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An Assessment of the Northern Shrimp Resource of the Gulf of Maine

by

Stephen Clark and Vaughn C. Anthony
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, Massachusetts 02543

Introduction

Pandalus borealis Kroyer is a medium sized shrimp attaining average lengths of 6-7 inches and average weights of 12-15 grams. Commercial concentrations occur both in the North Atlantic and the North Pacific. In the western North Atlantic, the Gulf of Maine represents the southernmost portion of its range. Figure 1 indicates the principal concentration areas in the Gulf of Maine.

The life cycle of this species is an interesting one and determines the character of the Gulf of Maine fishery. In December, egg-bearing females migrate inshore, where the eggs hatch. After a planktonic phase lasting two months, the young shrimp settle to the bottom in inshore areas, where they remain and grow rapidly for a period of 10-18 months. With approaching maturation as males at age 1, the young shrimp move offshore and mate as males in the summer of their third year (age 2½). Following mating, these shrimp pass through a series of transitional stages and become functional females in the summer of their fourth year (age 3½). With the onset of cooler weather, these females - now ovigerous - migrate inshore, where hatching occurs (age 4). Female shrimp older than age 5 now rarely occur in the Gulf of Maine.

In response to this cycle, two fisheries have developed, which are (1) the inshore winter fishery, prosecuted primarily in coastal Maine waters by small draggers and converted lobster boats, and (2) an offshore fishery during warmer months, prosecuted primarily by larger draggers from Gloucester. The inshore fishery harvests primarily adult females, while the summer fishery (located in concentration areas such as Scantum and Jeffreys Basins) harvests immature and mature males and transitionals as well.

The Gulf of Maine northern shrimp fishery was initiated in 1938 and by 1945 catches had increased to 500,000 lbs. Subsequently, however, catches declined drastically and from 1953-1957 no shrimp at all were landed. However, catches began to increase again in the late 1950's and during the next decade growth was explosive, culminating in a total catch of 28 million pounds in 1969. Since that time, landings have declined drastically (Figure 2).

Table 1 depicts recent trends in landings by state. Massachusetts fishermen caught few shrimp before 1969 but in that year catches began to increase substantially and since 1973 Massachusetts has accounted for 40% of the total quantity landed.

Table 2 provides data relative to age composition of the catch from 1973-1976 as determined from samples collected in Portland and Gloucester. These data reflect seasonal patterns of fishing referred to earlier in that the bulk of the winter catch consists of females, while high percentages of smaller immatures and males (age 1 and 2 shrimp) are caught in the spring, summer and fall. Yield-per-recruit studies (Rinaldo MS 1976) indicate that harvesting of age 1 and 2 shrimp results in substantial losses in biological yield; for example, at levels of fishery mortality observed in recent years (averaging approximately 1.5 from 1970-1974) yield per recruit can be increased by approximately 50% as age at first capture is increased from 1.5 to 3.0 years of age (Figure 3).

Current Assessment

The current assessment has been developed from research vessel surveys (by the State of Maine and NMFS), biological sampling, and commercial catch-effort data.

Maine began research vessel surveys in 1966 concurrent with studies by Apollonio and Dunton (MS 1969). Since that year, Maine biologists have developed an extensive year-round program including an annual summer survey in which sampling is conducted in and adjacent to known concentration areas (Figure 4). This survey provides data used to estimate mortality, recruitment, and indices of relative abundance. In addition, the NMFS provides coverage during its annual spring and fall bottom trawl surveys in the Gulf of Maine which is useful in determining trends in recruitment and relative abundance.

Indices of abundance from the above surveys are given in Table 3. Both sets of data agree in indicating pronounced declines in abundance in recent years. The value observed in the NMFS bottom trawl survey in 1976 was the lowest observed since 1968. The increase observed between 1974 and 1975 is believed to be due to an increase in availability and (for the Maine surveys) appears to have been somewhat artificial due to a change to a larger vessel with greater fishing power in 1975.

Commercial indices of abundance for small and medium tonnage-class vessels are available from catch and effort statistics since 1964 (Table 4). Again, both sets of data reveal pronounced declines in abundance since 1969. The indices for small tonnage-class vessels reveal a sharper decline. This probably is due to the greater range and increased searching capacity of the larger vessels and the trend observed for small tonnage-class vessels is assumed to be more realistic.

Instantaneous rates of fishing mortality, stock size and recruitment estimates calculated from commercial landings and Maine summer survey data are given in Table 5. To obtain estimates of F, instantaneous total mortality coefficients (Z) were calculated from catch-curve analysis and the instantaneous rate of natural mortality (M = 0.25) was then subtracted. Calculated values of F were extremely high for 1971, 1972 and 1974; unfortunately, the 1975 value could not be calculated directly due to the above-mentioned change in survey vessels and/or availability. Yield per recruit calculations for northern shrimp at a minimum age at harvest of 3.0 (for legal-sized mesh) indicate F_{max} (the level providing maximum yield-per-recruit) to equal 2.0; $F_{0.1}$ (an arbitrary level providing some protection against over fishing) is approximately 1.1 (Figure 5). Even the latter value may be excessive considering the low reproductive capacity of this species, and in any event, values in some recent years appear to have been considerably above F_{max}.

