CHANGES IN ABUNDANCE OF THE GREEN CRAB, *CARCINUS MAENAS* (L.), IN RELATION TO RECENT TEMPERATURE CHANGES

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ABSTRACT

Trap catches, shore surveys, and fishermen's reports demonstrated that declining abundance of green crabs in northern New England was associated with particularly cold winters and a cooling trend in the water. Since the mid-1950's, the once great abundance of green crabs in northeastern Maine has declined to a scarcity or total absence. Abundance in southwestern Maine and in Massachusetts has fluctuated widely, and moderate abundance in Rhode Island decreased consistently through 1959.

Mass mortalities of green crabs in winter coincided with periods of severe cold. The general abundance and commercial catch of the soft-shell clam (*Mya arenaria*), a common prey of the green crab, increased markedly during the period of decline of the crabs.

Although the decrease in abundance of green crabs is clearly associated with lower temperatures, the relation is not necessarily direct; there are a number of ways in which low temperature, in combination with lowered salinity, low dissolved oxygen, and other unidentified factors, may affect abundance.

The green crab, *Carcinus maenas* (L.), has undergone major changes in abundance and distribution along the northeast Atlantic Coast since the late 1800's. Scattergood (1952) traced the spread of the species northward to Casco Bay in southwestern Maine by the early 1900's, to scattered localities in central Maine by the late 1930's, and finally into far northeastern Maine and New Brunswick by 1951. He concluded that green crabs, if present at all in northeastern Maine, were scarce in 1939–42. Glude (1955) narrowed the period of greatest increase of green crabs along the Maine Coast to 1948–51 and recorded their spread to Wedgeport, Nova Scotia, by 1954 (fig. 1). The Fisheries Research Board of Canada (1961) reported that the species had extended its range as far east as Lockeport, Nova Scotia, 64 km. beyond Cape Sable.

The green crab is of minor commercial importance as bait for sport fishermen south of Cape Cod. A limited fishery in Maine, New Hampshire, and Massachusetts supplies this market.

The major interest in the species in the United States lies in its importance as a predator. Dow and Wallace (1952) pointed out the significance of the green crab as a predator on the soft-shell clam (*Mya arenaria*). Glude (1955) and MacPhail, Lord, and Dickie (1955) presented evidence to show the seriousness of predation by green crabs on clams in Maine, New Brunswick, and Nova Scotia.

The purposes of this paper are to document changes since the peak of abundance in the mid-1950's and to relate these changes to concurrent changes in temperature.

SOURCES OF INFORMATION

I have used data from three sources: (1) Records of surface sea-water temperature kept at Boothbay Harbor from 1905 through 1967; (2) estimates of the abundance of green crabs and soft-shell clams by biologists, wardens, and fishermen; and (3) quantitative sampling of green crab populations.

RECORDS

Records of surface sea-water temperature were kept at the BCF Biological Laboratory, Boothbay Harbor, Maine, from 1905 through 1967. From 1905 through 1949, thermometer readings were made thrice daily at the station wharf. From 1950 on, instruments have recorded the temperature, sensed at 1.68 m. below mean low water. Infrequent gaps in the recorded data were filled in from temperatures read in flowing water tanks. Daily, monthly, and annual means were derived from the three daily thermometer readings and hourly readings from the recordings. Figure 2 shows the

