Influence of temperature and effort on lobster catches at different temporal and spatial scales and the implications for stock assessments

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Abstract.–Correlation analysis was used to investigate how effort and temperature changes influence lobster catches at different spatial and temporal scales and how they may affect the use of catch statistics in stock assessments. At the largest scales examined (Atlantic coast of Nova Scotia, 50 yr), a significant correlation between catches and temperatures at short lags (0–3 yr) prior to 1974 suggests that catches were driven by temperature-induced changes in growth or lobster activity. However, changes in effort could not be ruled out as a cause of the observed cycles because sea surface temperatures may reflect weather conditions and the "fishability" of the grounds. Longer lags (6–8 yr) after 1974 are consistent with increased larval survival due to sharply rising temperatures and the "recruitment pulse" of the late 1980s. There was no clear relation between temperature and catches at intermediate scales (statistical districts, 10 yr), but effort changes indicate that catches alone do not accurately reflect changes in lobster abundance. At the smallest scale examined (distances between ports, days) correlations of both temperature and effort with catch in areas with similar coastal topographies indicated that the correlation between temperature and catch was not causative, i.e. changes in effort, were driven by wind events that were also influencing water temperatures. The results indicate that effort changes must be considered at all scales in stock assessments, but they become increasingly important at the smallest (i.e. <100 km, within years) scales. They also indicate that significant correlations between lobster catches and environmental parameters must be interpreted cautiously.

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In the absence of suitable effort data, long-term, large-scale changes in American lobster (*Homarus americanus*) populations are generally assessed by using summarized catch statistics (e.g. Harding et al, 1983; Pezzack, 1992; Drinkwater et al, 1991, 1996), under the assumption that catch trends reflect abundance changes. Two observations support this assumption. First, high exploitation rates in most areas probably remove the majority of animals recruiting to the fishery in any year (Miller et al, 1985). Second, similar catch trends over large areas of the Northwest Atlantic suggest a similar population response to a common environmental influence (Pezzack, 1992). Given that this assumption is correct at these large scales, it is of fundamental interest in survey design and data aggregation decisions to determine the spatial and temporal scales at which this assumption holds. For example, can the catch statistic alone be used to assess changes in lobster populations between, say, adjacent ports within seasons?

To understand the spatial and temporal variability of lobster catches on the Atlantic coast of Nova Scotia, Canada, and the underlying causes of this variability, I examined the influence of effort and an important environmental factor (temperature) on commercial lobster catches at different spatial and temporal scales. Temperature can affect lobster catches in the short term by altering the availability of lobsters to traps, i.e. by changing lobster behavior on the grounds (McCleese and Wilder, 1958) or by increasing growth of prerecruits to commercial sizes. In the long term it could also affect population growth by influencing survival of larvae or juvenile stages (Aiken and Waddy, 1986). Changes in effort affect lobster catches directly but how these changes occur is complex. In a lucrative fishery with a relatively short (approx. 60 d) open season and restrictions on the number of traps, fishermen tend to take the maximum number of lobsters possible with their gear. Consequently, changes in effort are more likely to be due to factors that decrease effort. For example, fishermen could decrease the number of traps fished and frequency of hauls when catches are too low to make fishing worthwhile. Because the fishery is conducted from small boats, adverse weather conditions will also decrease effort. Conversely, fishermen may respond to increasing catch rates or good weather by fishing harder. Because catches alone are often used as an indication of stock status, it is important to understand how changes in effort may be influencing catches at the different spatial and temporal scales at which assessments are conducted.