Stock size estimates (Table 5) were obtained by calculating exploitation rates from F and Z values obtained above and relating them to catch; recruitment estimates were obtained by subtracting survival in a given year from stock size in the year immediately following. All estimates indicate pronounced declines in abundance and recruitment in recent years. Unfortunately, the 1975 estimate could not be calculated directly and 1976 data were somewhat uncertain due to delayed sampling in that year; consequently, these values were obtained by extrapolation of the commercial abundance index for smaller tonnage-class vessels. Trends in computed estimates of stock size agree with NMFS survey data in indicating a decline in the order of 75-80% in recent years.

No discussion of trends in abundance and recruitment for this species would be complete without some reference to environmental factors - notably, temperature. Robert Dow (State of Maine) has commented on temperature influences in a series of papers during the 1960's and has recently demonstrated a highly significant negative correlation between landings and annual mean sea surface temperatures four years previous. (He used this lag period under the assumption that temperature influences during the first year of life would be most critical). To date, most studies on environmental influences have centered on the early life history of this species. In a 1969 paper, Apollonio and Dunton reported that high winter temperatures appeared to adversely affect embryonic development and suggested that the collapse of the fishery in the mid-1950's could have been caused by excessive egg mortality during high temperature years (1950-1953). More recently, Stickney (unpublished) has suggested that high winter temperatures could reduce larval survival by causing premature hatching before adequate sources of food were available. Possibly a number of factors are involved; in any event, it would certainly appear that temperature is of importance in determining trends in northern shrimp stock abundance (Figure 6).

On the other hand, there is evidence to suggest that temperature is not the only variable affecting northern shrimp stock abundance. In particular, a tremendous increase in effort has occurred in recent years, and resulting high exploitation rates may have been every bit as important as recent increases in temperature in determining recent declines in abundance. Figure 7 shows the relation between temperature, effort and stock size estimates calculated previously for 1968-1975 (effort and temperature lagged four years); we have chosen to lag effort by the same number of years under the assumption that fishing mortality on egg bearing females would be critical but clearly other approaches would be possible as well.

To evaluate the relative importance of effort and temperature in determining trends in abundance, we used partial correlation analyses; results of these tests indicate a stronger relationship between effort and stock size than between temperature and stock size (Table 6). The coefficient of determination (R^2) is only 0.42, indicating that a considerable amount of variation remains unexplained; however, R^2 is considerably increased when effort data are included as opposed to that obtained when temperature alone is considered. It would be our conclusion that in recent years high exploitation rates have been more important than temperature in determining trends in abundance.

Summary and Conclusions

The northern shrimp resource has been managed under the ASMFC by the Northern Shrimp Sub-Board (of the State-Federal Fisheries Management Board) which acts on recommendation from the Northern Shrimp Scientific Committee. Management efforts began in 1973 with the imposition of interim mesh regulations; current mesh regulations were instituted in 1975 after gear-evaluation studies by the Scientific Committee. Declining trends in abundance also led to a series of stock assessments (1974-1976); resulting management recommendations have run the gamut from proposals for catch quotas and closed seasons to a proposal for outright closure of the fishery until the stock could rebuild. The collapse of this stock was predicted as early as May of 1973.

Resulting regulations have centered around seasonal closure and mesh size regulations; for 1977, the fishery is currently operating under an open season extending from January 1 to May 15 and a quota of 3.5 million lbs; existing mesh regulations to remain in effect.

Future prospects for recovery are not good; given current low levels of abundance, time required for maturation, the potential for a relatively strong stock-recruitment relationship and apparently unfavorable environmental conditions (e.g., high temperatures) in recent years, it would appear unlikely that a significant degree of recovery would occur before the mid-1980's at the earliest.

Literature Cited

Apollonio, S. and E. E. Dunton, Jr. MS 1969. The northern shrimp, *Pandalus borealis*, in the Gulf of Maine. Job Completion Report, PL 88-309, Project 3-12-R. 65p.

Rinaldo, R. G. MS 1976. *Pandalus borealis* management modeling. Completion Report, Shrimp Project 3-189-R. 93p.

Table 1. Gulf of Maine northern shrimp landings (thousands of pounds) by state, 1958-1976.

	State			
Year	Maine	NH	Mass.	Total
1958	5	-	-	5
1959	12	-	5	17
1960	89	-	1	90
1961	67	-	1	68
1962	352	-	36	388
1963	538	-	23	561
1964	925	-	7	932
1965	2075	-	18	2093
1966	3831	40	23	3894
1967	6725	44	22	6991
1968	14363	95	114	14572
1969	24235	128	3909	28272
1970	16954	120	6398	23472
1971	18419	112	6005	24536
1972	16569	165	7726	24460
1973	12074	132	8528	20734
1974	9770	180	7656	17606
1975	7010	81	4588	11679
1976	1361	14	975	2350

Table 2. Age composition in northern shrimp commercial samples by season, 1973-1976.

