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# Lobster (*Homarus americanus*) Abundance in the Canadian Maritimes Over the Last 30 Years, an Example of Extremes

by

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**Abstract**

Lobster is one of the most important fisheries in inshore fishing communities of eastern Canada. During the last 30 years the fishery has experienced its lowest and highest landings in the 100 years of recorded landings. Landings in many parts of the coast reached record or near record lows in the late 1960's and early 1970's, then rose to high levels not experienced since 1900. Total Canadian lobster landings doubled between 1977 and 1986 and in some areas landings increased tenfold. The increase in landings during the last 10 years appears to be the result of increased recruitment. The recent increase in lobster landings have occurred in different stocks and management regimes, suggesting a wide spread environmental factor(s) as the primary cause.

SPECIAL SESSION ON CHANGES IN FISH POPULATIONS

## Introduction

Lobster is one of the most important fisheries in inshore fishing communities of eastern Canada (Fig.1), representing 28% of the total landed value of Atlantic Canada fish in 1985. Lobsters are a long-lived species not usually subject to large fluctuations in abundance but during the last 30 years the fishery has experienced the lowest and highest landings in the 100 years of recorded landings (Fig. 2). Landings in many parts of the coast reached record or near record lows in the late 1960's and early 1970's, then rose to high levels not experienced since 1900. Total Canadian lobster landings doubled between 1977 and 1986 and in some areas landings increased tenfold.

During the period of low landings in the early 1970's (Fig 2) there was concern over declining catches and predictions of recruitment overfishing leading to further declines (Robinson 1979 , Campbell and Robinson 1983). A recent increase in landings has alleviated concern for the stocks in most areas, and biologists are now being asked how long will the higher landings last? The increases observed are unprecedented in the lobster fishery and raise interesting questions as to what controls recruitment and stock size.

## Methods

The Canadian lobster fishery is a trap fishery conducted by inshore fishermen (only 8 offshore licences). The fishery is managed by Lobster Fishing Areas (LFA) (Fig. 3) which have trap limits, fishing seasons, and a minimum legal size set to fit regional biological and climatic conditions.

This paper examines trends in landings for the following Lobster Fishing Areas (LFA), regions and American states which account for over 95% of the western Atlantic lobster landings (Fig 3): Grand Manan

(LFA 38), Bay of Fundy (LFA 35-36), southwestern Nova Scotia (LFA 34), southeastern Nova Scotia (LFA 33), eastern shore of Nova Scotia (LFA 31-32), southeastern Cape Breton (LFA 28-30), northeastern Cape Breton (LFA 27), southern Gulf of St Lawrence (LFA 24-26), Quebec, Newfoundland, Massachusetts.(data courtesy of B. Estrella) and Maine (courtesy of J. Krouse) .

Landings are believed to be a good indication of recruitment to the standing stock of that year (Ennis 1986). Annual exploitation rates are generally high and it is believed that they have been so for many years. Present estimates show that they range from 60 to 90% (F= 0.9-2.0) (Anthony 1980; Campbell 1980; Miller *et al.* 1987). Most of the inshore fisheries are dependent on the sizes just above the minimum legal size. These lobsters are recruited into the fishery following the summer molting season.

Lobsters, unlike fish, have discreet grow increments and periods, referred to as the molt. Lobsters close to the legal size increase in carapace length (CL) by 15% and weight by 50% during the molt (Aiken 1980). Over most of the western Atlantic legal-sized lobsters molt once during the summer or early fall, though two molts do occur in some warmer areas within the southern Gulf of St. Lawrence (Aiken 1980).

Historical landings data (1892-1986) have been smoothed using a three year moving average to facilitate comparison of long-term trends Year to year variations are caused in part by weather and ice conditions, short term shifts in effort, and the use of annual data in fisheries which have a season partly in two calender years. Data reported by fishing season are more representative and less variable because it reflects the landings from a single recruitment pulse, but seasonal data is not available for the historical time period.

Landings data was normalized with respect to the mean landings of 1947-1986 to allow easier comparison of trends between LFA with landings that can differ by a factor of 100. A normalized catch value of 0.9 represents a catch that was 90% of the mean and a value of 3.0 represent a catch of 300% or 3 times the mean.

### History of Fishery

Commercial lobster fishing began in the mid 1800's (Dow 1980) and data on landings have been recorded in Canada since the 1880's. The fishery initially exploited a virgin population and Canadian landings exceeded 40,000 t annually in the 1880's (total North American landings over 60,000 t) (Ennis 1986). But even as landings continued to increase concern was expressed because the mean size of the lobsters was decreasing (DeWolf 1974). Size limits, seasons and a prohibition on landing egg-bearing females were introduced, but these regulations were not widely adhered to. By the 1890's concern had grown and between 1887 and 1913 numerous government enquiries and studies were commissioned to determine the cause of declining catches. Hatcheries were established but later abandoned (DeWolf 1979).

Declining catches led fishermen to adopt the more efficient parlour trap (DeWolf 1979), and the introduction of gasoline motors in the early 1900's allowed fishermen to fish more traps, up to 3 times as many according to DeWolf (1979). Landings continued to fall reaching 20,000 t in 1915 (Fig. 2) and fluctuated around 16,000 t during 1920-30, with a small increase in the early 1930's to 22,000 t. DeWolf (1979) suggested this small rise was due in part to an increase in the number of fishermen caused by high unemployment during the early years of the Depression. A short lived recovery occurred in the southern Gulf region and along the eastern shore of Nova Scotia (LFA 31-32) and southern Cape Breton, while landings remained low in the Gulf of Maine area. Newfoundland closed the lobster fishery for 2 years (1925-7) in an attempt to reverse the severe decline. Landings rebounded to 1910 levels then remained relatively constant. (Fig. 4).

Canadian landings increased in the mid 1940's, and peaking in the mid 1950's at 23,000 t. Landings declined again in the 1960's and early 1970's reaching a low of 14,000 t in 1972. The decline was sharpest along the eastern coast of Nova Scotia and in the southern Gulf of St Lawrence where landings reached record lows (Fig. 4). Maine landings increased in the 1940's and peaked in the mid 1950's. Though they declined in the 1960's and early 1970's they remained over twice as high as during the 1920's and 30's.