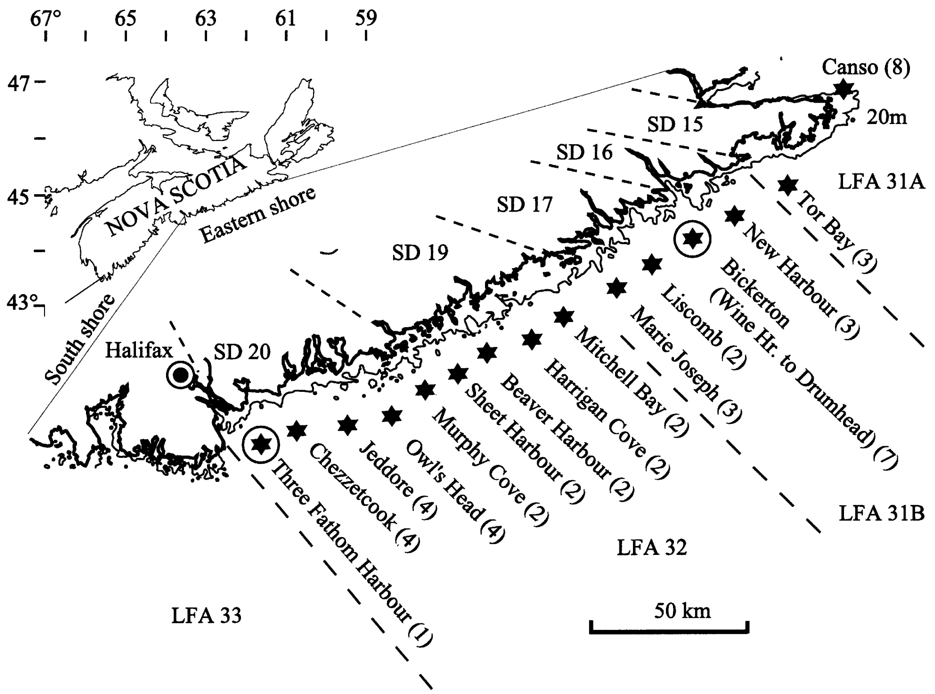

Figure 1

Study area, including locations of ports along the eastern shore where fishermen provided catch and effort information. The number of index fishermen at each location providing data in 1994 is given in brackets after the port name. The dashed lines show the boundaries between lobster fishing areas (LFAs) and statistical districts (SDs). The location of ports that are discussed in the text are circled.

Materials and methods

Annual lobster catch is recorded by statistical district from purchase slips by the Department of Fisheries and Oceans (DFO). These data are summarized by larger geographical units for assessment purposes, usually by lobster fishing areas (LFAs). In order to examine the large scale relationships between catches and temperature, catches were summarized in a similar manner for this analysis. The Atlantic coast of Nova Scotia (Fig. 1) was bisected into coastlines of approximately equal length, named the eastern shore (LFAs 31A, 31B, and 32) and south shore (LFA 33). Long-term records of sea surface temperatures (SSTs) are available from Halifax harbour which is located on the boundary between these areas and can be considered representative of both.

The three data series, i.e. total annual catches from the south and eastern shore and average annual SSTs, were smoothed with a 3-yr running average. Examination of the plots suggested that the series could be divided into two periods, a pre-1974 period of high-frequency, low-amplitude cycles, and a single post-1974 cycle of high amplitude. Correlations at lags of 0–10 years were then run for each period separately and combined.

Daily catch and effort information is collected for DFO by selected index fishermen in some areas of Nova Scotia. At minimum these fishermen provide total lobster catches (usually weight in pounds) and the number of traps hauled on a daily basis during the fishing season. The number of index fishermen varies between areas but tends to cluster around key ports that are also sampled for length frequencies by port samplers. On the eastern shore, about 20 fishermen have kept log books along a 200-km stretch of coastline between Canso and Halifax, some beginning as early as 1986. In 1994 an additional 28 fishermen associated with the Fishermen's and Scientists' Research Society (FSRS) kept logs in this area. Most FSRS fishermen also deployed continuous temperature recorders (Vemco Ltd., Halifax, N.S.) on their traps during the 1994 fishing season, which extended from 20 April to 20 June in LFAs 31B and 32, and from 1 May to 31 June in LFA 31A. Because effort information is available only for a limited num-

Table 1

Statistics for correlation analysis of data series in Figure 1.

	Eastern shore			South shore		
	significant lags (yr)	lag (yr) at maximum *r*	*r*	significant lags (yr)	lag (yr) at maximun *r*	*r*
Pre-1974	1–3	2	0.683*	0–2	1	0.688*
Post-1974	—	8	0.519	—	6	0.532

* = significant at $P<0.01$.

ber of index fishermen within each statistical district, total effort for each district was calculated by dividing its total catch by the average catch per trap haul (CPTH) for index fishermen in that district.