		AGE			
		0	1	2	3 & 4
Year	Season	Number sampled (percentage)			
1973 -	W	-	1 (0.2)	67 (15.8)	356 (84.0)
	S	-	19 (2.6)	292 (40.1)	417 (57.3)
	S	-	625 (28.5)	1034 (47.2)	531 (24.3)
	F	23 (1.9)	403 (32.8)	366 (29.8)	438 (35.6)
1974 -	W	-	41 (2.0)	657 (32.1)	1346 (65.9)
	S	-	101 (6.7)	693 (45.9)	716 (47.4)
	S	-	1363 (64.1)	395 (18.6)	370 (17.4)
	F	6 (0.5)	622 (47.0)	254 (19.2)	442 (33.4)
1975 -	W	-	23 (1.2)	559 (29.1)	1342 (69.8)
1976 -	W	-	531 (7.2)	1920 (26.0)	4936 66.8

Table 3. Research vessel survey abundance indices for Gulf of Maine northern shrimp, 1968 - 1976.

Year	Mean catch/30 minute tow (pounds) Maine Surveys	Stratified[1] mean catch/ 30 minute tow (pounds) NMFS Surveys
1968	125.5	2.9
1969	68.8	5.0
1970	90.0	5.1
1971	20.8	5.0
1972	15.2	4.9
1973	19.8	3.4
1974	9.8	1.9
1975	17.8	2.3
1976	11.9	0.9

[1] A stratified random sampling design has been used in this survey. Accordingly, the Gulf of Maine has been delineated into strata (primarily on the basis of depth); sampling stations are allocated to strata in proportion to the area of each and are assigned to specific locations within strata at random.

Table 4. Commercial abundance indices for Gulf of Maine northern shrimp by vessel class, 1964-1976

Year	Vessel class: Small, 0-50 GRT Catch/day fished (thousands of pounds)	Vessel class: Medium, 51-150 GRT Catch/day fished (thousands of pounds)	Vessel class: Combined index Catch/day fished (thousands of pounds)
1964	2.11	3.97	2.12
1965	2.98	3.14	2.98
1966	3.93	11.64	4.16
1967	5.33	10.20	5.62
1968	3.88	7.68	4.09
1969	5.70	9.49	6.15
1970	2.94	6.67	3.43
1971	4.48	8.35	4.99
1972	3.30	7.55	3.85
1973	3.32	7.88	3.94
1974	2.66	8.06	3.16
1975	2.57	9.05	3.05
1976	1.57	6.51	1.89

Table 5. Instantaneous fishing mortality, stock size, and recruitment, calculated from Maine summer surveys and commercial landings.

Year	Fishing Mortality Rate	Stock size (millions of pounds)	Recruitment (millions of pounds)
1968	0.71	32	-
1969	0.75	60	48
1970	0.71	52	30
1971	1.95	31	11
1972	1.72	33	30
1973	0.88	39	34
1974	1.95	22	9
1975	-	18[1]	(16)
1976	0.89	4-15[1]	-

[1] From extrapolation of commercial abundance index

Table 6. Simple and partial correlation coefficients relating stock size to temperature and effort. (Data for temperature and effort were lagged four years.)[1]

	Stock size vs temperature		Stock size vs effort
Simple correlation coefficient	-0.55		-0.62
Partial correlation coefficient	-0.23		-0.41
Multiple correlation coefficient		0.65	
Standard partial regression coefficients	-0.24		-0.46
Coefficient of determination		0.42	

[1] All data transformed to logarithms.

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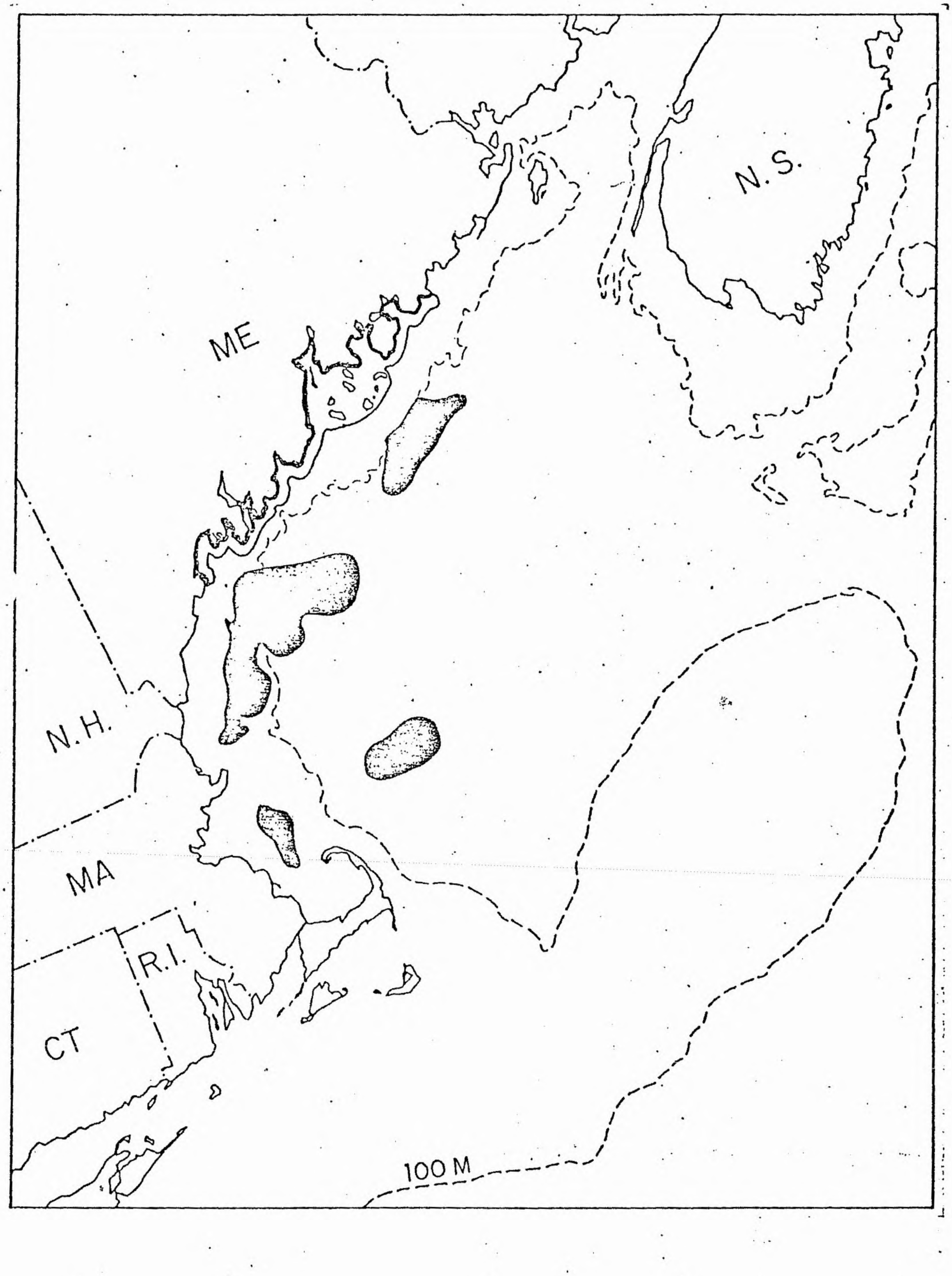