The southern Gulf and western Nova Scotia (LFA 33, 34 and the Bay of Fundy) landings rose sharply in the late 1970's and early 1980's respectively, reaching levels not seen since the early part of the century. Northeastern Cape Breton (LFA 27) landings are presently 2 times the previous high (Fig. 5). Not all areas have seen the dramatic increase, landings in Maine and Newfoundland began to rise in the early 1970's but remained within historical range in the 1980's.

**Trends 1947-86**

During the last 15 years landings have ranged between the lowest and highest levels this century, with the most recent rise in landings being the largest and most sustained increase ever observed in a lobster fishery. Effort has increased significantly during the increase, but so has the CPUE (kg/ trap haul) (Miller *et al.* 1987). The underlying cause of the increase in landings is increased recruitment due to a large and sustained recruitment pulse. Annual at-sea sampling of the commercial catch during the first two weeks of the fall season in LFA 34 indicate an increase in the proportion of the catch in Molt Group -1, those just below legal size (Fig 6). These lobsters will molt during the following summer into molt group 0. A comparison of 1981 and 1986 shows an increase in numbers as well as proportions of catch in prerecruit sizes.

Lobster data is collected by relatively small statistical units, and trends in these small units are highly variable and may differ from adjacent units and the larger LFA. These variations are of interest in studying local recruitment mechanisms, but can confuse the analysis of longer term trends observed over larger areas. Campbell and Mohn (1983) used cluster analysis to define stock areas by grouping areas with similar landings trends (1892-1982). They recognized three major groups: 1) the Gulf of St Lawrence, 2) the eastern shore of Nova Scotia/Cape Breton, and 3) southwestern Nova Scotia/Bay of Fundy/Maine and possibly the offshore. The present paper used cluster analysis on LFA landings data for the most recent 40 years (1947-86) (Fig 7 and 8) and found 2 major groups: 1) southwestern Nova Scotia/ Grand Manan/ Maine coast/ the Gulf of St Lawrence, northeastern Cape Breton (LFA 27) and Massachusetts and 2) LFA 33/ Bay of Fundy/ LFA 31-32 and LFA 28-30.

Group 1 accounts for approximately 75% of North American lobster landings and contains those areas which have shown greater stability over the last 40 years.The ratio of the minimum and maximum landings (recruitment) estimates the magnitude of recruitment variability which can be expected within a stock (Rothschild 1986). The Max/Min ratio during the 40 year period were low, ranging from 1.7 in Maine to 4.3 in LFA 27.

Grand Manan and LFA 34 (Fig. 3) were characterized by relatively stable landings between 1947 and 1980. LFA 34 landings rose from 3000 t to 7500 t between 1980 and 1986 while the much smaller Grand Manan fishery, remained near historical means. Landings in the Gulf of St. Lawrence and along the coast of Maine fluctuated around the mean during the late 1940's to 1950's then declined in the late 1960's and early 1970's. Though local areas experienced some severe decreases in landings overall relative decreases were less then the areas along the eastern coast of Nova Scotia. Beginning in 1975 landings increased, and LFA 27 reached an all time high and the southern Gulf had the highest landings since the 1890's. Landings in Maine and Newfoundland leveled off in the early 1980's and remained close to the historical mean.

Massachusetts' landings were stable over the 1947-75 period then rose to all time highs in the 1980's. A portion of this increase is the result of increased effort and expansion of grounds to more offshore waters, but as in Canada CPUE has increased indicating a real increase in numbers has occurred (Estrella, pers. comm.).

Group 2 includes areas along the east coast of Nova Scotia and the Bay of Fundy (minus Grand Manan), areas which have shown the widest variation of landings over the last 40 years. The Max/Min ratio range from 3.4 for the Bay of Fundy and 23.0 for LFA 30. The recent peak in landings in the mid 1950's was followed by a sharp decline to record low landings in the 1970's. Landings leveled off at very low levels from 1976-80 then increased during the early 1980's. Landings in LFA 33 had fallen to all time record low levels in the late 1970's but increased tenfold between 1981 and 1986 and reached levels equal to those prior to the major down turn in the early 1900's. Landings in LFA 28-32 have increased since 1980, but landings are still well below those of the 1950's.

All areas showed increased landings during the warming period of the 1940's and 50's followed by some decline during the 1960's. Areas outside the major concentrations experienced the largest increases as well as the largest declines. One of the severely depressed areas, LFA 33 has recovered to near record high levels in the 1980's, while the eastern shore, though showing a major increase, is still below historical levels. The historical data shows that these fringe areas are more prone to cyclical increases and decreases in landings then the major grounds of the Gulf of Maine and St. Lawrence.

The greater variability along the eastern shore of Nova Scotia, may be related to two factors, 1) the narrowness of available lobster habit of the eastern shore which makes the population more susceptible to environmental variability, and 2) the lack of warm water in the winter or high summer temperatures may make the region a marginal habit in some years. In contrast southwestern Nova Scotia and Maine have a wide shelf and direct access to deep-water areas which remain warm in the winter. Mature lobsters migrate to these deeper areas during the winter, and it is believed they are able to maximize the temperature available to assure egg development (Campbell 1986; Pezzack and Duggan 1986). Inshore fishing grounds in these areas extends to 90km with an offshore fishery in the basins and on the banks in the Gulf of Maine. The southern Gulf of St. Lawrence also has a wide expanse of shallow water which although freezing over in the winter, warms quickly and has the warmest temperatures on the Canadian east coast in summer.

The narrowness of lobster habitat and the openness of the eastern Nova Scotia coast may also play a role in reducing larval retention. Harding *et al.* (1983) suggested that small bays and inlets may be important to the recruitment of lobsters on this coast. Because of the limited habitat, shifts in wind direction could affect recruitment. Dadswell (1979) suggested that the Gulf and southwestern Nova Scotia represented closed recruitment cells in which larval retention is maximized while the eastern shores of Nova Scotia were open cells where larval retention was lower and more variable.

The data shows that landings trends apply over large areas with the major increases in the 1940-50's and 1970-80's and the decreases of the 1960-70's occurring in all areas. The data also shows that the timing and magnitude of the changes are not the same in all areas. The faster growth rate and smaller minimum legal size in the Gulf of St. Lawrence means the recruitment pulse is detected earlier than in colder water areas. The age at recruitment is believed to be 5-6 years in the southern Gulf, 6-8 years on the Atlantic coast of Nova Scotia (Wilder 1953, Aiken 1980).