Because seasonal trends were evident in temperature, CPTH, and effort data, any analysis involving daily observations of these parameters were detrended by using first differencing i.e. $i - (i - 1)$, where i is the individual observation of temperature, CPTH, or catch. This avoided spurious negative correlations between the decreasing catches throughout the season that were due to depletion of the fishable biomas, and increasing spring–summer temperatures. Because most fishermen on the eastern shore attempt to haul their traps daily and because longer soaks are usually associated with unfavorable weather (which tends to affect most fishermen in the same area), there was no attempt to adjust for differences in soak times within or between each fisherman's time series. Inspection of the data showed that gaps in the individual time series tended to occur on the same days, which coincided with storm days and Sundays.

Temperature information was also available from DFO moored recorders moored along the eastern shore during the period when logbooks were kept. Years with a strong association between temperature and catch were identified for further study at smaller spatial and temporal scales as follows: daily, temperature, catch, and effort data from the 1986–94 fishing seasons at the location with the most complete longer-term records, i.e. Port Bickerton, were detrended as described above and the resulting individual series correlated. This analysis identified 1991 and 1994 as years with significant correlations. The latter year was chosen for further investigation into the nature of this relationship because of the availability of data at small spatial scales throughout the area from FSRS records. Three matrices of port versus date, one each for the detrended temperature, CPTH and effort data, were then developed for further correlation analysis. Each matrix resulted in a port versus port matrix of correlation coefficients, i.e indices of similarity between port pairs in terms of the daily patterns of change for the respective parameters. Correlations between port pairs could then be plotted against distance between them.

Results and discussion

Effort information is not available at the largest spatial and longest temporal scale examined (Atlantic coast of Nova Scotia, 50 years). At this scale, however, there is a significant correlation between annual mean sea surface temperatures in the approximate center of the area (i.e. Halifax harbor) and summarized lobster catches (Fig. 2; Table 1) at short lags prior to 1974. This correlation was also noted by Campbell et al (1991). Catches are significantly correlated ($P<0.01$) with temperatures for three cycles prior to 1974 at lags of 1–3 years on the eastern shore and 0–2 years on the south shore. After 1974, correlations are highest (although marginally insignificant) at lags of 8 years on the eastern shore and 6 years on the south shore, approximately the time lobsters take to recruit to the fishery in these areas. This finding suggests that during this period, temperature or an unknown covariate also influenced the survival of larvae and subsequently increased recruitment to the fishery. The increase in catches in both areas after 1974 is consistent with the northwest Atlantic coast-wide "recruitment pulse" (Pezzack 1992), which is generally attributed to a common environmental influence, although Drinkwater et al (1996) concluded that this environmental influence was not temperature. Prior to 1974 the near in-phase changes in temperature and catch along the eastern and south shore could be due to temperature-induced changes in catchability during warmer years i.e. to greater activity of lobsters on the grounds or faster growth to legal size, or to both. However, without long-term effort information, changes in effort cannot be ruled out as a cause of the pre-1974 catch cycles. For example, because Halifax harbour sea surface temperatures reflect weather conditions in the study area, years with colder sea surface temperatures could also be years with less fishing activity. It is noteworthy that along the eastern shore both pre- and post-1974 catches lag temperatures by 1–2 yr longer than on the south shore. Hudon (1994) noted that the population along the eastern shore may be growth-limited owing to colder water temperatures than those in adjacent areas, and one would expect this area to react more slowly to the more moderate temperature increases.

Catch and effort in smaller statistical districts along the eastern shore, along with available temperature indices in the area (Fig. 3), reflect the catch patterns of most other lobster fishermen in the northwest Atlantic during this period, i.e. peak catches in the late 1980s and subsequent declines. There was an increase in effort along the eastern shore throughout the period. There is no apparent relation between catches and available temperature indices, although the warmest water and highest catch both occurred in the same year (1989).