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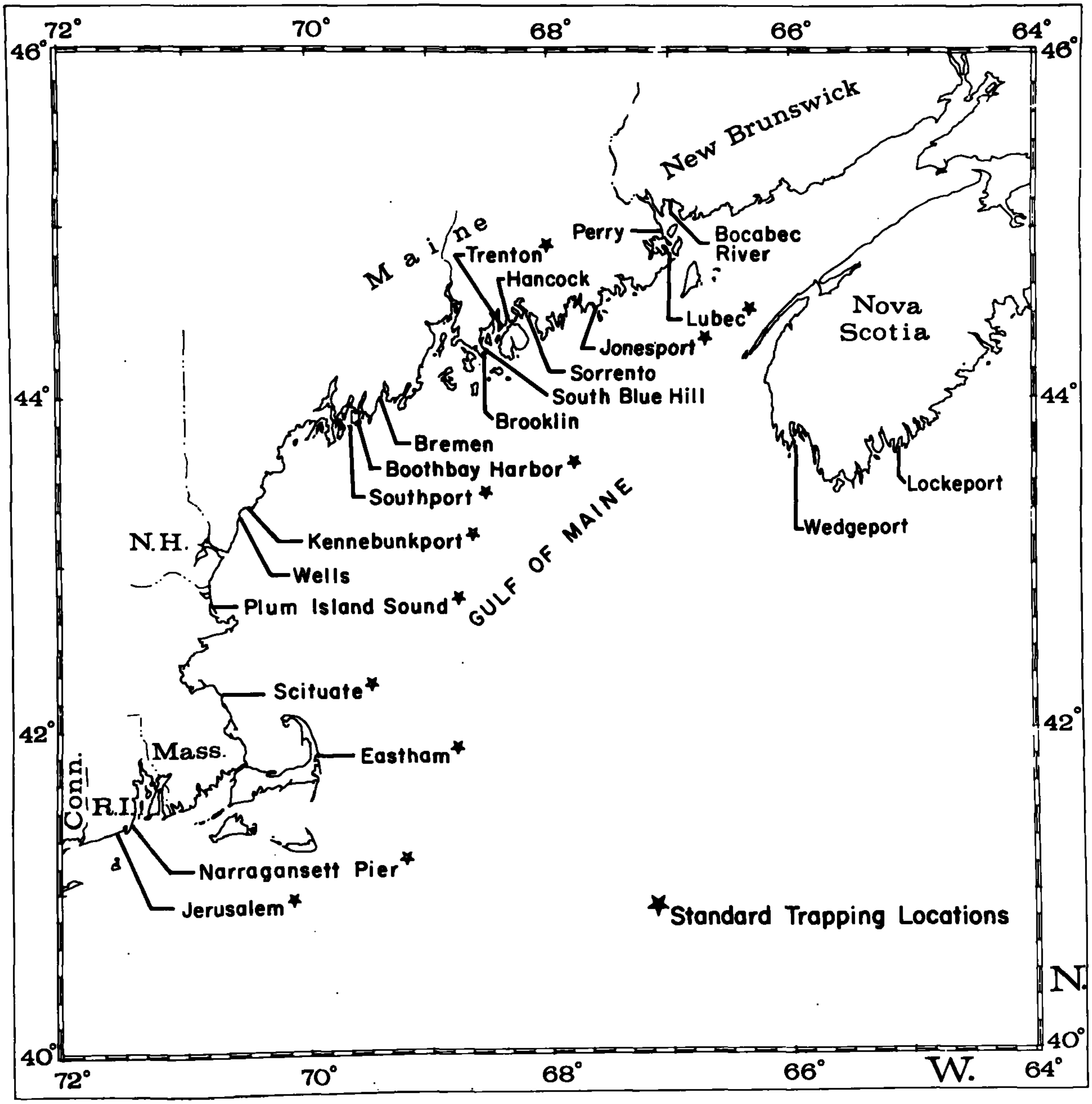

FIGURE 1.—Location of trapping sites and other areas mentioned in text.

annual means and means for the coldest month of each year.

ESTIMATES

Estimates of the abundance of green crabs and soft-shell clams from the early 1920's to 1951 were obtained from two sources. First, F. E. Goucher, the Clam Commissioner of Essex, Mass., who dug clams for over 22 years, wrote of his own and other fishermen's observations in northern Massachusetts.[1] Second, about 100 coastal wardens and fishermen were interviewed in cooperation with the Maine Department of Sea and Shore Fisheries. Their recollections applied to Maine, but the information reported for southwestern Maine agreed well with that of Goucher (see footnote 1) for northern Massachusetts.

[1] Goucher, Franklyn E. 1951. Commentary of a clam digger. Unpublished manuscript on file at the BCF Biological Laboratory, Boothbay Harbor, Maine.