Figure 1. Northern shrimp concentration areas in the Gulf of Maine.

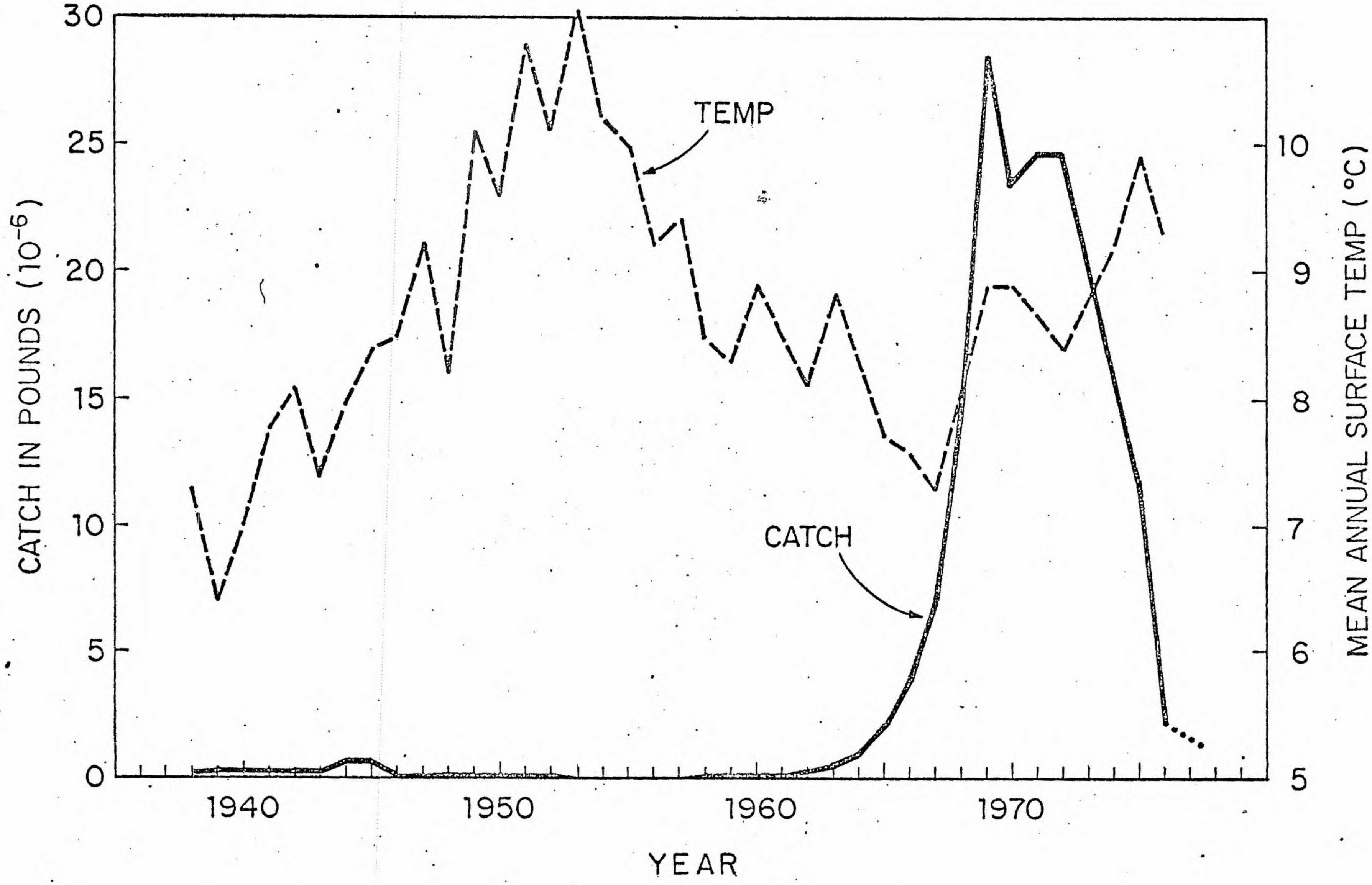

Figure 2. Northern shrimp landings and sea surface temperature trends.

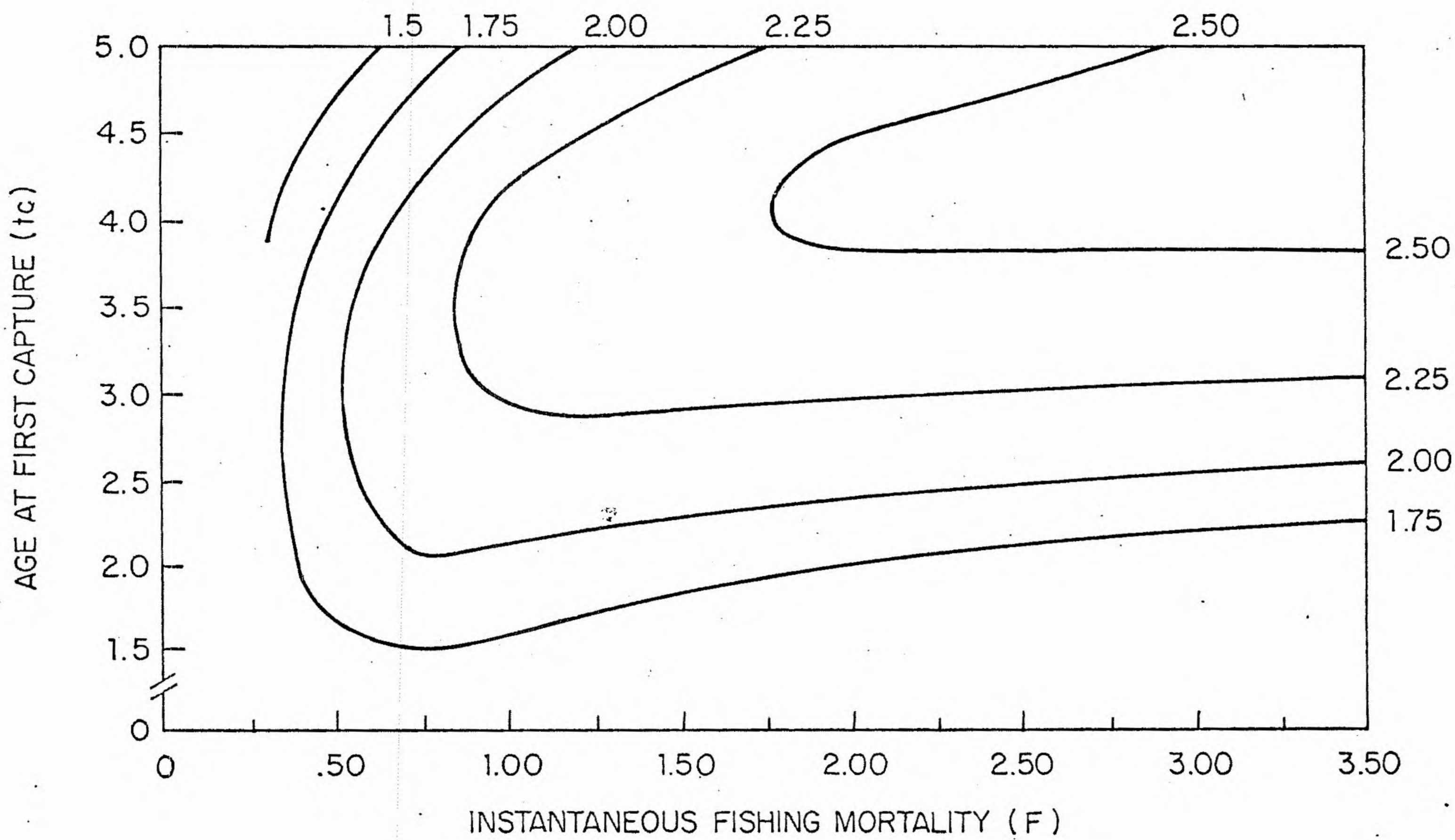

Figure 3. Yield per recruit isopleths for northern shrimp.