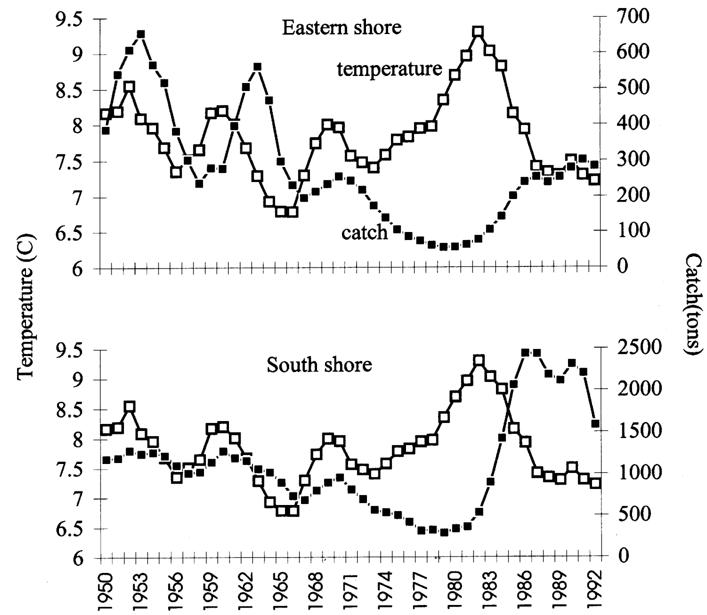

Figure 2

Total annual lobster catch for the eastern shore and south shore of Nova Scotia and average annual sea surface temperatures in Halifax harbor, 1950–92. All data series were smoothed with a three year average.

Port Bickerton reflected the catch and effort pattern of the eastern shore as a whole, including an increase in effort throughout most of the period (Fig. 4). Note that the increase in the average daily number of trap hauls leveled off when catches started to decline after 1991. Perhaps fishermen were increasing effort in response to increasing lobster catches during the 80s. Pringle and Duggan (1984) noted that as many as 25% of the maximum number of traps (eastern shore trap limit is 250) can remain unused in the Nova Scotia lobster fishery. Although the use of catches alone would have overestimated the rate of increase in the population during the 80s and underestimated the subsequent decline, the differences are small and would not have affected conclusions on annual population changes.

A significant correlation between average daily temperatures and CPTH at Port Bickerton occurred in only 2 of the 8 years for which temperature, catch, and effort information is available at this scale, suggesting that short-term, temperature-induced changes in catchability occurred, or were detectable, during those years (Tables 2 and 3). However, a multiple regression of daily catch (dependent variable) versus effort and temperature during these years also indicates that short-term changes in lobster catches were largely determined by effort changes. Cross correlations between total daily catch and effort at Port Bickerton at lags of 0–7 days showed no significant correlations at lags other than 0, indicating that fishermen's effort was not influenced by catches at short time scales.

Table 2

Pearson correlation coefficients for average daily temperature (at 10 m) vs. total daily catch, total daily effort, and average daily catch per trap haul for index fishermen at Port Bickerton 1986–94.

	Catch	Effort (trap hauls)	Average CPTH
1986	0.0491	0.1066	0.0830
1987	0.2158	0.0065	0.1740
1988	–0.0380	–0.0373	0.1060
1989	–0.0551	0.0718	0.1580
1990	0.1317	0.1239	0.1690
1991	0.311*	0.1014	0.408*
1992	–0.1426	–0.2853	0.2110
1993[1]			
1994	0.2477	0.1888	0.262*

* = significant at $P<0.05$.
[1] Temperature data for 1993 were not available in Bickerton during the fishing season.