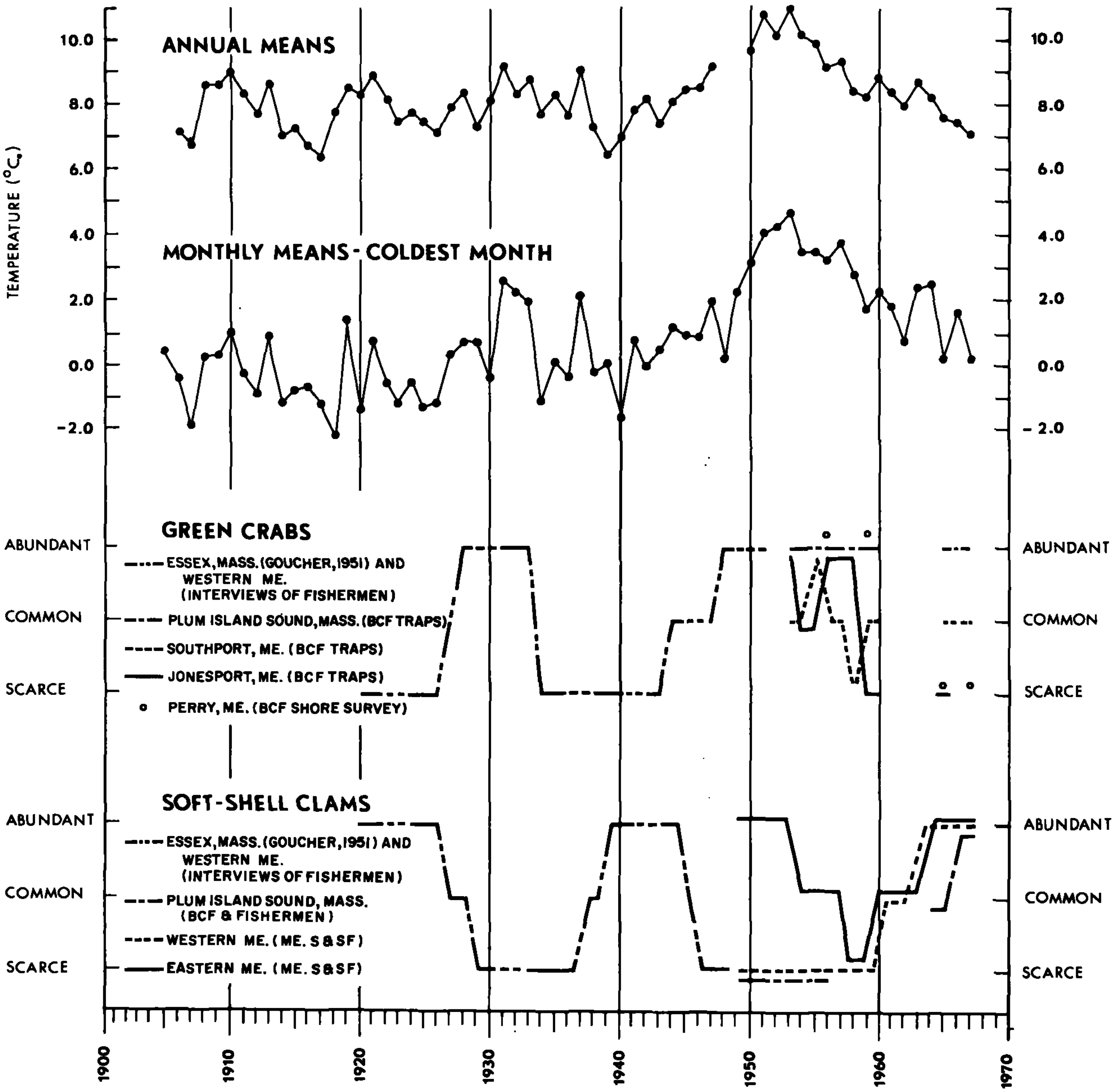

Figure 2.—Comparison of annual mean temperatures and lowest monthly mean temperature for each of the years 1905–67, with the abundances of green crabs and soft-shell clams. Equal levels of abundance occurring at the same time and place are shown as slightly displaced lines.

Estimates of the abundance of clams from 1949 through 1967 were furnished by biologists of the Maine Department of Sea and Shore Fisheries.

QUANTITATIVE SAMPLING

BCF biologists used standardized methods to trap crabs in various locations from 1953 through 1960 and 1965 through 1967. The specially designed traps (fig. 3) were built to the same dimensions, were baited with 4.5 kg. of fresh or frozen herring each day, and were fished at the same locations in the same depth of water each time. The traps were fished for 24 hours on 2 consecutive days during the first week of each month from late spring to late fall, when the crabs were most active. The catch and old bait were removed each day. The crabs were sexed, counted, measured, and destroyed. The catch per trap per day, used

FIGURE 3.—Standard trap used for sampling green crab populations. The deep, sheet-metal funnel prevents escape. The outside dimensions are 81 cm. long by 61 cm. wide by 34 cm. high.

as a measure of abundance, was calculated for each month and each location.