Variations in the timing and magnitude of increases and decreases in landings are also a function of the initial stock biomass and population size structure, local exploitation rates, potential fishing effort and the lag periods for changes in these, local environmental differences and the initial state of the variable(s) which triggers the change in recruitment levels. These variables make it difficult to relate the recruitment pulse to a controlling or triggering factor. Detailed knowledge of the local biology and fishery are required to study the causes of the changes in recruitment, since the same environmental or man made input will result in different responses in different areas.

### Factors controlling recruitment

Lobster management is based on the belief that a stock recruitment relationship exists. The decline in landings during the 1960's was blamed in part on overfishing and some biologists warned of the potential of recruitment overfishing (Robinson 1979). The solution suggested was to increase egg production by raising the minimum size closer to the size of maturity. This recommendation was not acted upon, but the fishery has recovered without it.

The present landings are based on newly recruited lobsters which hatched and settled to the bottom 6-8 years previously, when the stocks were at their lowest biomass in the history. Similarly the low catches of the 1970's resulted from animals spawned during a period of above average biomass in the 1950 and 1960's.

What factors contributed to low landings of the 1970's and the high landings of the 1980's? Numerous hypotheses were developed by biologists during the 1970's to explain the decline, including the direct effects of fishing leading to recruitment overfishing (Robinson, 1979), indirect effects of fishing leading to ecological changes (Breen and Mann 1976), the construction of the causeway between Nova Scotia and Cape Breton Island which disrupted recruitment systems (Dadswell 1979), a combination of the latter two (Harding *et al.* 1983), variation in river outflows (Sutcliff 1973) and changing temperature conditions (Dow 1977).

The Canso Causeway (Fig. 1) constructed in 1955, had according to one hypothesis (Dadswell 1979, Harding *et al.* 1983) cut off the supply of larvae from the southern Gulf of St. Lawrence needed to support the fishery of the eastern coast of Nova Scotia. The hypothesis suggest that there would be a cascading affect down the coast with each area dependent on the upstream population to supply larvae.

Evidence suggests that the causeway was not the cause of the down turn in landings along the coast, though it may have had some local effect. Landings declined on the Atlantic coast (LFA 28-32) immediately after the causeway was built. If the causeway was the cause, landings should not have declined for 6 to 8 yrs, the time for the larval recruits to attain legal size. The peak in landings during the 1950's and the downturn in the 1960's were part of a wider scale change. Landings reached record lows in the late 1970's, but like all other lobster areas landings increased in the early 1980's and though still well below historical means, they increased 5 fold over 5 years.

Changes in the species composition or productivity of the ecosystem can result in changes in abundance of species within it. The destruction of kelp beds by the sea urchin grazing in the late 1970's has been cited as a cause of the lobster decline (Breen and Mann 1976), though there is evidence against such a relationship (Miller 1985). Harding *et al.* (1983) links the destruction of kelp to the closing of the Canso Causeway suggesting that a combination of cooling trends and the causeway closing reduced lobster recruitment initiating an imbalance in the ecosystem. The resulting declining lobster stocks allowed sea urchins to increase unchecked, destroying the kelp beds which decreased the carrying capacity of the environment for lobster.

Kelp beds reappeared in the early to mid 1980's, but lobster landings in St. Margarets Bay doubled in 1980-1981, prior to kelp recovery (Miller 1985) (Fig.10). The lobsters recruited into the fishery in 1981-1984 were spawned in the mid 1970's, during the peak of the urchin outbreak. Similarly, declines and increases in landings had occurred in areas where no kelp was destroyed and where kelp has not recovered (LFA 30).

A potentially important factor in increased recruitment may be the reduction in predators caused by heavy exploitation of groundfish. Little is known about lobster predators or mortality during the time between larval settlement and recruitment to the fishery. Fogarty and Idoine (1986) suggest this period may be important in determining recruitment levels and Brander (1986) has shown a relationship between cod abundance and *Nephrops norvegicus* in the Irish Sea, but the majority of Canadian fish feeding studies have been offshore and do not represent the inshore habitat where juvenile lobsters are concentrated. Further studies are required to determine the role of groundfish in lobster natural morality.

Management measures, including limited entry licences (1968), trap limits (1979), licence buy-back to reduce number of fishermen (1978-1980), and increased enforcement of seasons and size limits, were introduced over the last 30 years to control or reduce fishing effort as a means of reducing the high exploitation rate. Increased landings in the 1980's cannot be attributable to management changes though they have reduced the potential effort which could be applied to the recovering stocks. The measures may be important in sustaining both the recovery and higher landings in the future, and improving the general economics of the remaining fishermen.

The recent increase in lobster landings has occurred in different stocks (Campbell and Mohn 1982, 1983) and management regimes, suggesting a wide spread environmental factor(s) as the primary cause. Shepherd *et al.* (1984) point out that while both environmental factors and interactions between different species are likely to produce similar effects on several stocks within a particular area where they live together, only large-scale environmental factors are likely to produce similar effects on stocks from different areas.

Temperature is the environmental parameter most often examined to relate recruitment to environment, but the relationship between temperature and the biology and physiology of the organism is far from simple. Temperature affects the lobsters at all life history stages (Aiken and Waddy 1986) controlling growth , size of maturity, timing of spawning and egg hatching, duration of egg development, condition of larvae at hatching (energy reserves), duration of larval stages, and adult migration patterns (Uzmann *et al.* 1977; Campbell 1986). Temperature can also affect lobster production indirectly, through changes in the general ocean production that change the food supply for both planktonic and bottom stages, and through changes in the numbers of predators or competing species. The measure of temperature used is also important, surface temperature affects larval stages while bottom temperature acts on the juvenile and adult stages. Temperature is often expressed as mean annual temperature (Dow 1977; 1978; Orach-Meza and Saila 1978), mean monthly temperature (Fogarty 1988), or mean temperature over a portion of the year (Flowers and Saila 1972), but other valid criteria are degree days, duration above a set temperature, or temperature during a critical period. Failure to find relationships between temperature and landings may be due in part to the use of inappropriate measures of temperature. For example using the readily available mean annual surface temperature data may produce no correlations when the important temperature is bottom temperature during the critical summer molting period. A working hypothesis of the recruitment mechanism being tested is essential to avoid correlations with no valid biological basis.