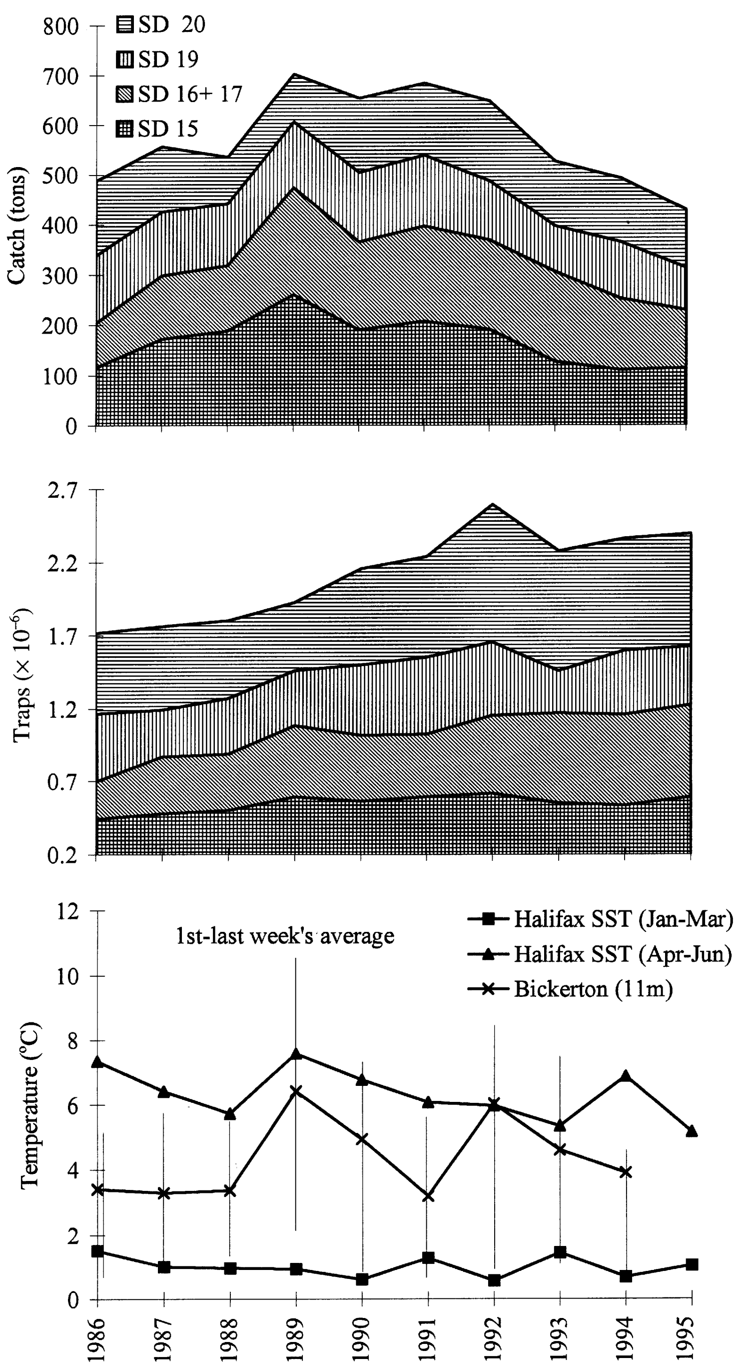

Figure 3

Total annual lobster catch (top) and total annual effort (middle) for eastern shore statistical districts from 1986–95, the years for which effort information is available from index fishermen. Also shown for these years are three temperature indices (bottom), including average sea surface temperatures (SST) in Halifax harbour from January to March; average SST from April to June i.e. during the lobster season; and average water temperatures (11 m) at Port Bickerton during the lobster season. The bars show the average temperature for the first (lower) and last (upper) week of the lobster season.

