from 0.14 kg in 1977 to 0.06 kg in 1978 (Table 2). During 1978-1979 the NEFC spring index declined, although summer and autumn indices remained relatively stable (Table 2). Taken together, available survey data suggest a decline in abundance of over 90% during 1968-1977, followed by stabilization at a very low level.

Stock Size and Mortality Estimates

Stock size and mortality estimates for 1969-1979 have been calculated from annual landings data and Maine survey catch at age data (Table 3). Estimates of instantaneous total mortality (Z) were obtained from catch at age data for age groups 2 and older; data for age group 1 were omitted in this assessment as recent analyses and ancillary information suggest the potential for considerable variation in availability of this age group to the survey gear between years (Sampson MS 1979). Estimates of instantaneous fishing mortality (F) were then obtained by subtracting the estimated instantaneous natural mortality (M) value for this stock of 0.25 (Rinaldo 1973). Corresponding rates of exploitation (μ) and survival (S) were then obtained (Ricker 1975) and applied to total catch in weight to provide stock size and recruitment estimates. Stock size estimates were calculated by dividing catch by the appropriate exploitation rates; recruitment estimates were calculated by subtracting survival estimates in year i from stock size estimates for year i+1. Results are given in Table 3.

Estimates of F and μ fluctuate considerably but increase substantially from 1969-1972, apparently reflecting increasing effort in offshore waters. F averaged 1.13 during 1973-1977; mortality estimates for 1978 were the lowest in the series (Z=0.09), apparently reflecting closure of the fishery during that year. The estimated F value for 1979 was 0.38, a relatively low value compared to former years. Stock size and recruitment estimates declined by over 90% during the 1969-1979 period, in reasonable agreement with NEFC survey data and the Maine abundance index.

Trends in the NEFC autumn survey index agree very closely with trends in stock size estimates calculated for the year following the survey (r=0.94, Figure 6). Use of the preliminary 1979 index value in a linear regression between stock size estimates for 1969-1979 (Table 3) and

corresponding NEFC autumn survey index values for 1968-1978 (Table 2) provides an estimate of approximately 1,000 tons for 1980, comparable to levels observed for 1977-1979 (Figure 7). Thus, available data are consistent in indicating that abundance has stabilized at a low level since the mid-1970's.

The striking decline in abundance in recent years has been attributed both to environmental influences (i.e., temperature) and to heavy fishing pressure. The influence of temperature on historical trends in abundance has been well documented (Dow 1963, 1964, 1966; Apollonio and Dunton MS 1969); results of the latter study indicate an apparent relationship between high (winter) temperatures in 1950-1953 and the collapse of the fishery four years later, the stated implication being that high inshore winter temperatures resulted in poor egg production and a marked reduction in abundance. More recently, Dow (1977) reported a strong negative correlation between mean annual sea surface temperatures as measured at Boothbay Harbor and landings in the Maine winter fishery four years later. A plot of annual landings and mean annual surface temperatures (^{o}C) as measured at Boothbay Harbor, Maine (lagged four years) clearly reflect an inverse relationship (Figure 8) although effort data available since the early 1960's (Northern Shrimp Scientific Committee MS 1979b) suggest that high fishing pressure may have contributed to the rapid decline observed in recent years.

Figure 9 provides a plot of mean autumn bottom temperatures for the Gulf of Maine derived from NEFC autumn bottom trawl surveys (Davis 1978), standardized effort (thousands of days fished) and stock size estimates obtained as described above (Table 3). Here, both temperature and effort data have been lagged by four years under the hypothesis that recruitment could be affected both by temperature conditions and by fishing mortality

on ovigerous females. Trends in both temperature and effort were generally very similar, with values for both variables increasing to peak levels in recent years while stock size declined rapidly. Unfortunately, effort data used are subject to a number of limitations, e.g., definition of "directed" trips in calculation of commercial index values used to derive total standardized effort estimates (see Commercial Index) was somewhat arbitrary, and effects of high exploitation rates in recent years were likely cumulative over the life span rather than being confined to the year of hatching due to use of small mesh gear in offshore areas. Consequently, it is difficult to quantify the relative importance of these variables in contributing to declines in abundance observed in recent years.

The precise mechanism by which temperature affects trends in abundance is unclear. Stickney (MS 1977) was unable to demonstrate significant egg mortality within the range of 2°-12°C, and since ovigerous females would seldom if ever encounter temperatures as high as the latter value in the western Gulf of Maine direct egg mortality would not be expected to be of major consequence. It appears more likely that higher than average temperatures may cause increased mortality through other interactions, e.g. by resulting in hatching before adequate food supplies are available or by enhancing survival of a parasitic dinoflagellate which attacks egg masses during the ovigerous period (Stickney MS 1977). Studies on this problem are continuing (Stickney and Perkins MS 1979). It is interesting to note that the incidence of egg parasitism appears to have dropped considerably with recent declines in temperature (Stickney and Perkins MS 1979).

Autumn bottom temperatures observed in NEFC surveys in the western Gulf of Maine declined from 8.7°C in 1976 to 6.9°C in 1978 and then increased to 7.4°C in 1979, while spring bottom temperatures declined from 7.3°C in 1976 to 5.3°C in 1979. The 1976 spring and fall values were the highest observed in the history of these surveys. The 1977-1979 autumn survey values are intermediate between the 1964-1967 average (5.7°C) associated with high recruitment and stock abundance in the late 1960's and early 1970's and the 1971-1974 average (8.2°C) associated with current low levels of abundance. Similarly, mean annual surface temperatures as measured at Boothbay Harbor (Welch, pers. comm.) have declined from 9.9°C in 1975 to 8.0°C in 1978, a level intermediate between the 1964-1967 average (7.7°C) and the 1971-1974 average (8.8°C). A continued decline may improve recruitment prospects.

YIELD PER RECRUIT

The applicability of yield per recruit models to northern shrimp assessments is limited due to lack of reliable information concerning the necessary parameter estimates (Ulltang, pers. comm.); also, previous analyses indicate that as a general rule maximum yield per recruit for northern shrimp can be achieved only with high F levels and a relatively low age at entry-an ideal scenario for low recruitment (ICES 1978a). Nevertheless, yield per recruit modeling does provide insight relative to applicability of certain management strategies for the Gulf of Maine.

The level of instantaneous natural mortality (M) for this stock is uncertain; Rinaldo (MS 1973) reported M to be 0.25 based upon regressions of instantaneous total mortality (Z) upon total effort, and this value may be appropriate for younger ages although M appears to increase sharply after eggs of mature females hatch at age 4 (Haynes and Wigley 1969). Maine and NEFC survey data for 1977-1978 (collected during

the period of closure) do suggest a relatively low M value for younger age groups. Unfortunately, there is little information on M for other northern shrimp stocks in the Northwest Atlantic; no estimates are currently available for West Greenland, Labrador, or the Scotian Shelf (Horsted pers. comm.; Parsons pers. comm.; Labonté pers. comm.). Fréchette and Labonté (in press) have obtained estimates for M of 0.37 between ages 2-3 and 0.71 for older ages (3+) in the Gulf of St. Lawrence; these results should be regarded as tentative (Fréchette pers. comm.) but they are nevertheless in reasonable agreement with expected patterns for the Gulf of Maine.