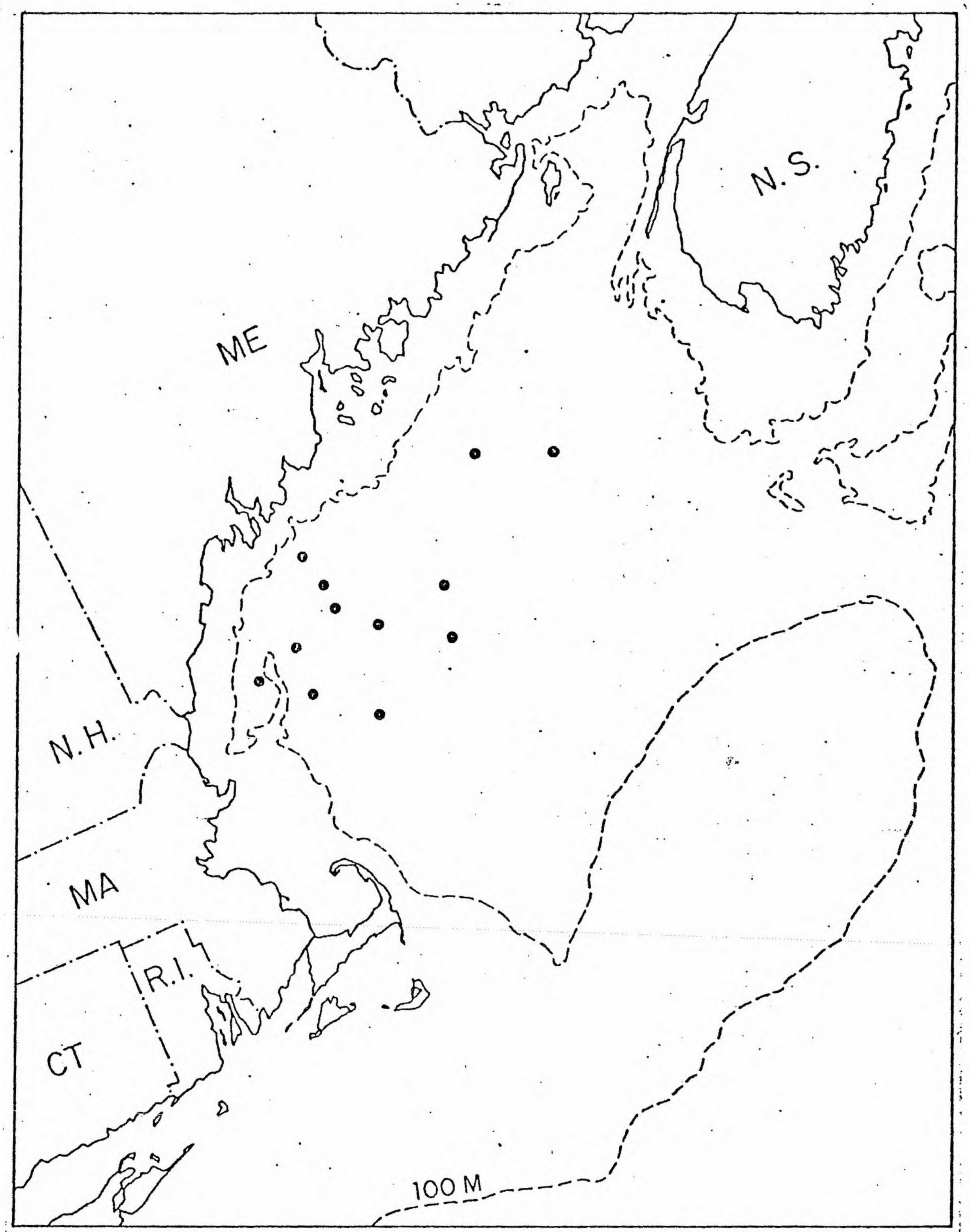

Figure 4. Location of northern shrimp sampling stations, Maine summer survey.