Numerous studies relating temperature to landings suggest the importance of water temperatures approximately 6 yrs earlier (Flowers and Saila 1972; Dow 1977, 1978; Orach-Meza and Saila 1978; Fogarty 1988). Since the time to grow to legal size, in the areas studied, is estimated at 5-7 yrs, it is believed that temperature acts on the larval or early juvenile period. Landings in the Gulf of Maine have shown significant correlation with surface temperatures (Dow 1977, 1978; Harding *et al.* 1983), but Harding *et al.* (1983) found no similar correlation along the eastern coast of Nova Scotia.

Lobster presently being landed were hatched during a period of warm coastal water temperatures (Fig. 9) that began in 1976 (Mountain 1982; Drinkwater and Trites 1987, 1988). Increase in abundance of offshore lobsters appears to be related to increases in bottom water temperatures on Georges Bank and in the basins of the Gulf of Maine during the 1970's (Fogarty and Idoine 1988).

Temperature affects on lobster landings are unlikely to be simple or linear. Dadswell (1979) dismissed temperature as a factor in the decline of lobster following the Canso Causeway in the 1960's and 1970's because the decline in temperature was small and could thus only explain 20% of the drop. Recent work with nonlinear and complex systems show that small changes can have large effects and that the effect can vary with the initial state of the system (Rothschild 1986). The coastal temperatures during the 1970's and 1980's were below those of the early 1950's, a period of lower abundance, which suggest that though temperature plays a roll in recruitment success, the relationship is neither simple, nor is it likely the sole factor.

Fresh water runoff has been correlated with Quebec lobster landings in the northern Gulf of St Lawrence (Sutcliff 1973). The paper reports a significant correlation between lobster landings and river runoff 9 years earlier and though the mechanism is not understood, the correlation appears to be holding up into the early 1980's (Drinkwater 1987). This is an example of a correlation that appears to work but the biological basis for it is unknown. The best estimate of lobster age at capture in the area concerned is 5-6 years, meaning that the effect of river runoff would have to be acting on the parent stock 2-3 years before the larvae are produced. Other studies have questioned the importance of river runoff and have suggested that climatic events in the ocean, forced by large scale atmospheric circulation may be the primary mechanism (Koslow 1984; Koslow *et al.* 1986; Sinclair *et al.* 1986).

### Stock-recruitment relationships

The stock-recruitment relationships for lobster populations are unknown. Lobsters have a complex life cycle with several life history stages having different ecological characteristics. Fogarty and Idoine (1986) presented evidence for density dependent relationships. Using a multi-stage model they describe an asymptotic relationship between the final larval stage and subsequent recruitment, which results in a stable population which is resilient to exploitation. The model explains the resilience and stability of lobster populations to high exploitation. Paulik (1973) illustrated the complexity of stock recruitment curves in animals with complex life histories and the paper illustrated the potential of multiple equilibriums and the importance of the initial starting conditions on the ultimate outcome.

The relationships between egg and larval stages vary with temperature, and changes in larval survival or a shift in the asymptotic relationship between the final planktonic stage and recruitment would result in a larger or smaller number of recruits and the resulting spawning stock. The relationship between recruitment and the resulting spawning stock may not be a simple linear function. A trap fishery can efficiently remove animals even at low densities subjecting the population to high exploitation rates. At higher densities, trap saturation can occur reducing the efficiency of each unit of effort. In addition the trap limits and limited seasons in Canada determine the maximum effort which can occur, thus at very high recruitment levels the proportion of lobsters removed by the fishery may be reduced. The relationship between stock and recruitment in lobster populations is likely complex and the potential of multiple equilibrium points exist.

### Conclusions

A recruitment pulse has resulted in the largest increase in landings in the 100 years of recorded landings. The increase in landings is evident in all lobster areas, though the greatest increases have been observed in LFA 27, 33 and 34, the southern Gulf of St. Lawrence and in Massachusetts. The smallest changes are in Maine and Newfoundland, which after an initial rise in landings during the late 1970's, have increased little and even shown a small decline.

The wide spread nature of the increases suggest it is related to environmental change. Variations in recruitment levels related to changes in water temperature are a possible mechanism, but in trying to understand the interaction of environment and population variability we are dealing with complex and potentially nonlinear systems which are extremely difficult to quantify. Small changes may have no effect, delayed effects or not always the same effect as other variables in the system will have changed (Rothschild 1986). Looking for a single mechanism or attempting to understand lobster recruitment cycles without knowledge of how environmental and biological variables interact could be misleading and unrewarding. Numerous authors have pointed out the pitfalls in attempting to find correlations between the environment and fish abundance without an underlying model or hypotheses to be tested (Shephard *et al.* 1984; Sissenwine 1984; Walters and Collie 1988).

Nova Scotia, Massachusetts and southern Gulf of St. Lawrence landings continued to rise during 1987. Massachusetts and the southern Gulf of St. Lawrence, have shown an upward trend since the mid 1970's with no indication of leveling off. The present increase in landings could simply be a short term explosion which will pass or a new equilibrium may be reached and landings sustained at a higher level. The unprecedented nature of the recent increases and our lack of knowledge on stock recruitment relationships makes it impossible to use the historical data set as a guide to future events.