In the absence of more definitive information, yield per recruit calculations have been made assuming M to be constant at 0.25 and 0.50, subsequently increasing to 1.0 after first hatching; calculations were also made assuming M to be constant throughout the life span for comparative purposes. Obviously, M may exceed these limits seasonally or on an annual basis due to variation in predator biomass, temperature, or other factors.

The von Bertalanffy growth equation

$$l_t = l_\infty (1-e^{-k(t-t_o)})$$

where t = age (years),

l_t = mid-dorsal carapace length at age t,

L_∞ = maximum mid-dorsal carapace length attained,

k = Brody growth coefficient, and

t_o = age at which $l_t = 0$,

has been used to describe growth of northern shrimp in a number of studies (ICES 1978a). While inadequate to precisely model the discontinuous growth pattern of crustacean species, it has been recognized as a useful approximation providing the basis for yield per recruit modeling (ICES 1978b). Application of the von Bertalanffy growth equation to Maine summer survey length at age data for 1974-1978 yielded the following parameter estimates:

L_∞, 29.38mm, K, 0.462, and t_o, -0.07 (Northern Shrimp Scientific Committee

MS 1979a). Predicted lengths at age were then converted to weight at age estimates by the relation $w=0.00070418L^{2.9746}$ (Schick pers. comm.) for use in yield per recruit modeling.

The Ricker model (Ricker 1975:238) has been employed for yield per recruit analyses[2] in this study, as it permits flexibility in M and F with age. Biomass vectors under the assumption of zero harvest per unit recruitment (Figure 11) differed considerably dependent upon levels of M assumed, with peaks occurring at 4.0 years at M=0.25 and 2.8 years at M=0.50. Assuming M equal to 0.25 prior to age 4 it would appear reasonable to harvest in spring (March-May) when age 4 females would be most readily available; this would contribute towards maximizing yield and could also enhance the management objective of stock rebuilding by reducing fishing mortality on inshore concentrations of ovigerous females. In recent years hatching has been essentially complete by mid-March (MacIsaac pers. comm.; Schick pers. comm.).

The current 50% selection length (l_c) assuming use of 4.5 cm (1.75 inch) mesh trawls is approximately 21 mm mid-dorsal carapace length, corresponding to a mean age at entry (t_c) of 2.6 years. Yield per recruit curves for this t_c under the above assumptions relative to M are given in Figure 12. Resulting curves tend to be flat-topped (with no maximum except for a constant M of 0.25). There is no appreciable change in yield for any of these curves above F=1.0 and indeed higher levels of F would appear undesireable at current levels of abundance.

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[2] Calculations were performed using the program of Paulik and Bayliff (1967).

Yield per recruit curves for 4.5 cm and 5.1 cm (2.00 inch) trawls assuming M=0.25 and 0.50 prior to first hatching, followed by M=1.0 at older ages and seasonal F patterns observed during 1970-1974 (prior to seasonal closures) appear in Figure 15. Curves rise very sharply with no clearly defined maximum, apparently due to attainment of maximum biomass at age 3 or 4 followed by high natural mortality. An increase in mesh size to 5.1 cm would result in a significant loss in yield at F levels observed in recent years.

SUMMARY AND CONCLUSIONS

The Gulf of Maine northern shrimp resource is currently at a very low level. Recent declines appear to have been closely associated with warm temperatures during the early and mid-1970's; the relative impact of high exploitation rates is not precisely known at present. Since 1976, temperatures have declined somewhat and recruitment prospects may improve if this trend continues. The reproductive strategy of the animal would also be expected to enhance prospects for recovery (Apollonio, public testimony, Northern Shrimp Section Meeting, November 8, 1978).

Since 1975, the Northern Shrimp Scientific Committee has recommended indefinite closure of the fishery to enhance prospects for stock rebuilding. This recommendation has been based upon the premises that prospects for stock rebuilding will be better the higher the available biomass and continued exploitation at low levels of abundance entails the risk of delaying recovery indefinitely. Management under ASMFC has included seasonal closures (1976, 1977, and 1979), an annual closure throughout 1978, a minimum mesh size regulation of 4.5 cm and (in 1977) quotas. Throughout this period the management approach taken has evolved into implementation of a late winter and early spring fishery restricted to use of 4.5 cm mesh trawls; for

1980, the fishery has been opened from February 15-May 31, subject to previous mesh size regulations.

Given inshore migration of ovigerous (age 4+) females in wintertime, attainment of maximum biomass at age 4, an apparent rapid increase in M at older ages, and completion of hatching by mid-March, a late winter and early spring fishery employing 4.5 cm mesh trawls would appear to constitute a logical management approach. Under the most desireable circumstances this would allow harvest of spent females at the point at which yield is maximized prior to significant losses from natural mortality. Unfortunately, data for the 1979 season suggests that the bulk of the harvest will likely be taken in deeper offshore areas where significant catches of younger age groups (ages 1-3) would be expected, and this problem could be magnified considerably if illegal gear is used. Consequently, there is grounds for concern that the 1980 fishery will impair future recruitment prospects. Monitoring through commercial sampling and research vessel surveys has been upgraded considerably in recent years and such work should be continued to properly evaluate the effects of the 1980 season.

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Table 1. Commercial landings of northern shrimp (tons) in the western Gulf of Maine by state, 1958-1979.

Year	Maine	New Hampshire	Massachusetts	Total
1958	2.3	--	0.0	2.3
1959	5.4	--	2.3	7.7
1960	40.4	--	0.5	40.9
1961	30.4	--	0.5	30.9
1962	159.7	--	16.3	176.0
1963	244.0	--	10.4	254.4
1964	419.4	--	3.1	422.5
1965	947.0	--	8.0	955.0
1966	1737.8	18.1	10.5	1766.4
1967	3141.1	20.0	10.0	3171.1
1968	6515.0	43.1	51.9	6610.0
1969	10992.9	58.1	1772.8	12823.8
1970	7712.8	54.4	2902.3	10669.5
1971	8354.7	50.8	2723.9	11129.4
1972	7515.5	74.8	3504.6	11094.9
1973	5476.6	59.9	3868.2	9404.7
1974	4431.9	36.7	3477.3	7945.9
1975	3177.1	41.7	2079.9	5298.7
1976	617.2	7.3	397.8	1022.3
1977	148.0	2.3	236.9	387.2
1978	0.1[1]	--	3.3[1]	3.4[1]
1979	32.9	--	406.0	438.9

[1] Landings negligible due to closure of the fishery from May, 1977 to February, 1979.

Table 2. Research vessel survey abundance indices for Gulf of Maine northern shrimp.

Year	Mean catch per tow (kg) Maine summer survey [1]	Stratified mean catch per tow (kg) NEFC bottom trawl surveys[2]		
		Spring	Summer	Autumn
1968	56.9	10.82	--	2.75
1969	31.2	5.76	--	4.14
1970	40.8	2.36	--	2.55
1971	9.4	2.41	--	3.45
1972	6.9	2.21	--	3.08
1973	9.0	2.22	--	2.83
1974	4.9	1.76	--	0.62
1975	6.7	5.46	--	0.49
1976	4.8	1.33	--	0.01
1977	1.6	0.66	0.14	0.05
1978	3.2	0.25	0.06	0.17
1979	4.4	0.13	0.05[4]	0.16[4]

[1]Mean catch per 30-minute tow (daytime).