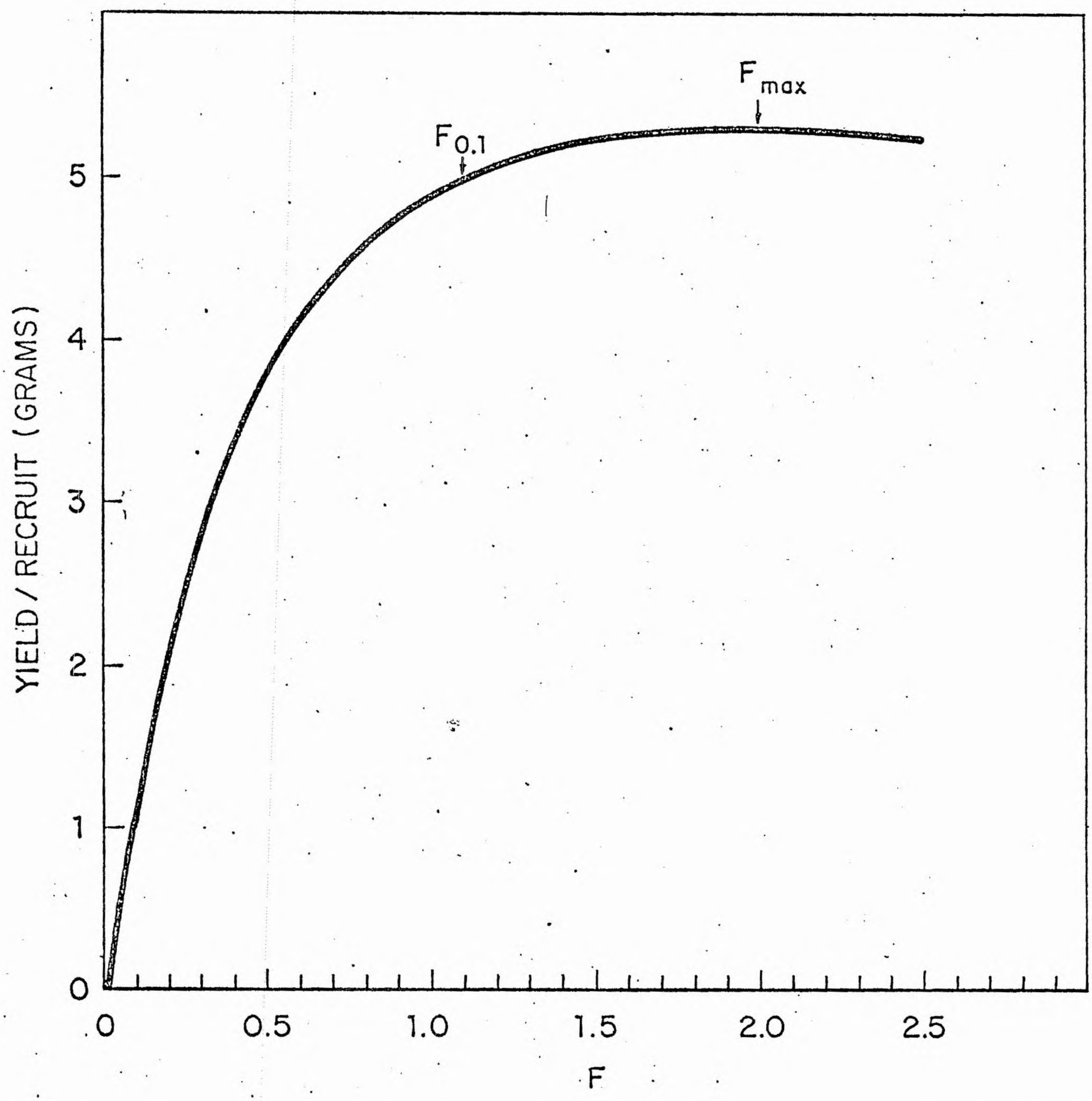

Figure 5. Yield per recruit curve for northern shrimp assuming a mean age at first capture of 3.0 years.