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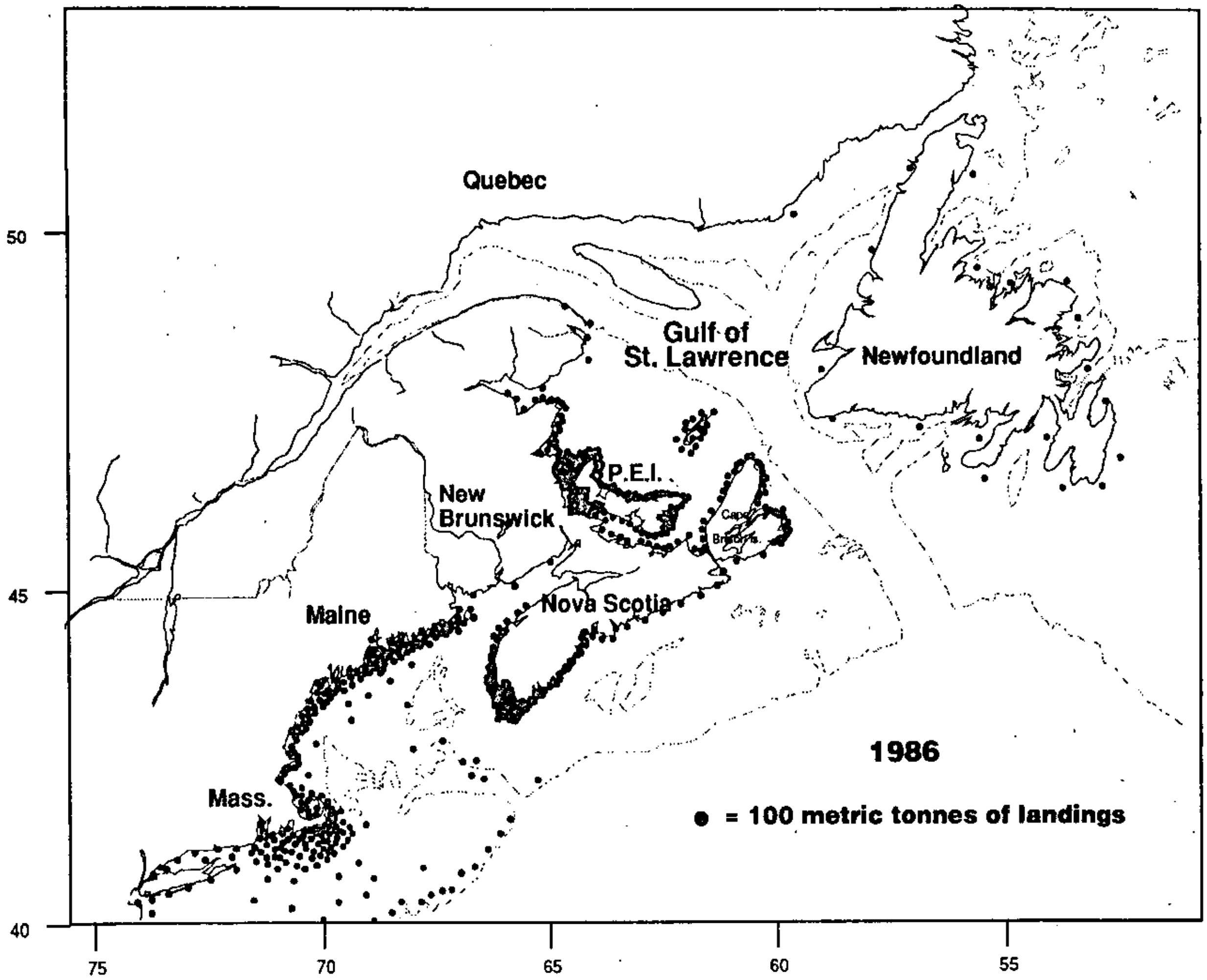


Figure 1: Distribution of lobster landings 1986 (each dot represents 100 t)