[2]Stratified mean catch per 30-minute tow (daytime), NEFC spring, summer, and autumn bottom trawl surveys. Spring and autumn indices are based on data for strata 24, 26-30 and 36-40; the summer index is based on data for strata 24, 26-28 and 37-40.

[3] Preliminary

Table 3. Catch, stock size, recruitment estimates and related parameters used in assessment of the Gulf of Maine northern shrimp stock. Estimates of instantaneous fishing mortality (F) calculated from analyses of Maine survey catch at age data assuming M = 0.25.

Year	Instantaneous fishing mortality (F)[1]	Exploitation rate (μ)	Survival rate (S)	Catch (000's tons)	Stock Size[2] (000's tons)	Recruitment[3] (000's tons)
1969	1.28	0.655	0.217	12.8	20	--
1970	0.78	0.487	0.357	10.7	22	18
1971	2.29	0.830	0.079	11.1	13	5
1972	1.83	0.770	0.125	11.1	14	13
1973	0.99	0.567	0.289	9.4	17	15
1974	1.08	0.597	0.264	7.9	13	8
1975	1.13[4]	0.612	0.252	5.3	9	6
1976	1.30	0.661	0.212	1.0	2	--
1977	1.14	0.616	0.249	0.4	1	1
1978	--	--	--	--	1[5]	--
1979	0.38	0.282	0.533	0.4	1	--

[1]Calculated as $\ln\left[\frac{(\Sigma \text{ age } 2+)}{(\Sigma \text{ age } 3+)}\right] - 0.25$.

[2]Calculated by dividing catch by exploitation rate.

[3]Calculated by subtracting survivors (year i) from stock size (year i+1), e.g. the 1970 estimate is calculated as 22 - 20(.217)

[4]F value not calculated directly due to introduction of new survey vessel in 1975; 73-77 mean value used.

[5]Assumed equal to the 1977-1979 average.

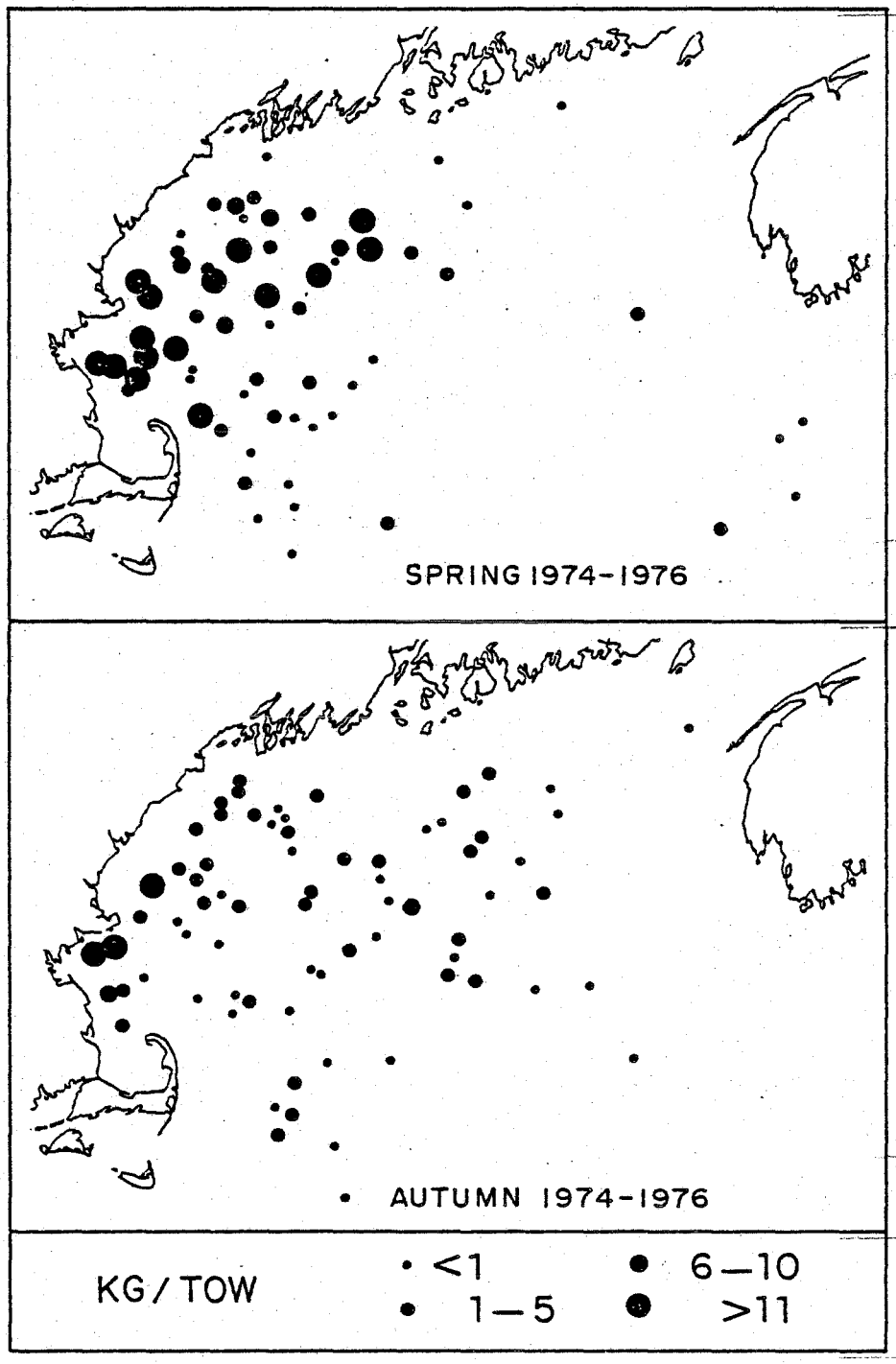

Figure 1. Distribution of northern shrimp (Pandalus borealis) in the Gulf of Maine as observed during NEFC spring and autumn bottom-trawl surveys in 1974-1976.