Correlation coefficients of the daily first differenced CPTH data from individual fishermen on the eastern shore were plotted against distance from Port Bickerton and Three Fathom Harbour (Fig. 5), situated about 125 km apart near the northeastern and southwestern end of the study area (Fig. 1). Correlations were strongest in the immediate vicinity of these ports, decreased to insignificance at about 50 km, then increased to a second maximum at 125 km. This pattern was still apparent when all ports were included in the analysis (Fig. 5, bottom), but the least-squares fit to the polynomial was not as good, perhaps because local factors influence the main spatial trend in other areas. In contrast, short-term changes in water temperature are strongly correlated throughout the area (Fig. 6) because they are caused by wind events that impact the eastern shore as a whole. Apparently, the correlation of catches and temperatures at Port Bickerton in 1994 (Table 2) occurred only at either end of the eastern shore. To determine if this correlation was truly a direct environmental influence on catch, I plotted the daily correlation coefficients of all ports against distance separately for CPTH and effort (Fig. 7). The fourth-order polynomials fitted to the data are similar for both, indicating that the similarity in catches between ports on either end of the eastern shore and their similarity to short-term temperature changes are mainly due to similarities in the daily pattern of change in effort. This is confirmed by plotting the coefficients for effort versus temperature directly. Similar results were obtained for 1991, the other year in which significant correlations between temperature and catches were found at Port Bickerton. The reason why fishermen separated by 125 km have similar day-to-day fishing patterns is apparent when one examines the nature of the coastline along the eastern shore (Fig. 1). The coast near Three-Fathom Harbour and Bickerton is characterized by relatively long and narrow bays generally oriented in a north–south direction, which offer more shelter than the relatively exposed coastline between them. If the winds that cause temperature decreases are also those that make fishing more difficult,

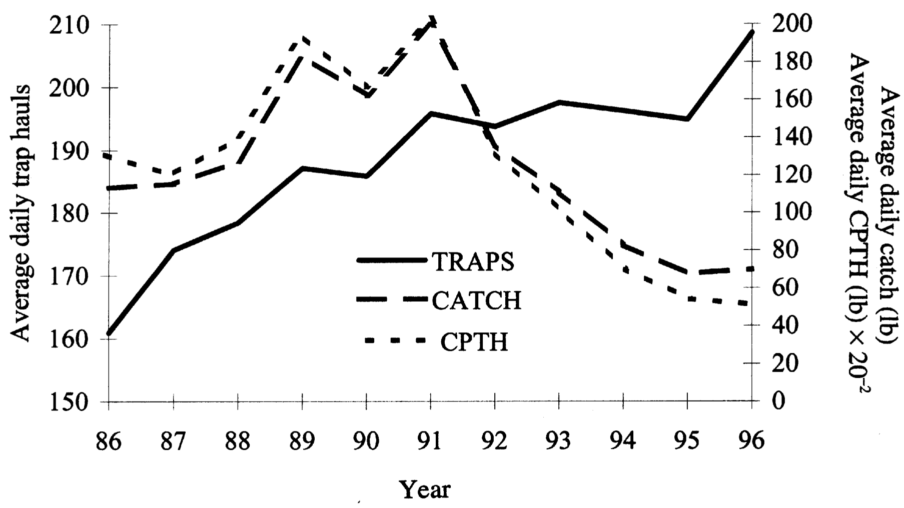

Figure 4

Annual averages of daily catch, trap hauls, and catch per trap haul for index fishermen at Port Bickerton 1986–96.

Table 3

Multiple regression analysis of total daily catch (dependant variable), total daily effort (trap hauls) and average daily temperatures for the two years where significant correlations between temperature and catch per trap haul were found (Table 1). Statistics shown include slope and intercept values (B), standard error of B, and regression coefficients (Beta), with their significance levels (Sig. T).

		B	SE B	Beta	T	Sig. T
1991	Effort	1.1382	0.1055	0.8241	10.7840	0.0000
	Temperature	50.9725	62.0185	0.0628	0.8220	0.4148
	(Constant)	–0.9795	34.8649	–0.0280	0.9777	
1994	Effort	0.4000	0.0528	0.7179	7.5760	0.0000
	Temperature	61.3956	51.8943	0.1121	1.1830	0.2423
	(Constant)	–10.4788	28.9416	–0.3620	0.7188	

e.g. those that are southerly and enter directly into the bays, and are of a minimum force, or both, one would expect a positive correlation between water temperatures and catches in these areas. The apparently spurious correlation between lobster catches and temperature would be weaker in the exposed central area where fishing activity is vulnerable to winds from a wider direction and of less force than those which significantly impact near-shore water temperatures. Although it is clear that the observed correlations between short-term changes in lobster catches and temperatures are strongly influenced by changes in effort, these results do not rule out a concurrent direct affect of temperature on lobster activity and catches, i.e. effect of catchability. Possibly fishermen are aware that winds of a certain direction and force affect lobster activity and catchability and alter their fishing activity accordingly, or the factors that decrease fishing activity also decrease lobster catchability independently.