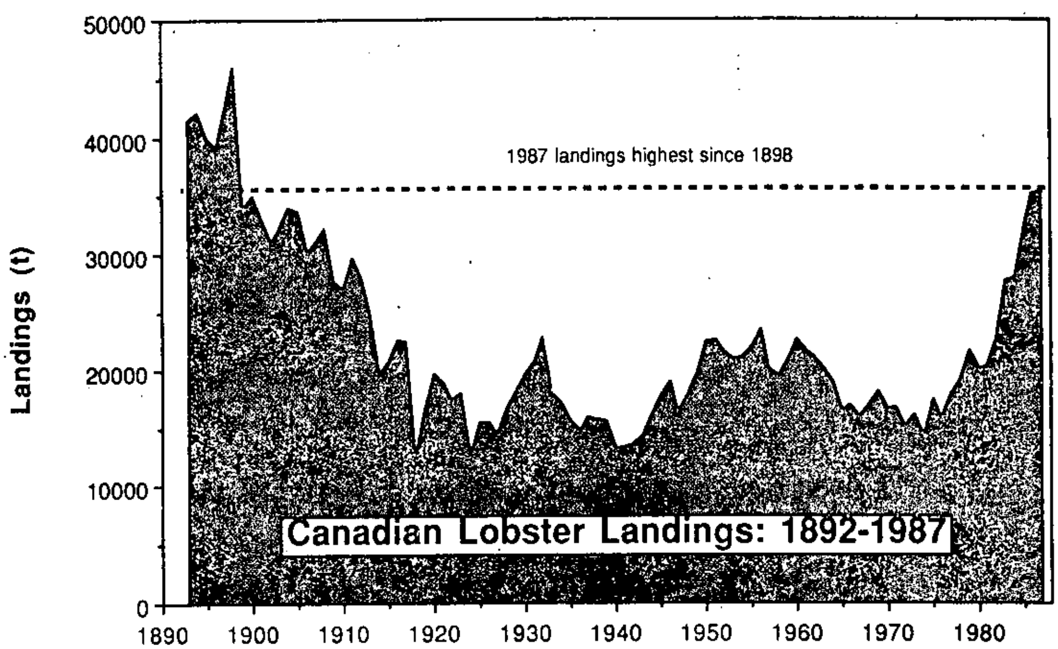


Figure 2: Canadian Lobster Landings 1892-1987

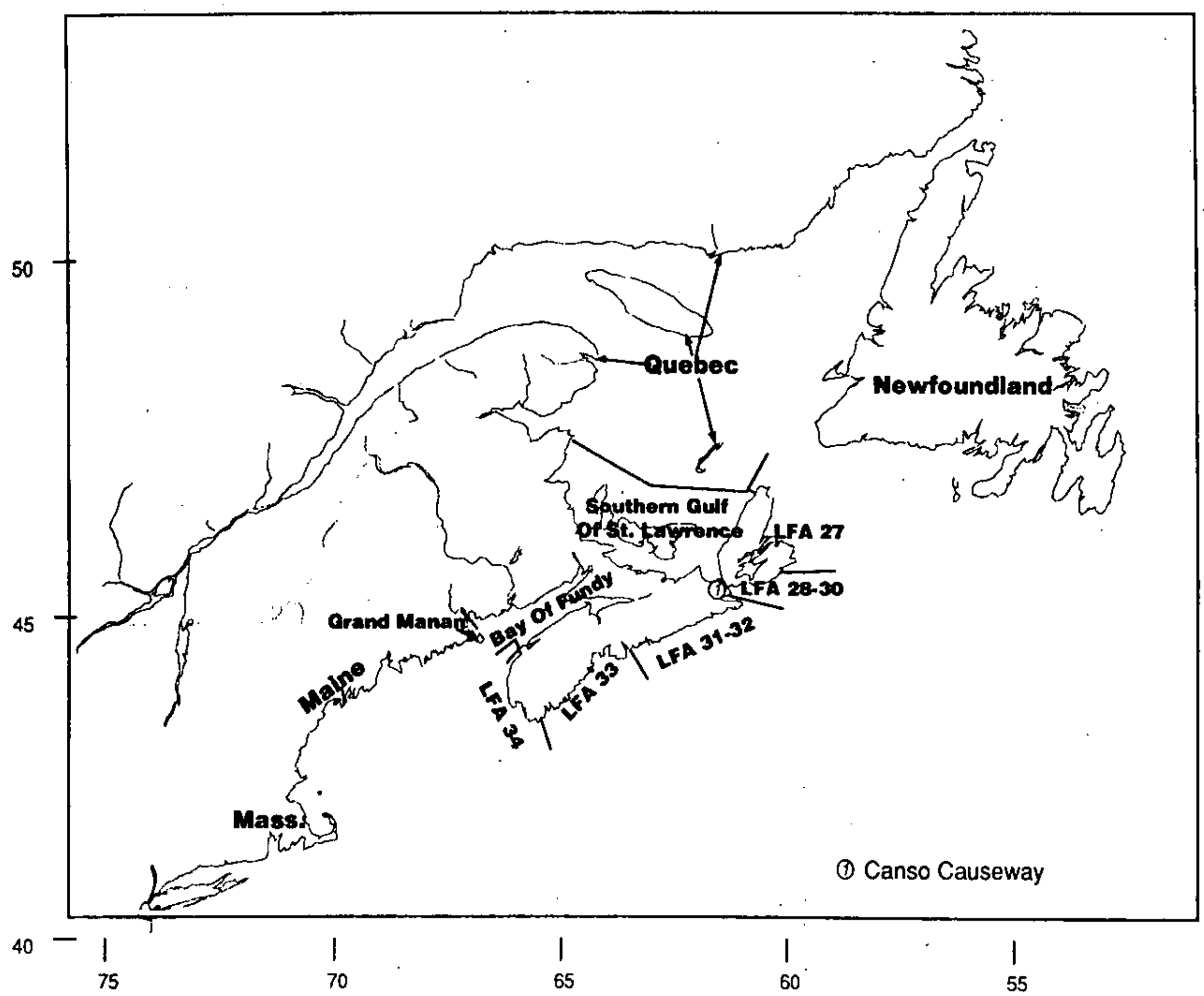


Figure 3: Canadian LFA's, Provinces, and American States for which landings data is discussed.

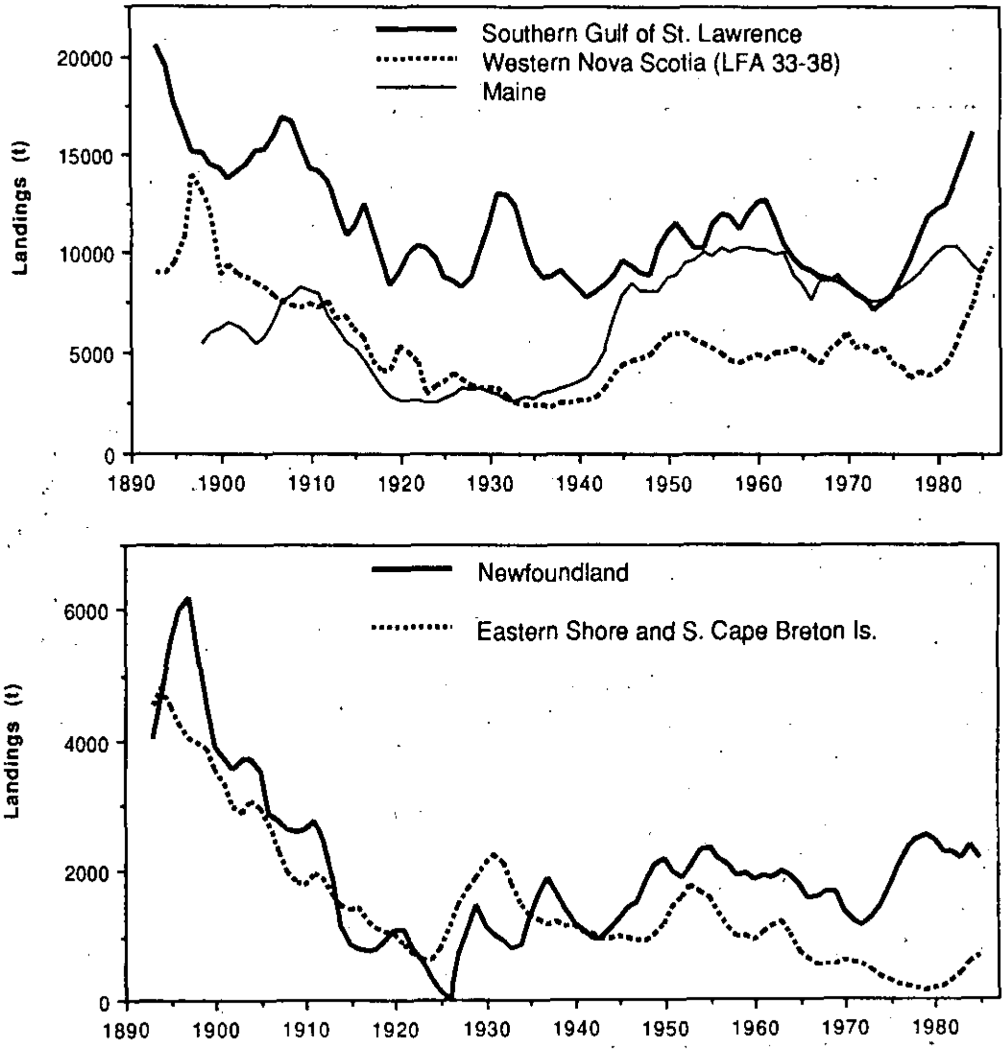


Figure 4: Lobster landings 1893-1986. Data smoothed using 3 year moving average.