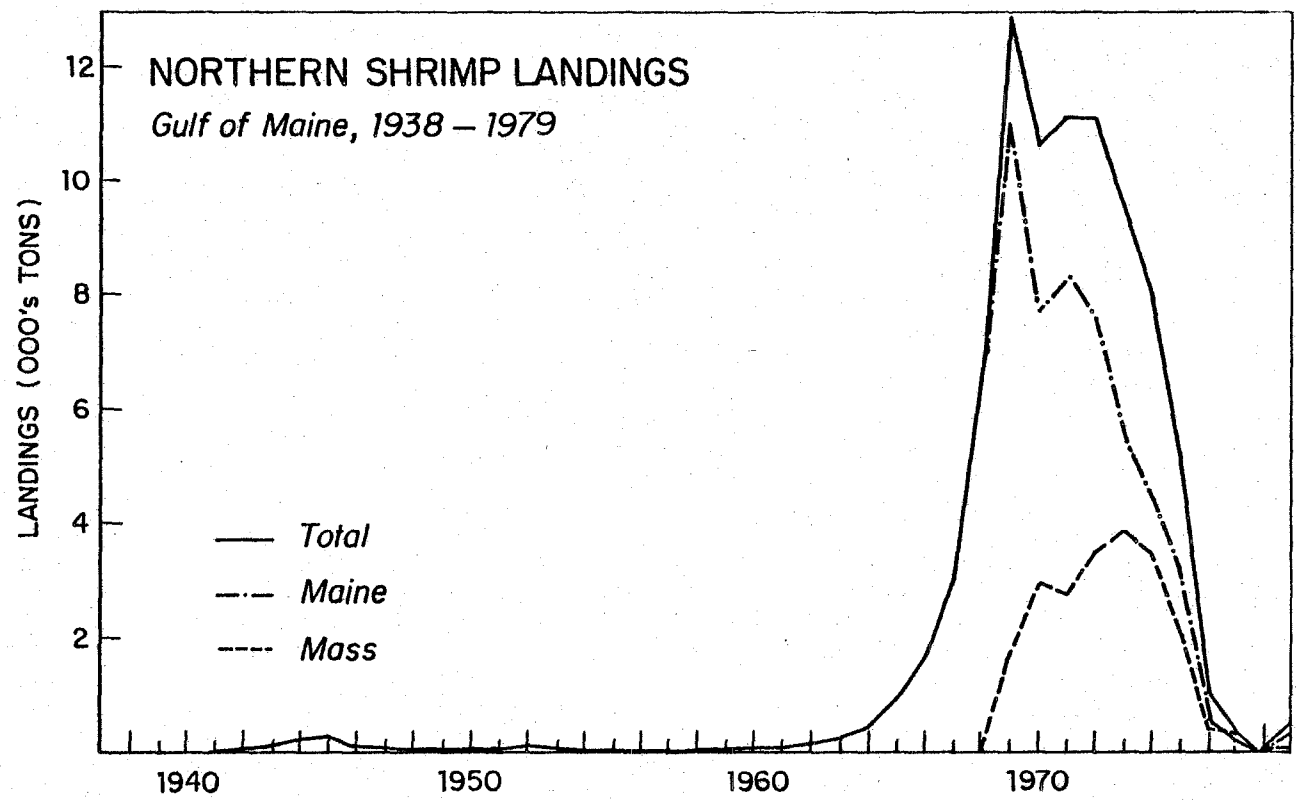

Figure 2. Gulf of Maine northern shrimp landings, 1938-1979.

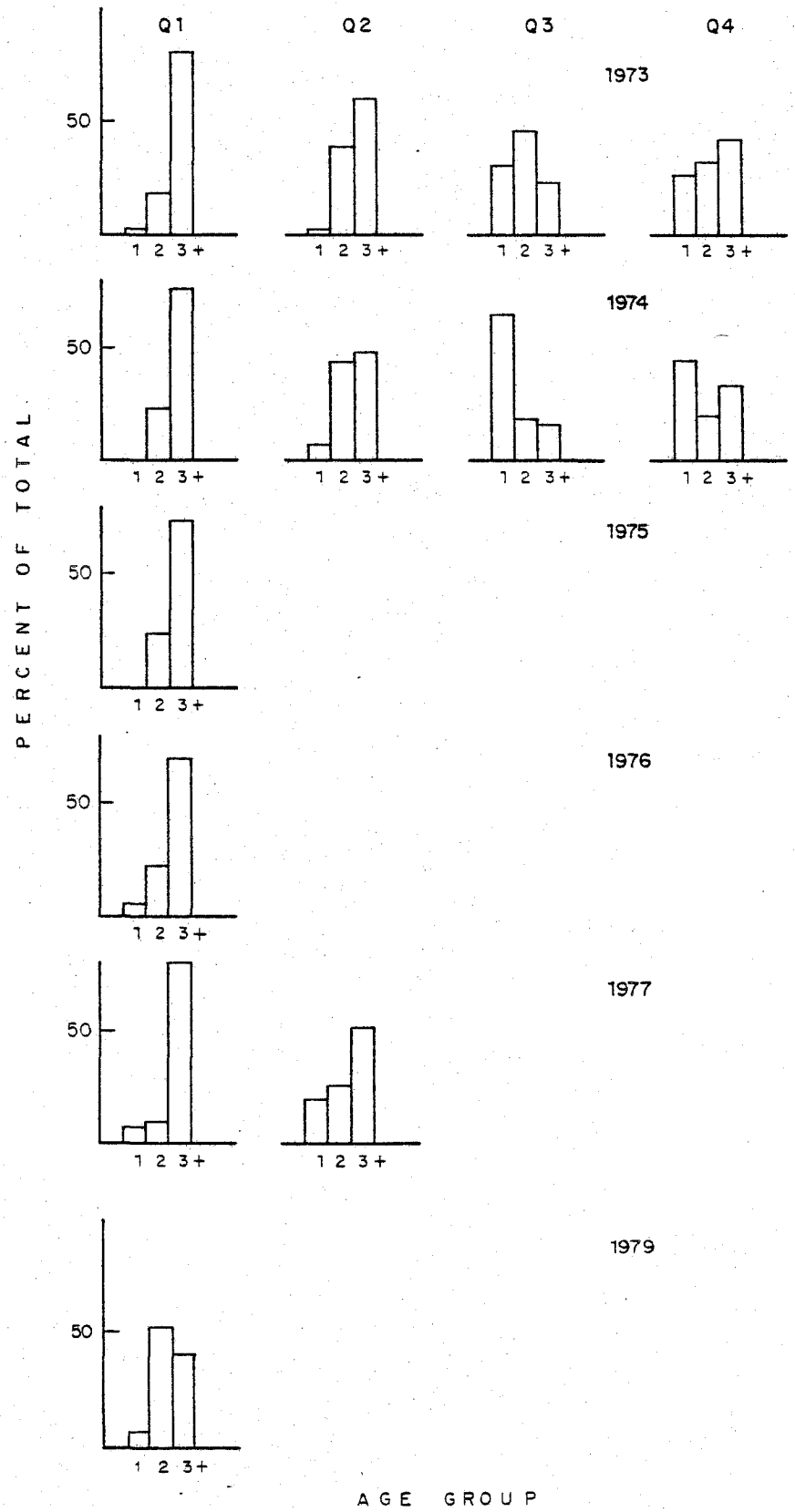

Figure 3. Percent age composition of the Gulf of Maine northern shrimp catch (numbers) by quarter, 1973-1979. Sample data are unavailable for the second and fourth quarters of 1975; the remaining omissions reflect seasonal closures.