Occasional shore surveys in the intertidal zone supplemented trap catches. The surveys were at low tide in widely scattered areas where traps were not being fished and where there was good to excellent cover for crabs. During a timed search, requiring at least 1 man-hour of effort, all crabs that could be found in the open, under seaweed or stones, or in burrows, were collected, sexed, counted, and measured. Abundance was expressed as the number of crabs found per man-hour of effort expended.

CHANGES IN ABUNDANCE OF GREEN CRABS

In 1953–67 green crab populations were sampled to detect major changes in abundance. Because the month of maximum catch varied from year to year and place to place, I have used only the maximum monthly mean catch per trap per day for each year when comparing years and areas (fig. 4). Individual trap catches at any location during one monthly trapping period (3 traps for 2 days, or 6 catches) showed an average variation of ±15 percent around the mean, with an extreme of ±40 percent. This degree of variability in catch limits the quantitative value of the trapping surveys, but the trends were consistent with general observations and the results of the shore surveys.

The possibility of reducing crab populations by trapping was tested by fishing 18 traps daily for 36 consecutive days in a 5.7-hectare (14-acre) cove. A total of 33,760 crabs was removed at an average catch rate of 52 crabs per trap per day, but there was no significant reduction in numbers by the

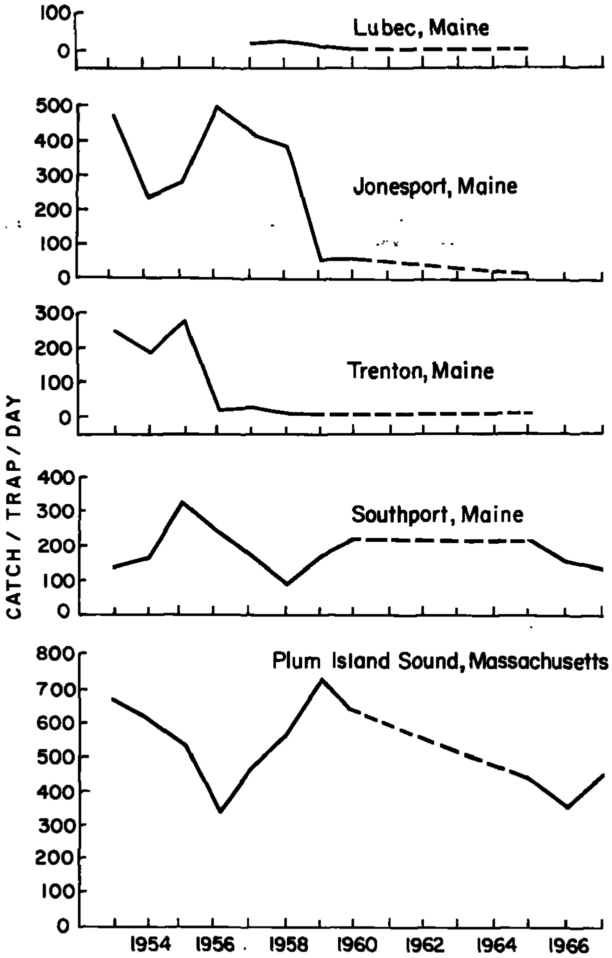

FIGURE 4.—Greatest monthly mean catch of green crabs per trap per day in each year, 1953–67. Locations are arranged from northeast (top) to southwest (bottom). Broken lines indicate periods when no trapping was done.

end of the period. In Canada, MacPhail et al. (1955) fished two traps daily for 24 days and removed 14,915 crabs without a drop in catch. It appears that, in areas where crabs are generally abundant, they move about sufficiently to fill any gap temporarily caused by trapping.

The most radical changes in abundance have been in Canada and northeastern Maine. During the summer of 1954, MacPhail et al. (1955) trapped an average of 343 crabs per trap per day for 24 days in a rocky area of the Bocabec River in New Brunswick, Canada. Soon after 1954 the green crab population started a continuous decline; the catch per trap dropped to 53 in 1958, 41 in 1959, and 7½ in 1960 (Fisheries Research Board of Canada, 1961).

In Perry, Maine, on Passamaquoddy Bay, shore surveys yielded 552 crabs per man-hour in August 1956 but only 7 per man-hour in September 1965. At nearby Lubec, where trapping was not started until 1957, maximum monthly catches were 13 and 16 crabs per trap per day in 1957 and 1958, but dropped to zero by 1960 and were still zero in 1965.