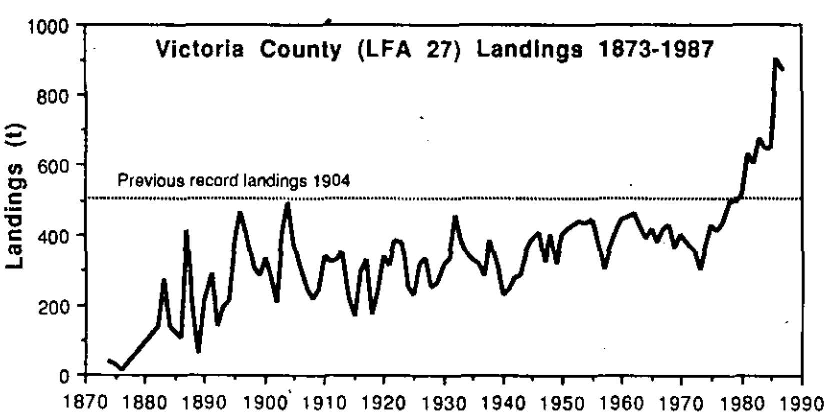


Figure 5: Historical lobster landings from LFA 27 (1873-1987)

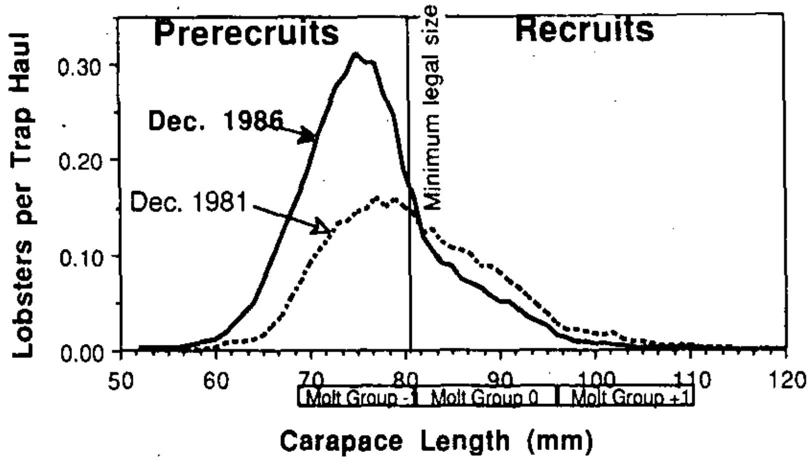


Figure 6: Comparison of lobster size frequency distribution of lobsters during December at-sea sampling 1981 and 1986

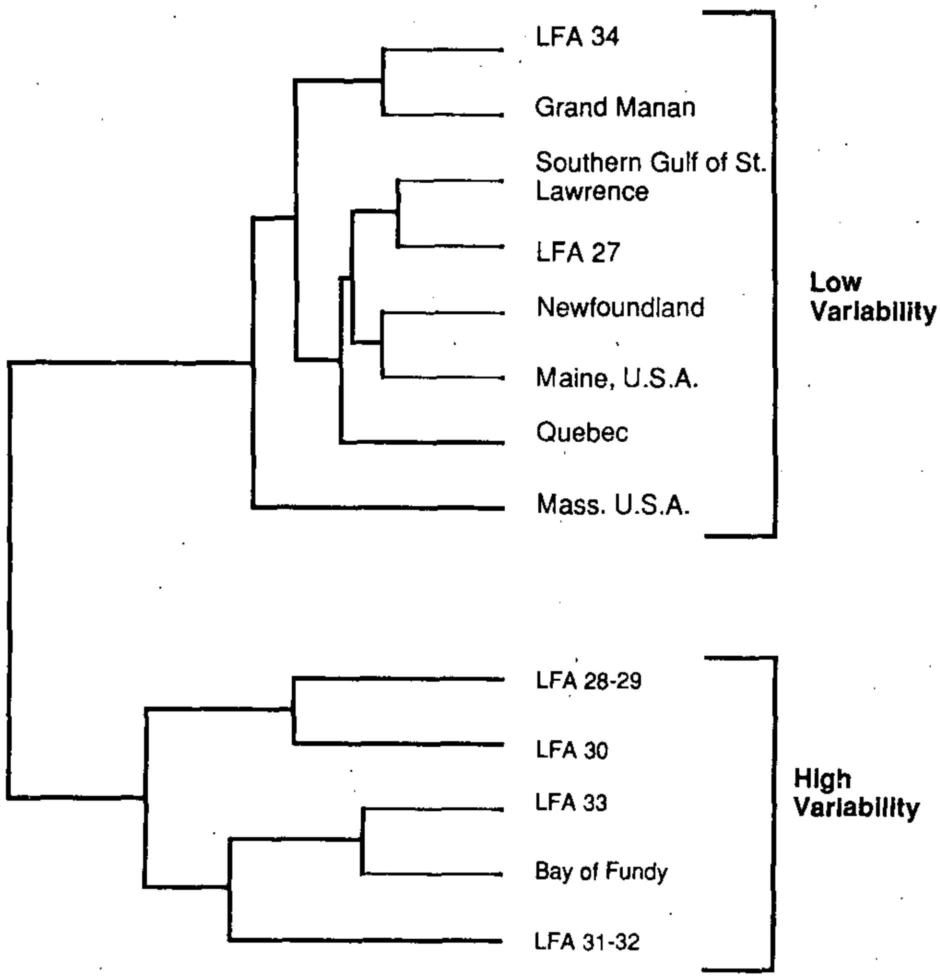


Figure 7: Cluster analysis of landings 1947-86 showing groupings of high and low variability