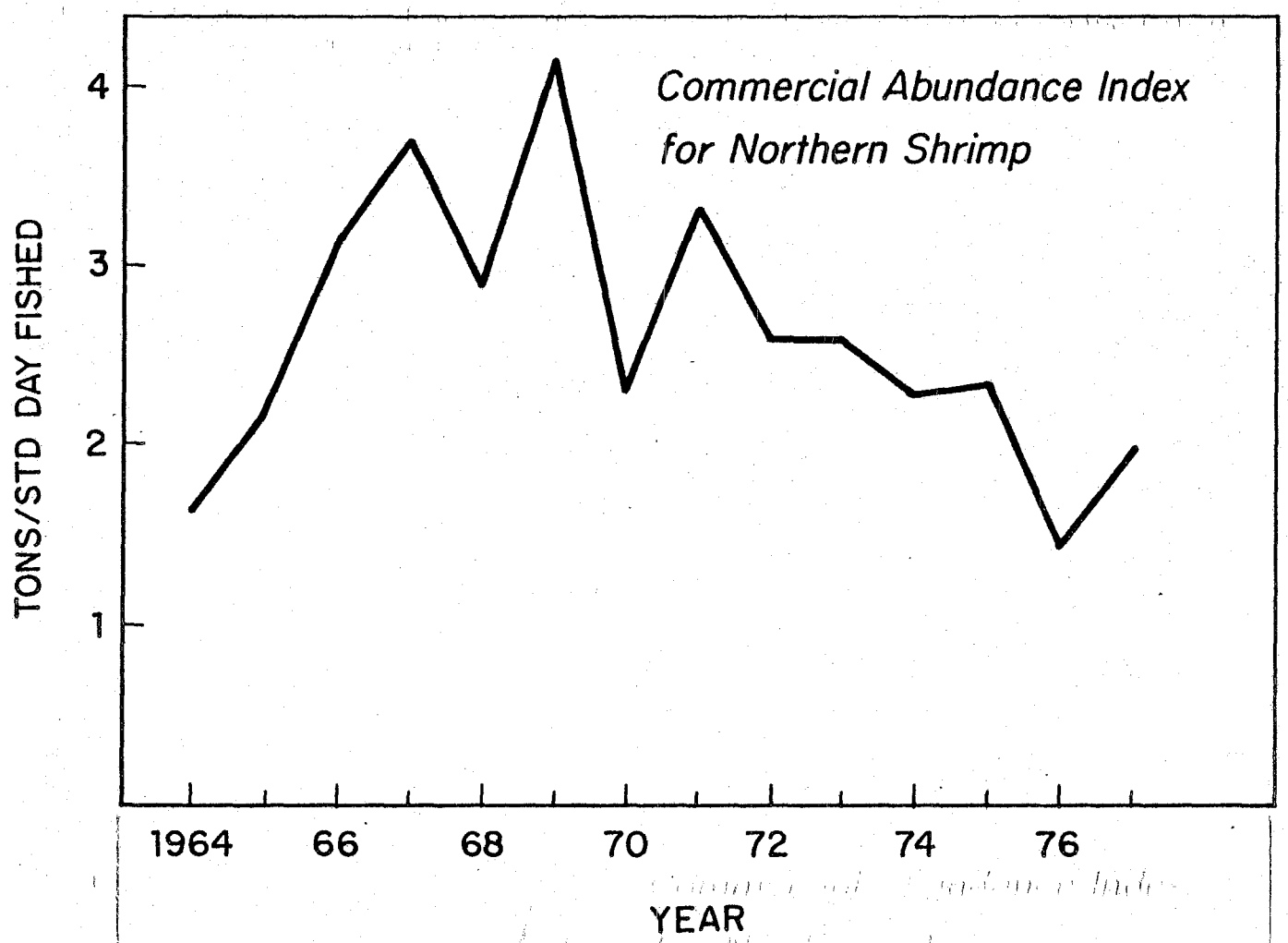

Figure 4. Commercial abundance index for Gulf of Maine northern shrimp calculated from NMFS catch-effort data, 1964-1977.

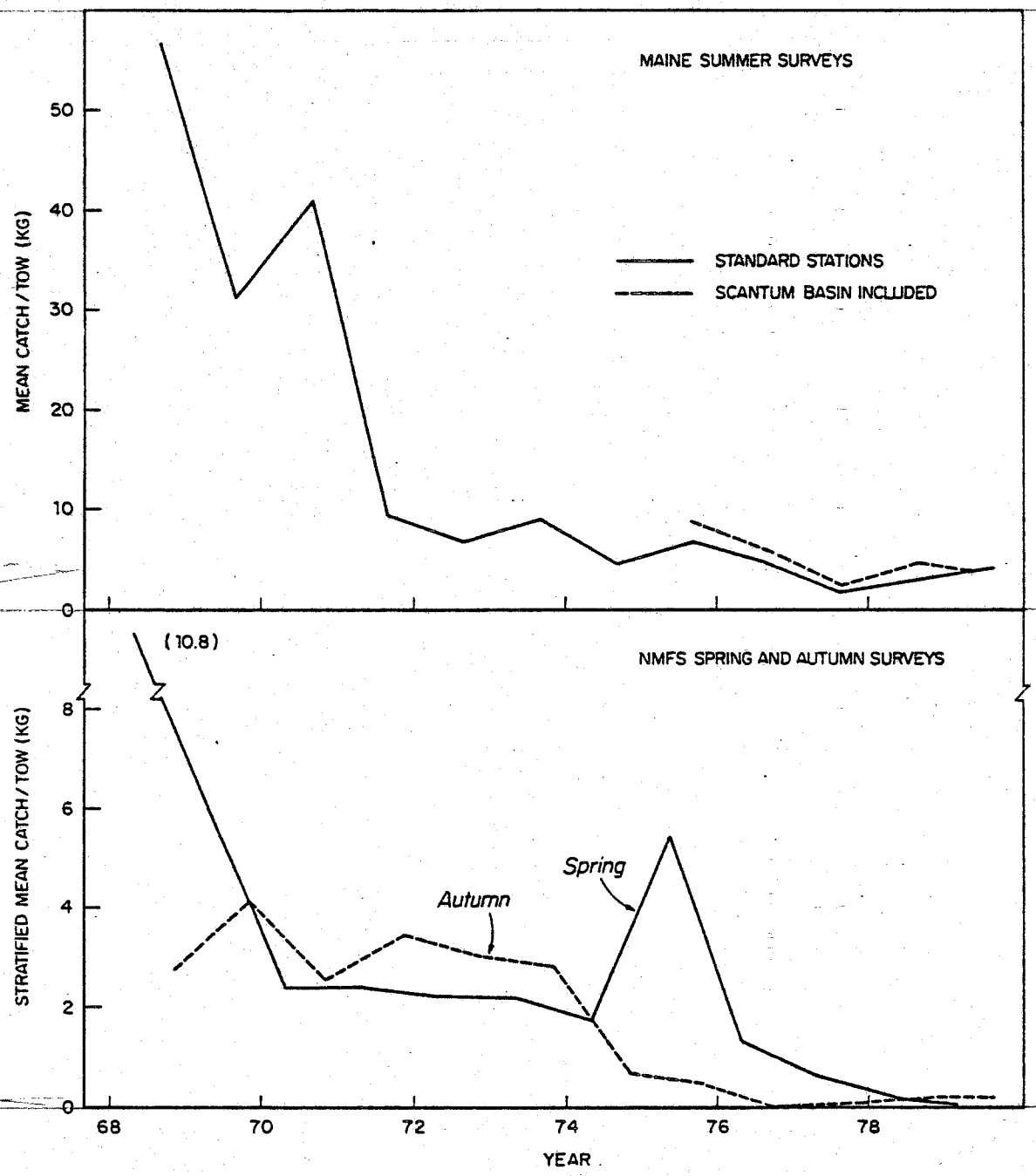

Figure 5. Research vessel survey abundance indices for Gulf of Maine northern shrimp calculated from Maine summer and NEFC spring and autumn bottom trawl survey data, 1968-1979.