Trap catches at Cummins Beach, Jonesport, Maine, ranged between 235 and 500 crabs per trap per day in 1953–58, dropped to 50 in both 1959 and 1960, and to 6 in 1965. Shore surveys made in September 1965 at two locations near Jonesport yielded 3 and 11 crabs per man-hour.

In Trenton, Maine, at the Mount Desert Island bridge, where trapping began in 1953, catches dropped abruptly from a maximum of 271 crabs per trap per day in 1955 to 5 and 8 in 1956 and 1957. Catches then dropped to zero in 1958 and were still zero in 1965. A shore survey in nearby Sorrento yielded 14 crabs per man-hour in September 1965.

Trap catches have fluctuated in 1953–67 at Southport in central Maine and Plum Island Sound in northern Massachusetts; and over shorter periods in Boothbay Harbor and Kennebunkport, Maine, and in Scituate and Eastham, Mass. None of these fluctuations have reached points as low as those given above for northeastern Maine and Canada.

Two locations in Rhode Island showed a more gradual but consistent decline of crabs over several years. At Narrow River in Narragansett Pier maximum monthly means dropped steadily from 127 crabs per trap per day in 1956 to 51 in 1959. At Potter Pond Outlet in Jerusalem the means dropped from 334 in 1955 to 88 in 1959. The abundance in later years was not determined.

CHANGES IN WATER TEMPERATURE

The trend in coastal sea-water temperature has changed markedly since the early 1950's when the importance of the green crab was first being realized in northern New England. I have shown (Welch, 1967) that the peak of warming of surface sea water at Boothbay Harbor, Maine, since 1905 was in 1953 (annual mean, 11.1° C.); that the subsequent trend has been toward lower temperature (1967 annual mean, 7.3° C.); and that, although both summer and winter temperatures have followed the same downward trend as the annual means, the decreases have been greater during the winters. Lauzier (1965) has shown that air and sea temperature trends similar to those recorded at Boothbay Harbor have occurred at various points along the western north Atlantic Coast from Atlantic City, N.J., to Halifax, Nova Scotia, and stations over the Scotian Shelf. The sea temperature trend at St. Andrews, New Brunswick, is of particular interest because the station is on Passamaquoddy Bay, a part of the Bay of Fundy where observations were made on crab abundance, and because the general trend is similar to that at Boothbay Harbor. The peak of the warming period at St. Andrews was in 1951, and the temperature declined rapidly after 1954.

RELATION OF CRAB ABUNDANCE TO TEMPERATURE CHANGE

Past records in different areas have indicated that the green crab suffers from extreme or sudden decreases in temperature and apparently prospers in periods of increasing temperature. Broekhuysen (1936), working near Den Helder, Netherlands, found that the development of the eggs of this species was most successful within an optimum range of water temperature and salinity and that a combination of low temperature and low salinity adversely affected egg development and probably the development of adults as well.

Glude (1955) associated increases in green crab abundance with the increase in sea-water temperature—especially winter temperature—and speculated on ways in which temperature could affect the crabs. He also pointed out that Goucher (see footnote 1) had recorded an increase in green crabs at Essex, Mass., between 1926 and 1933 (a period of warming); an abrupt decrease of crabs after the very severe winter of 1933–34; and an increase in abundance again from 1944 to 1951, coincident with the most recent warming period.

Taylor, Bigelow, and Graham (1957) discussed the changes in distribution and abundance of numerous marine animals during the period when information on abundance and temperature has been available. They mentioned that too little was known about the life history of the green crab to say what environmental factors affected it so favorably, but that the winter temperatures of the mid-1950's seemed sufficiently high to account for the northward extension of its range.

Waugh (1964) and Crisp (1964), investigating the effects of the severe winter of 1962–63 on marine life in southern England and North Wales, respectively, found heavy mortality among adult green crabs, but smaller individuals seemed less affected. During most of January and February 1963 the water temperature was about 5° C. below normal, often reaching well below 0° C.

Along the Maine Coast, the most drastic and noticeable decreases in crab abundance were during the winter of 1955–56. Mean monthly water temperatures at Boothbay Harbor for December 1955 (4.9° C.) and January 1956 (3.4° C.) were the coldest in 8 years. These conditions occurred at a time when crab abundance was near an alltime high and when fishermen and others had been alerted to the threat of the green crab. Throughout 1956, I received numerous reports attesting to a decrease in the numbers of crabs seen along the shore or taken in lobster traps during the summer. Of greatest interest were the reports of dead crabs during the winter.