These results indicate that although changes in effort can influence lobster catches at all spatial and temporal scales examined, data on effort is particularly critical in correctly interpretating the meaning of changes in catch at smaller scales i.e. <100 km and <1 yr. In particular, they indicate that small-scale correlations between environmental parameters such as winds and water temperatures with lobster catches alone should be treated cautiously because inferences made about their underlying mechanisms may be wrong. For example, Hudon (1994) concluded that differences in annual catches between approximately 100-km lengths of the Nova Scotia coastline were due to differences in the orientation of these coastlines to upwelling winds, the resultant change in wa-

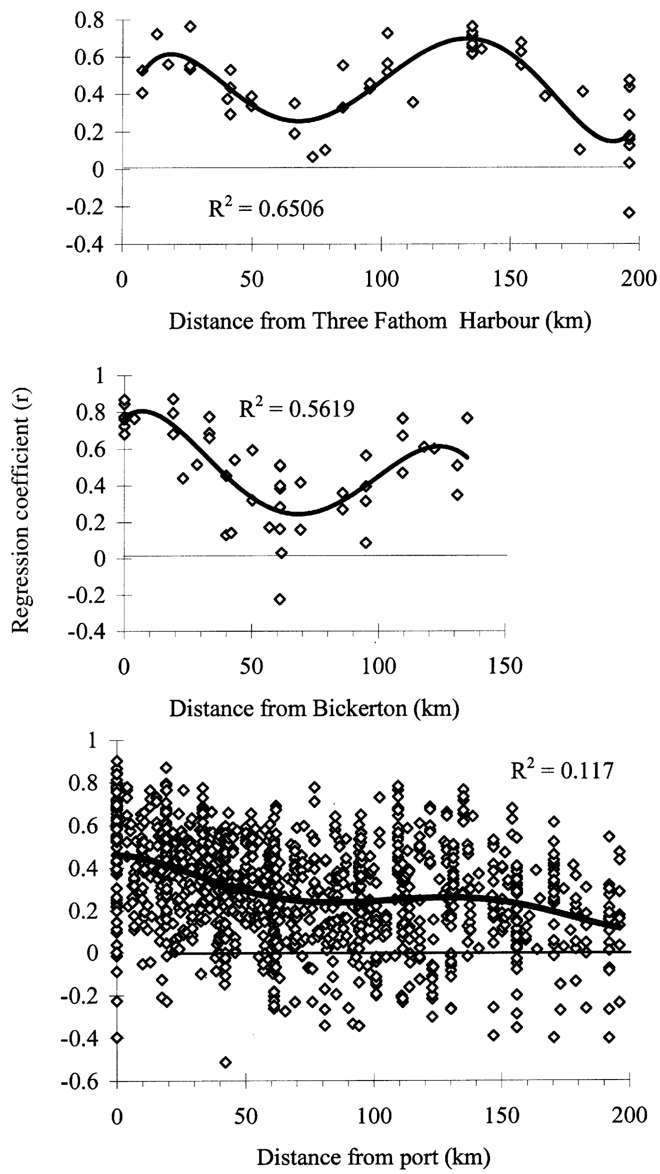

Figure 5

Pearson correlation coefficients of first differenced daily CPTH of all index fishermen along the eastern shore versus increasing distance from Three Fathom Harbour (top) and Bickerton (middle). The bottom figure plots the same statistic for all ports versus distance from each other. A fourth order polynomial provided the best least-squares fit to each data set.

ter temperature, and the effect of the latter on lobster productivity. This study suggests that at least some of these differences may be due to differences in effort and "fishability" of the coastlines involved.