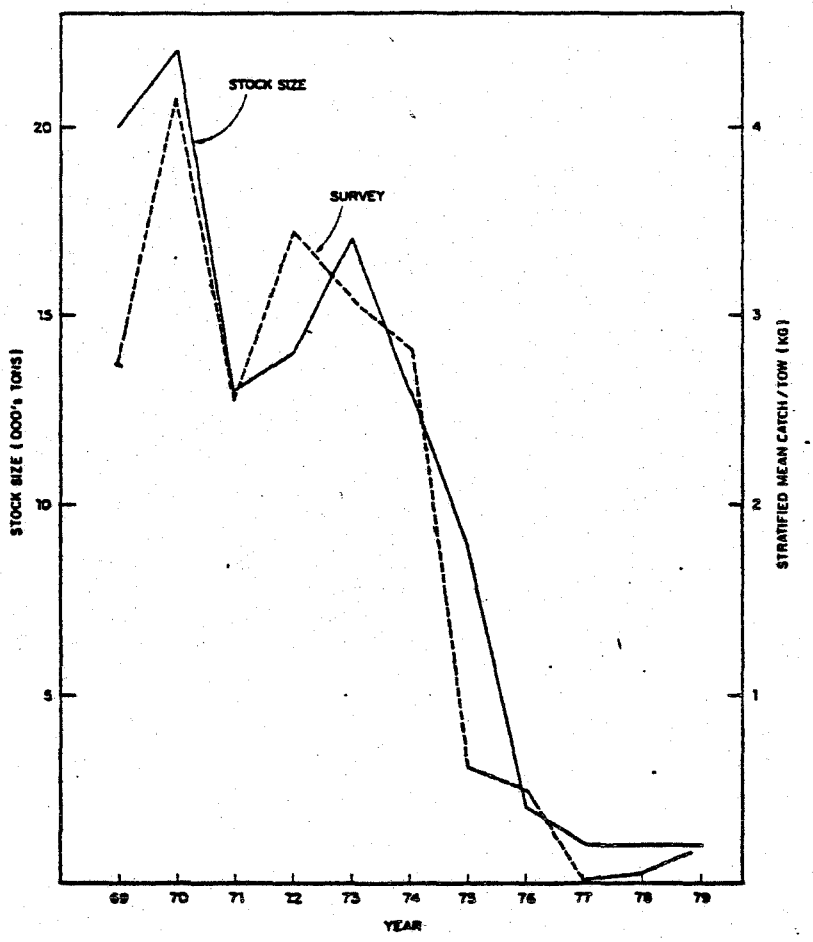

Figure 6. Comparison between stock size estimates and NEFC autumn bottom trawl survey indices (lagged one year) for Gulf of Maine northern shrimp, 1969-1979.

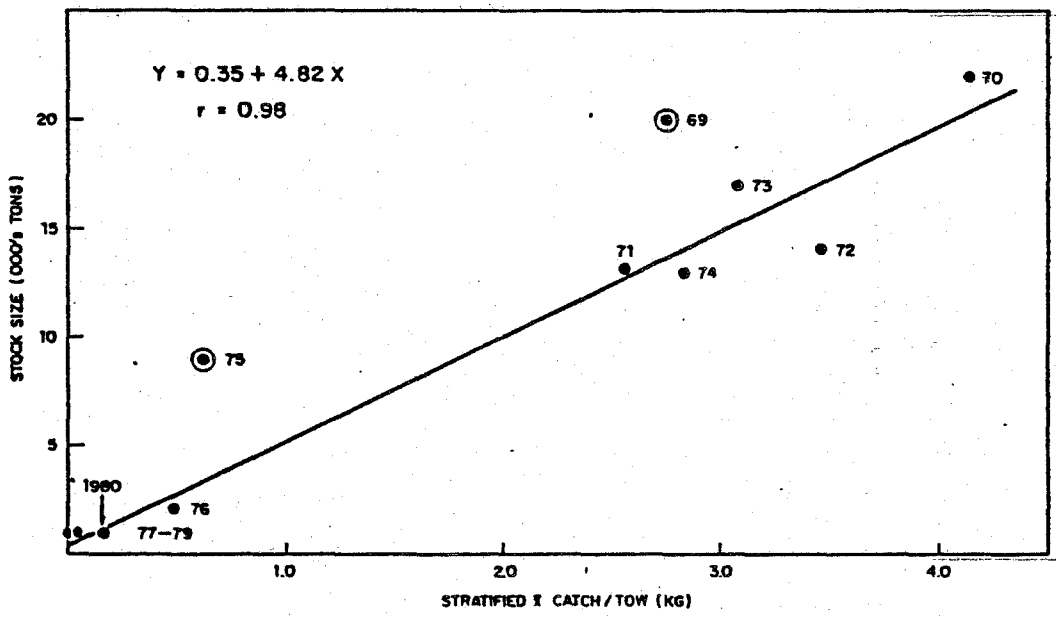

Figure 7. Relationship between stock size estimates and NEFC autumn bottom trawl survey indices (lagged one year) for Gulf of Maine northern shrimp, 1969-1979 (1969 and 1975 points not used in calculating the regression line).