On the Skillings River, in Hancock, Maine, clam diggers observed that green crabs became very active during a thaw in January and were out in the open on the clam flats. The temperature dropped suddenly, and shortly thereafter many dead crabs were found along the shores. This area is near the trapping location at Trenton, where catches dropped sharply from 1955 to 1956.

A lobsterman reported that when the ice broke up in Blue Hill Bay in 1956 he saw large numbers of green crabs washed up along the South Blue Hill shore.

Another lobsterman reported many dead green crabs during the winter of 1955–56 at Herrick Bay in Brooklin, Maine. During the following summer, he found the crabs far less numerous in his lobster traps there.

At Sams Cove, Bremen, Maine, in January 1956, BCF biologists saw hundreds of dead and dying green crabs on muddy bottom at 0.3 to 1.2 m. below mean low water. Heavy ice cover prevented us from examining much of the bottom, but we found crabs lying on the bottom at a time when they would normally be buried. We do not know when the conditions occurred that killed the crabs nor do we know what those conditions were. A few days after the crabs were found, temperature, salinity, and dissolved oxygen in the water between the ice cover and bottom were within the normal range for green crabs. Winter mortality was sufficiently heavy to reduce trapping and shore collections during the following summer to about one-tenth the catches of the previous year.

During the winter of 1958–59 BCF biologists observed another winter kill in southwestern Maine. Monthly mean water temperatures from January through March 1959 were the lowest for all 3 months since 1948. Monthly mean air temperatures for December and February were the lowest for those months since 1917 and 1934, respectively (U.S. Environmental Science Services Administration, 1967). In the tidal marshes in Wells, where many crabs overwinter intertidally in burrows in banks of *Spartina* sod, we found hundreds of dead crabs of both sexes and all sizes. Trap catches in the marshes during the 1959 season were much smaller than in previous years, and the proportion of small crabs in the catch was much higher. This last observation seems to confirm Waugh's (1964) and Crisp's (1964) observations that the smaller individuals of the species suffer less from the effects of low temperature than do the larger ones.

CONCURRENT CHANGES IN CLAM ABUNDANCE

Although the primary purpose of this paper is to report on changes in green crab abundance, the importance of the species as a clam predator justifies mention of changes that have taken place in Maine soft-shell clam stocks as a result of decreased predation. Glude (1955) demonstrated correlations among the increase of green crabs, the decrease of soft-shell clams, and the increase in water and air temperatures. Because of the overwhelming abundance of crabs, he predicted a bleak future for the clam industry if the weather continued mild.

During clam population surveys in the period of heavy predation, BCF biologists consistently found evidence of adequate annual sets of clams; however, each year class was regularly destroyed as the individual clams became large enough for the crabs to find. Nevertheless, the reproductive potential existed for the recovery of clam stocks at any time when predation either decreased naturally or was controlled by man.

The decreasing abundance of crabs during the late 1950's caused a lessening in the effects of predation on the clams and resulted in an increasing supply of clams. Catches of clams have improved markedly in recent years in the two southwestern counties of Maine and to a lesser extent in the rest of the State (fig. 5). In the northeastern counties, where the decrease in crabs has been most pronounced, catches have also increased, but to a far less extent because of an unfavorable market. Reports from clam diggers, coastal wardens, and the resident State biologist, have indicated that clam flats in the northeastern area are well populated with market-size clams (fig. 2). During the course of the crab surveys, I have confirmed these reports by sampling a number of clam flats. Year classes of the past 3 to 5 years were represented consistently in the samples, and usually sufficient market-size clams were present to make clam digging worthwhile.

SUMMARY OF EFFECTS OF TEMPERATURE ON ABUNDANCE OF GREEN CRABS

Carcinus maenas is markedly affected by temperature changes. Documentation is sufficient to show that mass mortalities are often associated with unusually cold winters and that widespread increases and decreases in abundance are associated with long-term warming and cooling trends.

The direct correlation of abundance of green crabs with water temperature and the inverse correlation of abundance of clams with abundance of crabs is compared in figure 2. The close relation of the very low February temperatures of 1934 to the scarcity of crabs later in the same year as observed by Goucher (see footnote 1), and the ensuing increase in the number of clams is especially notable.