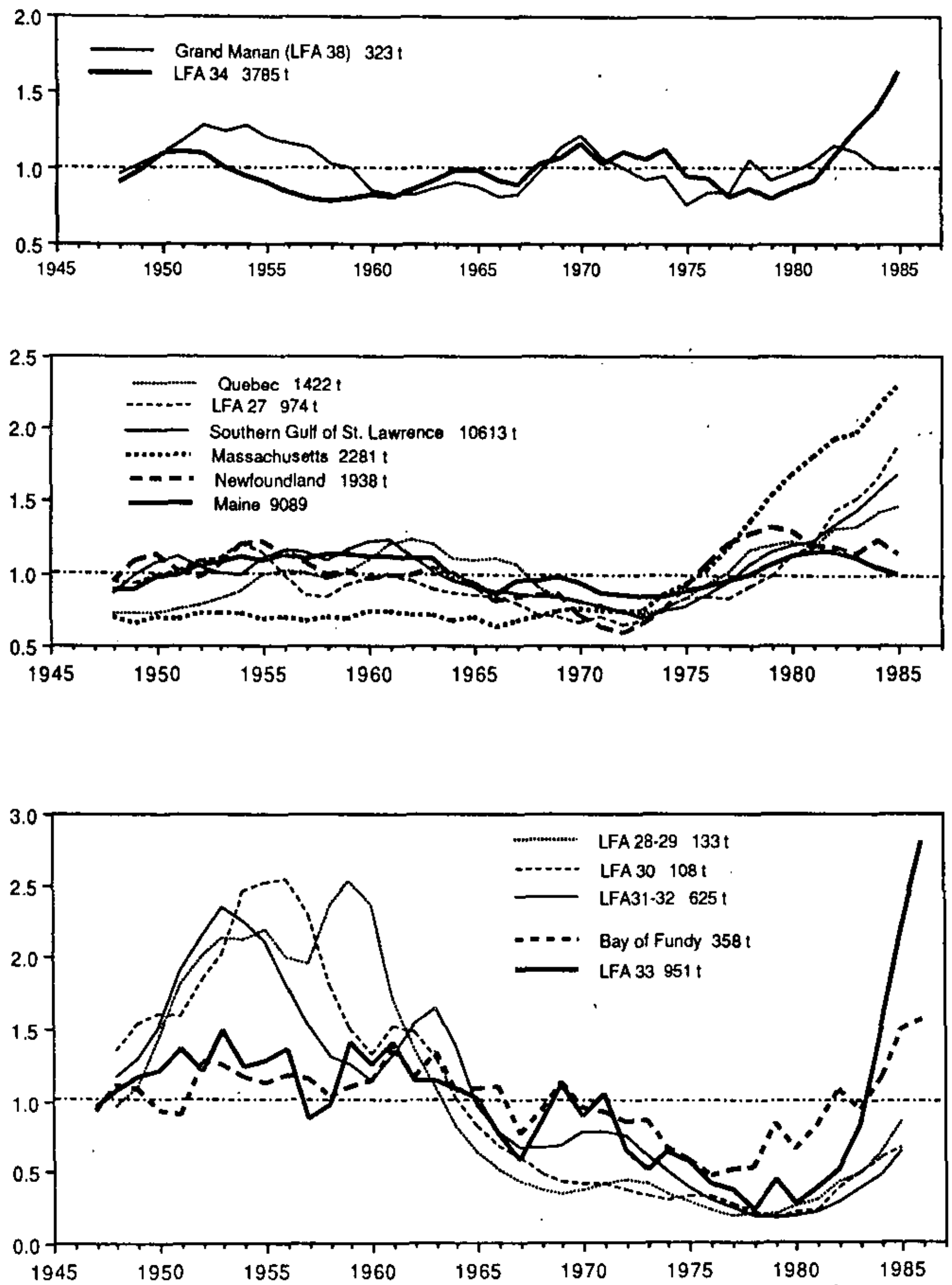


Figure 8: Normalized lobster landings 1947-86. Mean landings given in legend

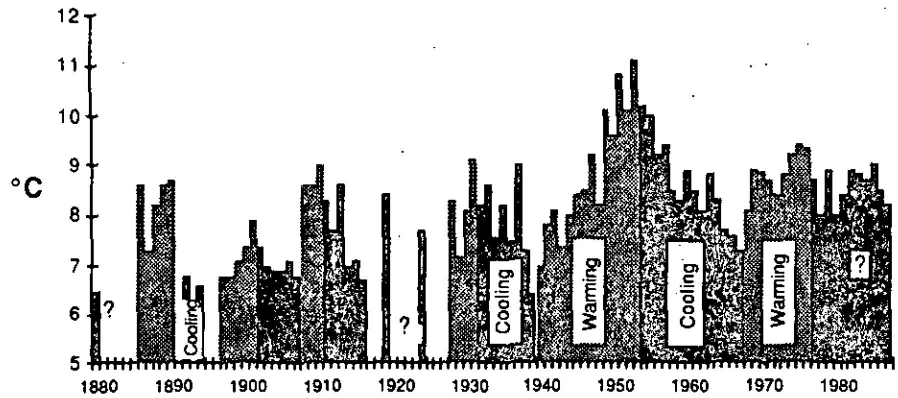


Figure 9: Mean annual sea temperature Boothbay Harbor, Maine

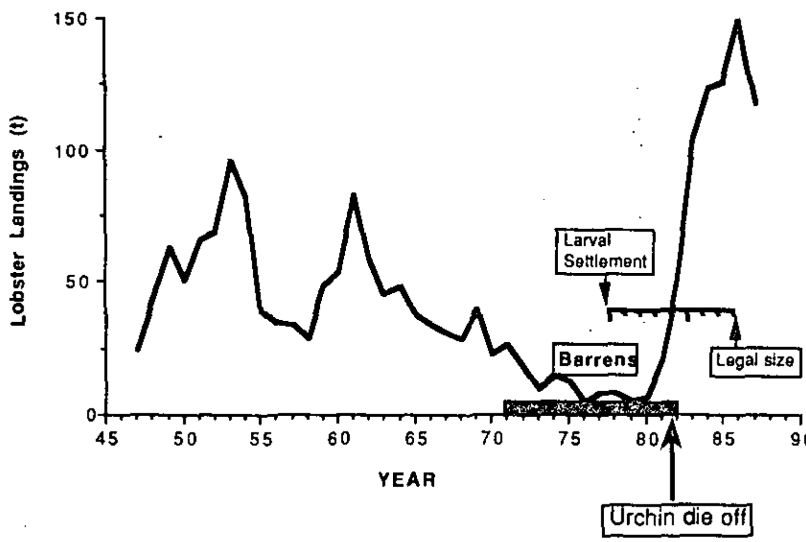


Figure 10: Lobster Landings in St. Margaret's Bay (Stat. Area 23), showing period of sea urchin barrens and year of larval settlement for peak landings in 1986