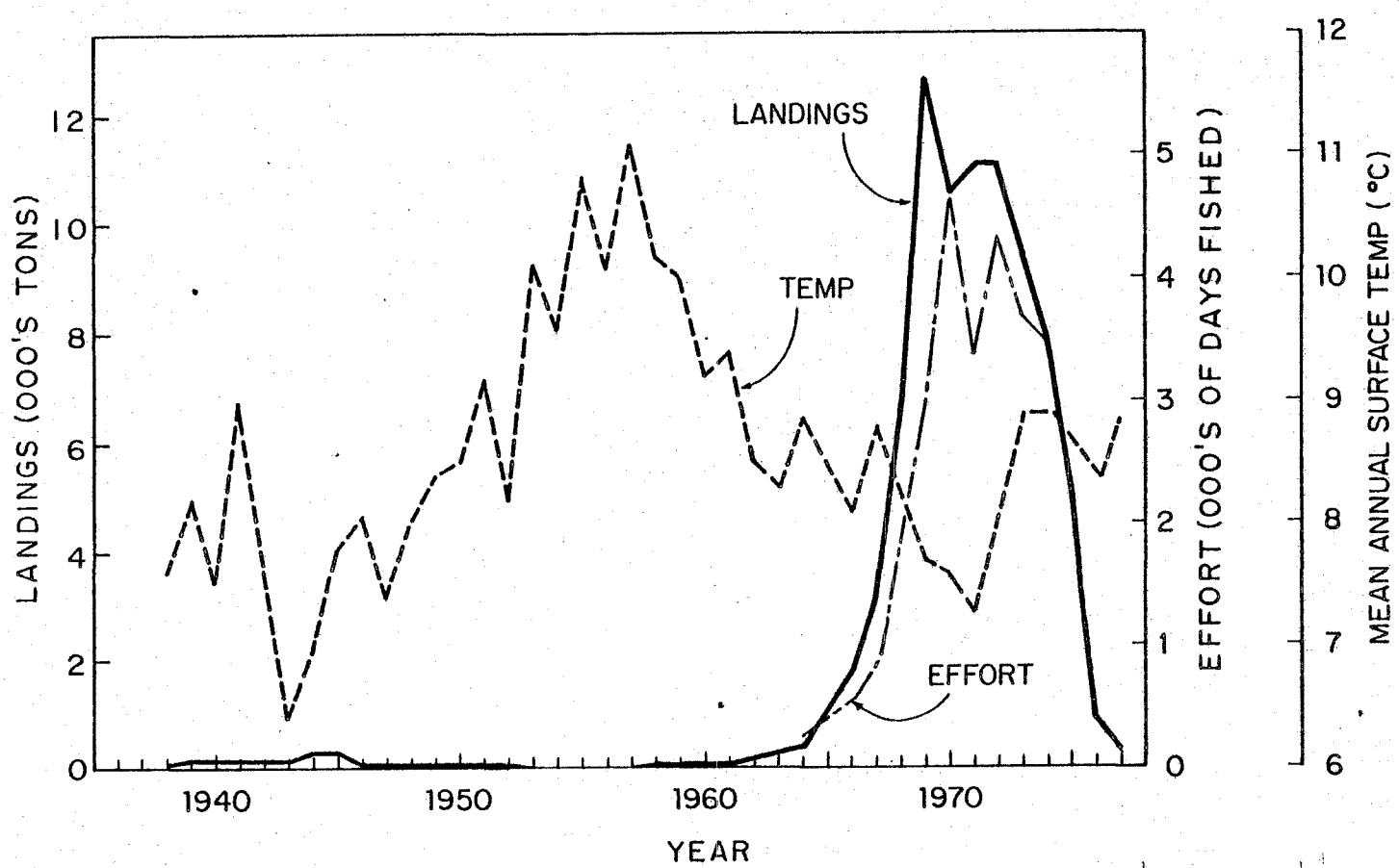

Figure 8. Gulf of Maine northern shrimp landings plotted against annual mean sea surface temperatures measured at Boothbay Harbor, Maine and standardized effort (thousand of days fished). Temperature data are lagged by a period of four years.

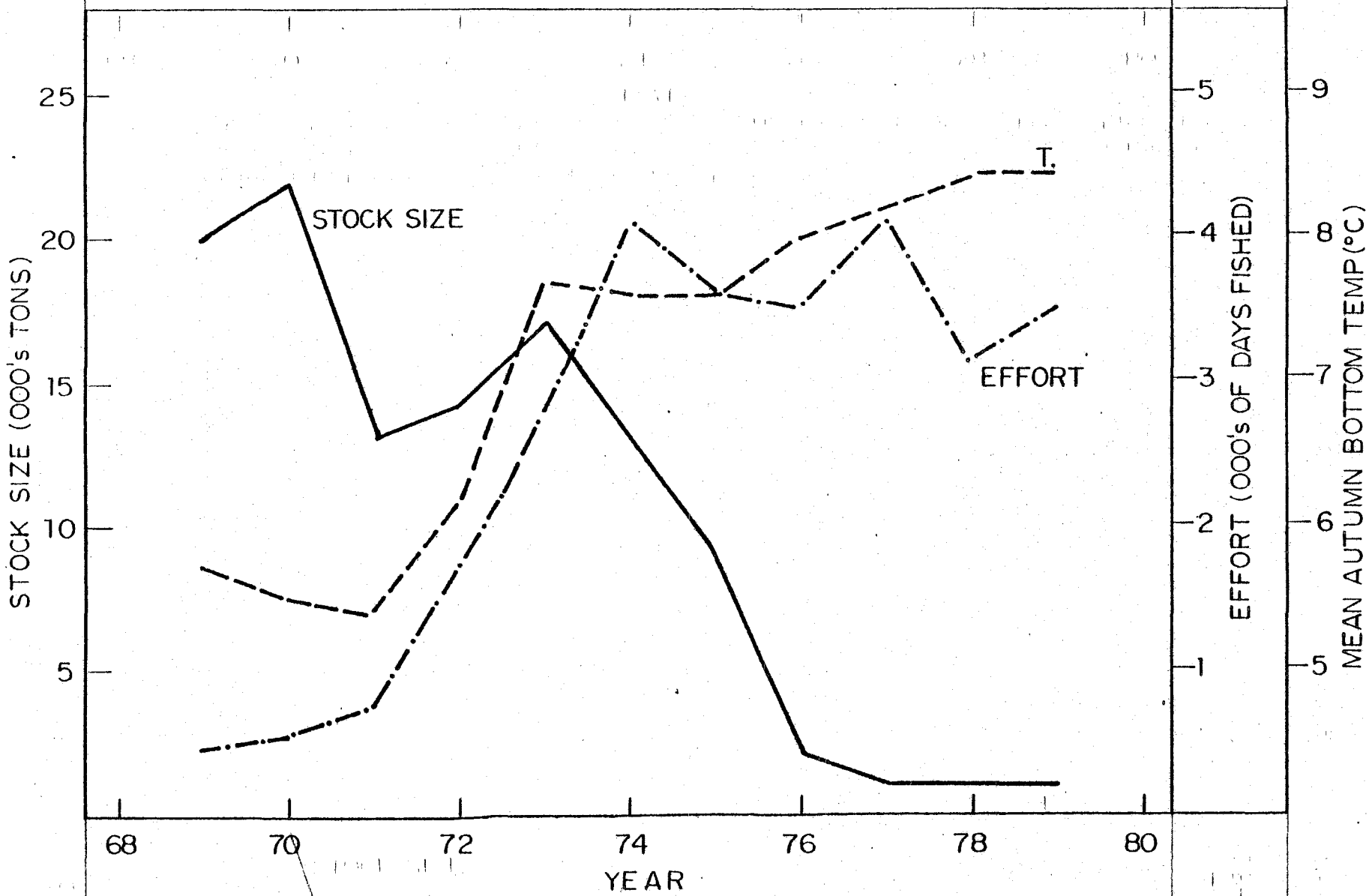

Figure 9. Stock size estimates (thousands of tons) for Gulf of Maine northern shrimp, plotted against mean autumn bottom temperatures observed in NEFC surveys and standardized effort (thousands of days fished). Effort and temperature data are lagged by a period of four years.

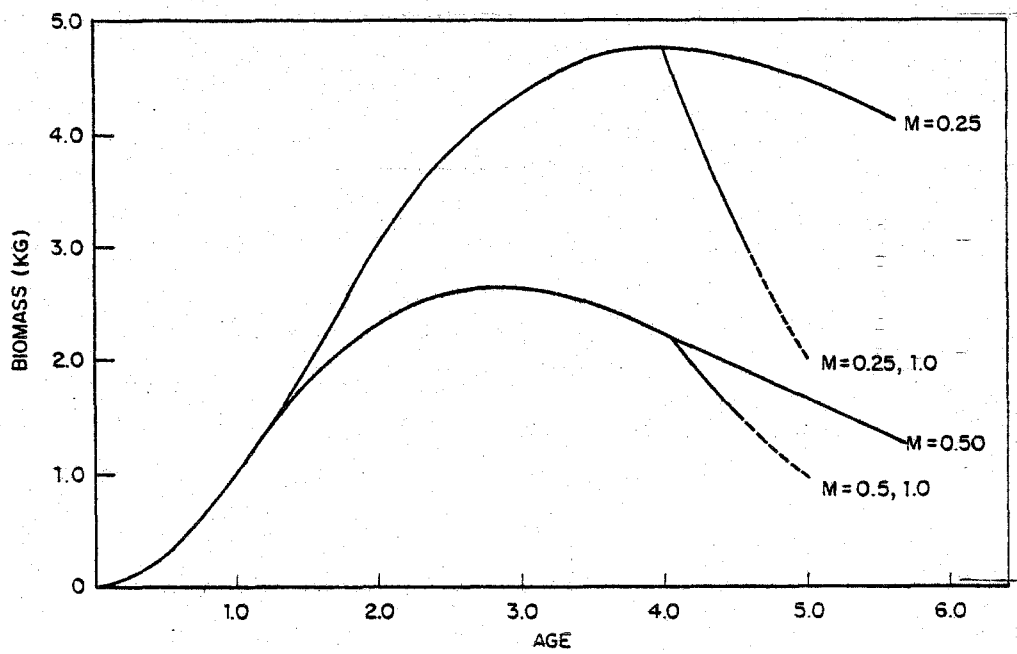

Figure 10. Biomass at age per 1000 recruits (kg) for Gulf of Maine northern shrimp in the absence of fishing, calculated under different assumptions relative to instantaneous natural mortality (M).