There are many ways in which this crab may be favorably affected by higher temperature, either directly or indirectly. Scattergood (1952) pointed out that numerous means have long been available to aid in the spread of the green crab northward—for example, the transportation of larvae by ocean currents, or of adults in fish and lobster shipments. Survival and successful reproduction did not

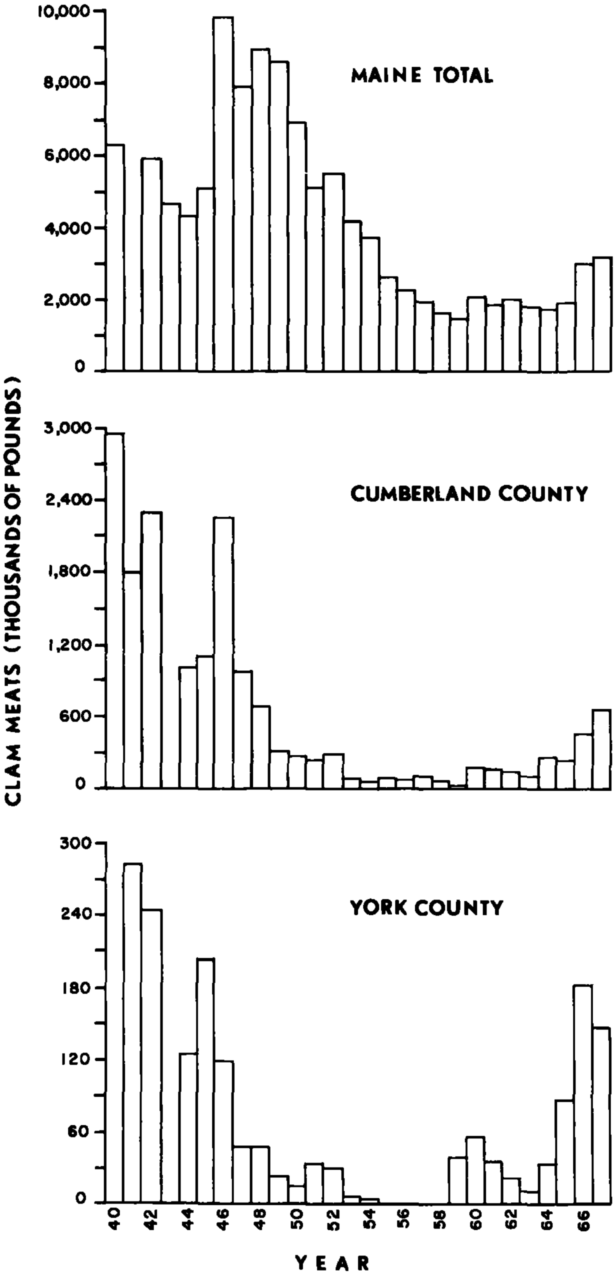

FIGURE 5.—Landings of soft-shell clams in Maine and Maine's southwestern counties, 1940–67. County totals for 1940–46 from Dow and Wallace (1961); Maine totals for 1940–56 from Power (1958); and county totals for 1947–67 and Maine totals for 1957–67 from Fish and Wildlife Service (1948–68). No totals were available for York County, 1940 and 1943; Cumberland County, 1943; and Maine, 1941. Landings in York County in 1955–58 were less than 300 lbs.

occur, however, until a certain stage of the warming trend had been reached.

Similarly, the effects of low temperature may be direct or indirect, short- or long-term. Broekhuysen's (1936) evidence and ideas on the deleterious effects of combined low temperature and low salinity may apply to upper estuaries and semienclosed bays. Since *Carcinus* consumes considerably more oxygen in dilute sea water than in water of normal salinity (Waterman, 1960), unfavorable temperature, salinity, and dissolved oxygen may combine to provide an environment lethal to *Carcinus*.

As the species ordinarily seems tolerant of low temperature, lowered salinity, or low dissolved oxygen when the conditions are met singly, it is more likely that widespread reduction in numbers results from more complex causes or chronic conditions. Examples might be the ones described in the foregoing section, "Relation of Crab Abundance to Temperature Change," in which unseasonable warming brought the normally dormant crabs out into the open where they were later killed by falling temperature, or where an excessively long dormant period, caused by a long, cold winter with heavy icing of the shore, may have been fatal.

In the northern part of its range, *Carcinus maenas* is apparently among the most responsive of common marine animals to temperature change; consequently, the species may be a useful indicator of changes in the environment that affect associated animals to a less obvious but perhaps no less serious extent.

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