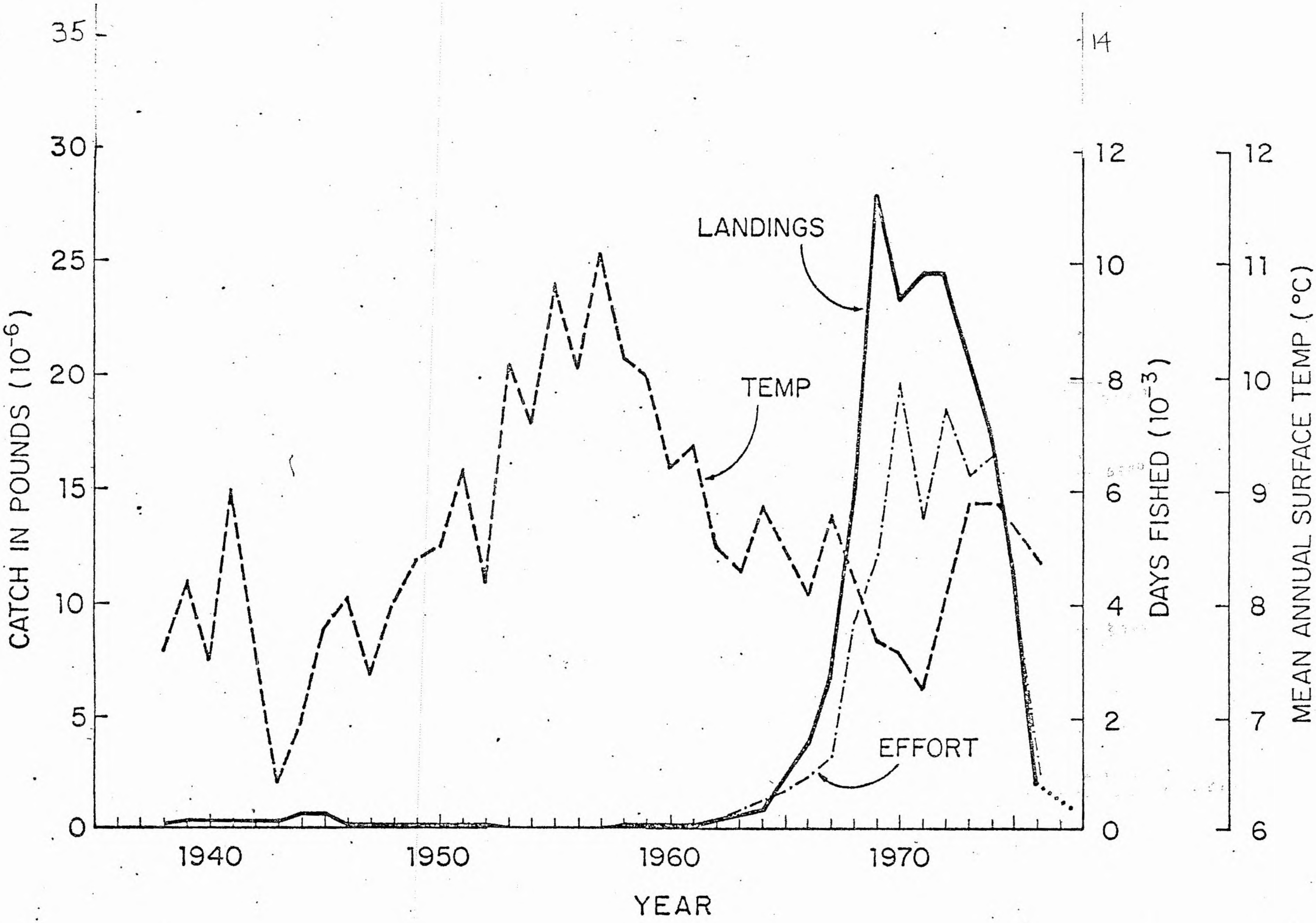

Figure 6. Landings of northern shrimp (1938-1976) plotted against annual mean sea surface temperature and effort. Temperature data are lagged