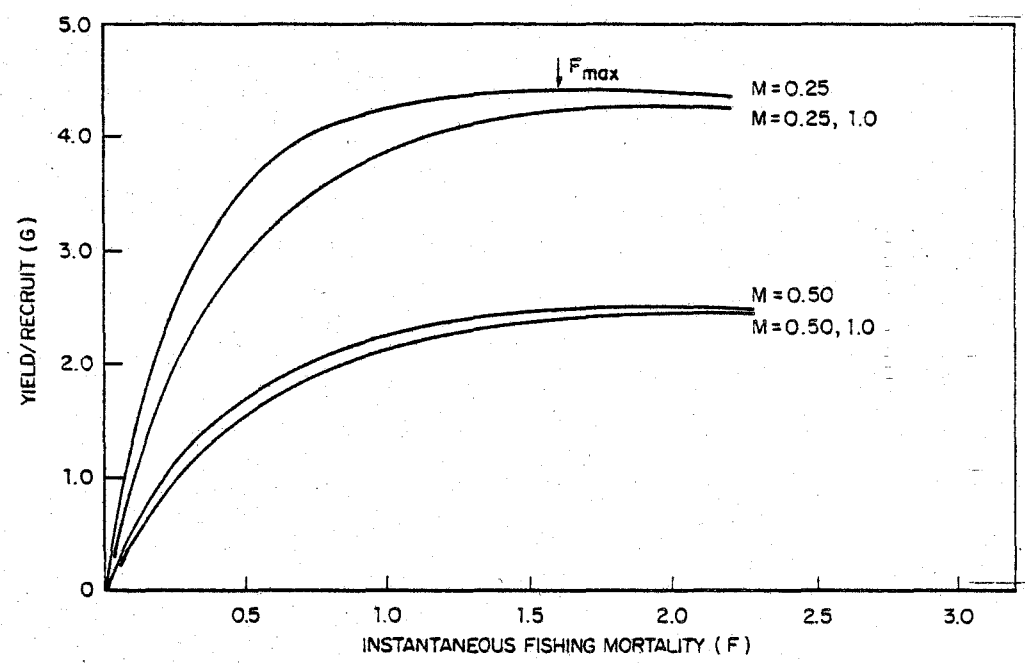

Figure 11. Yield per recruit (g) for Gulf of Maine northern shrimp under different assumptions relative to instantaneous natural mortality (M) assuming use of 1.75 inch (4.5 cm) trawls.

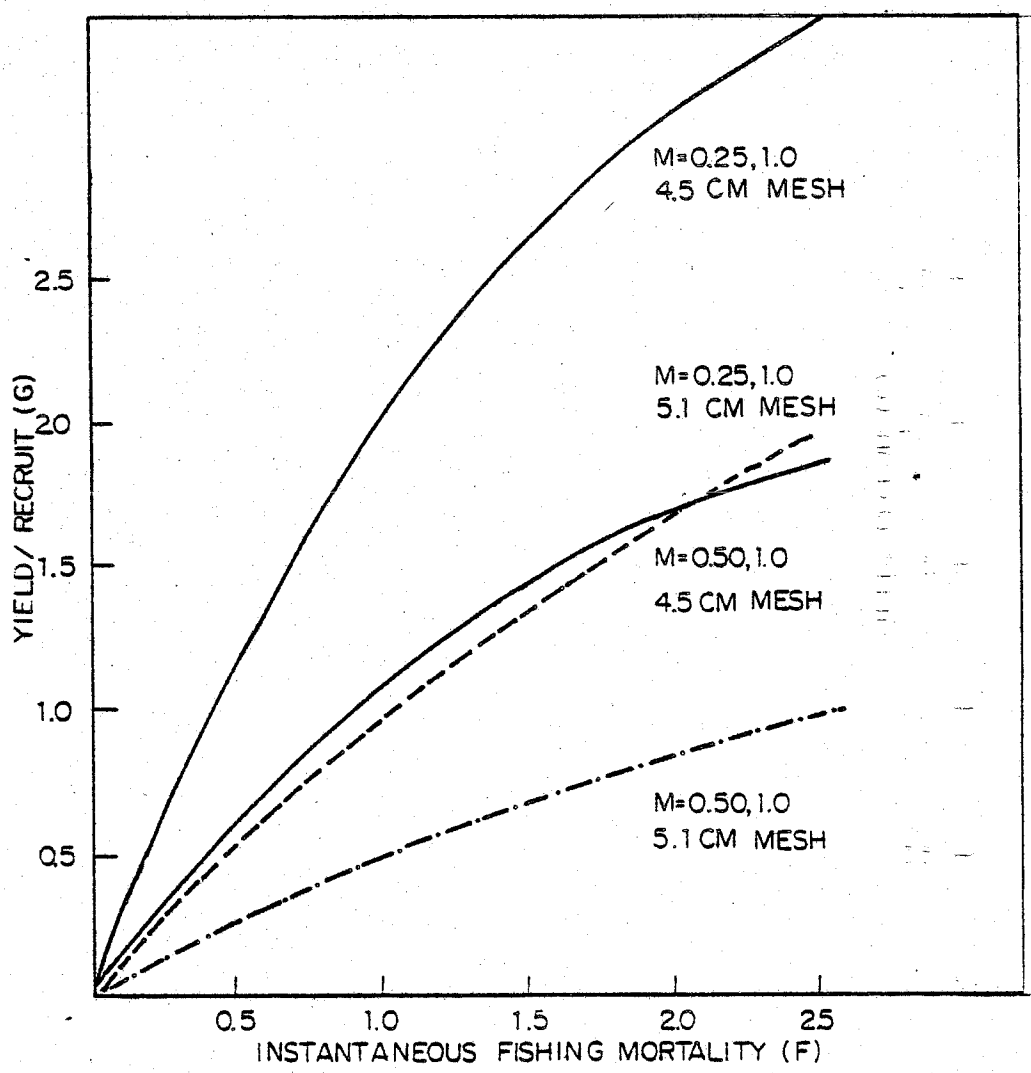

Figure 12. Yield per recruit (g) for Gulf of Maine northern shrimp under different assumptions relative to instantaneous natural mortality (M) assuming seasonal fishing mortality patterns observed in 1970-1974 and use of 1.75 inch (4.5 cm) and 2.0 inch (5.1 cm) trawls.