by a period of four years.

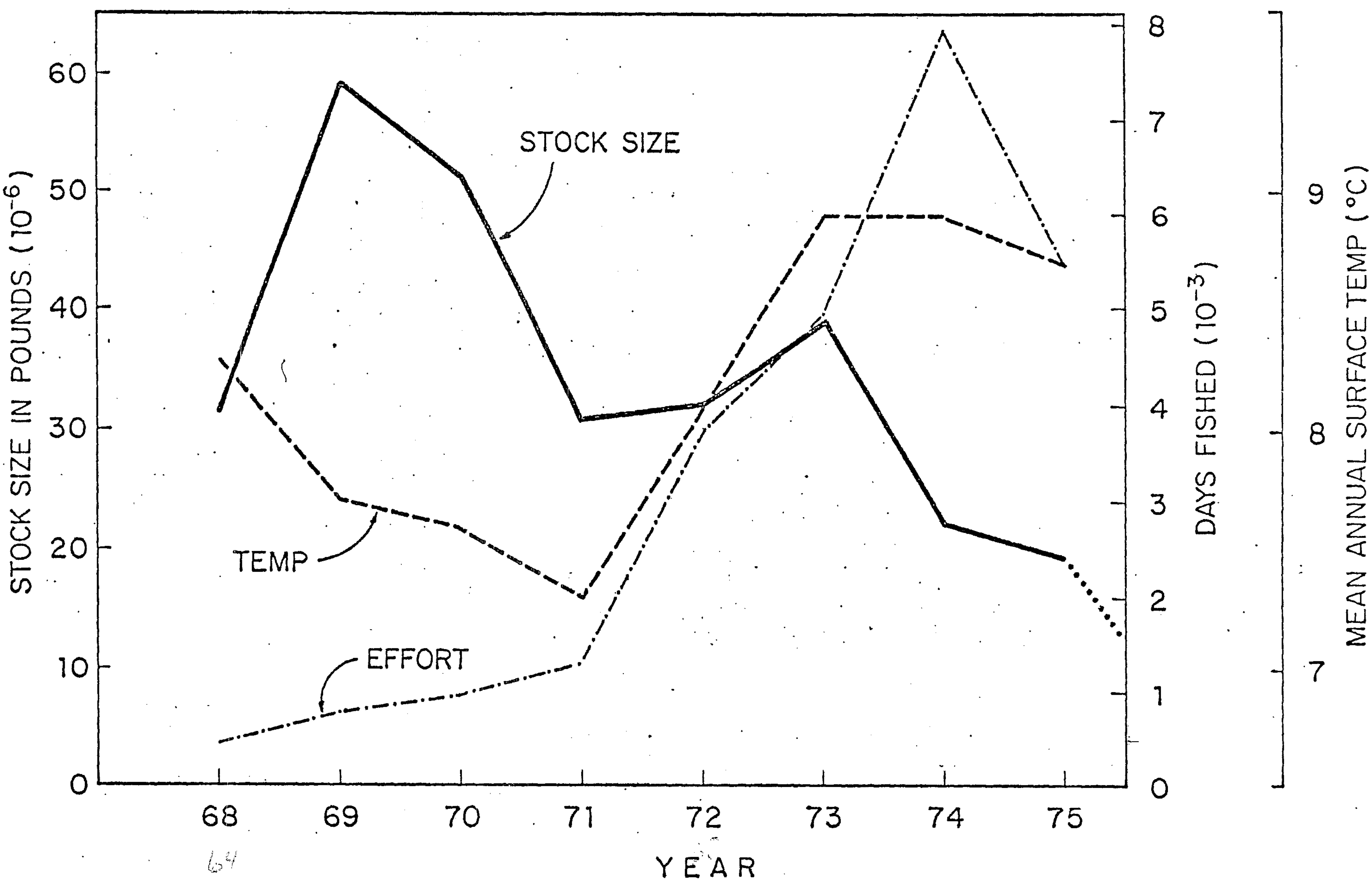

Figure 7. Trends in stock size (1968-1975) compared to trends in temperature and effort (lagged four years).