These results also give a general indication of the sampling effort (i.e. number of index fishermen) and distribution (spacing of index fishermen) required of a program whose objective is to characterize and assess changes in effort for an entire coastline. Because changes in effort from index fishermen separated by short distances, i.e. within the working reaches of a fishing port, are strongly correlated, it would be more effective for any given total sampling intensity to space samples evenly along that coastline, rather than cluster them in ports. Since the correlation of index fishermen's catch data decreases quickly at dis-

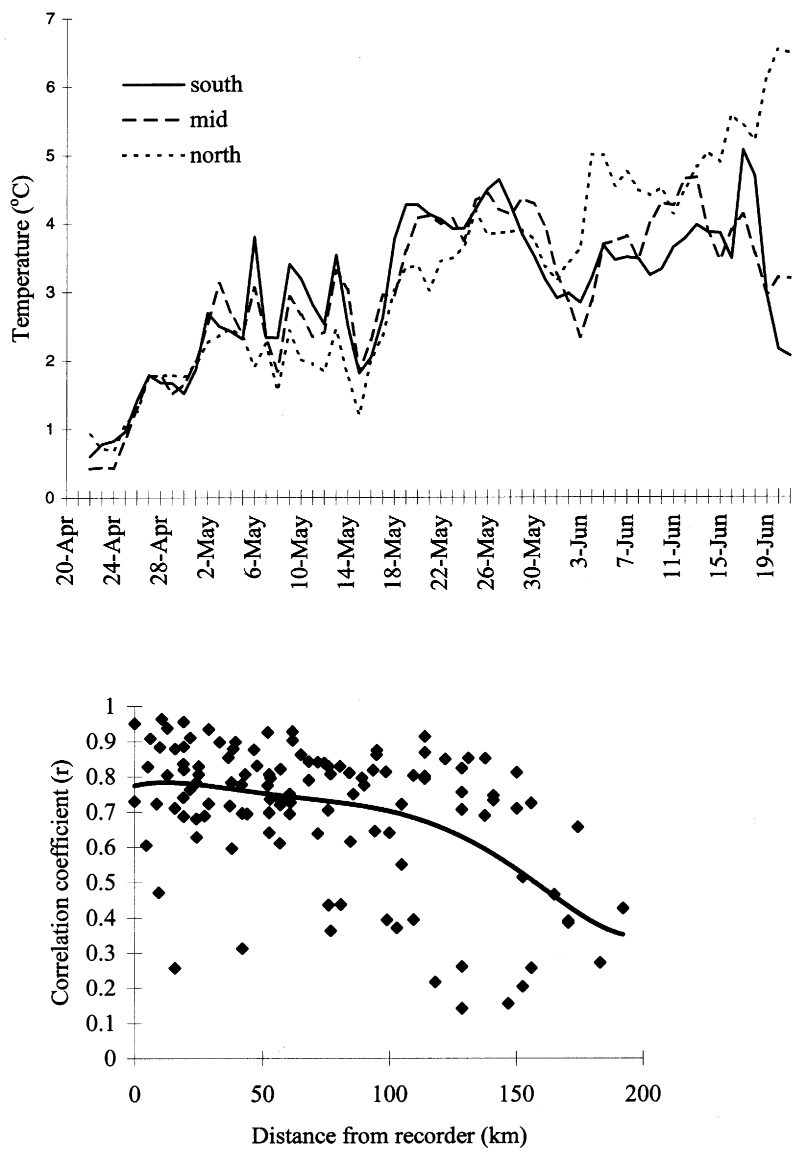

Figure 6

(Top) Average daily temperatures from temperature recorders deployed by index fishermen on their traps during 1994, for the southern (south of Murphy Cove), middle (Murphy Cove to Liscomb) and northern (north of Liscomb) sections of the eastern shore. (Bottom) Pearson correlation coefficients of first differenced temperature data from all temperature recorders deployed by index fishermen versus distance between instruments in 1994.

tances greater than about 25 km, the samples should be more closely spaced. On the eastern shore, where the annual average number of fishermen providing information is about 20, the resulting 10-km spacing at this sampling level should be adequate to provide a representative sample.

Although these results have not eliminated the possibility of temperature-induced changes in catchability, they do indicate that quantifying these changes with fishermen's data would be extremely difficult.

Acknowledgments

I wish to thank the Nova Scotia lobster fishermen who provided information used in this study, especially those who have collected data since the begin-

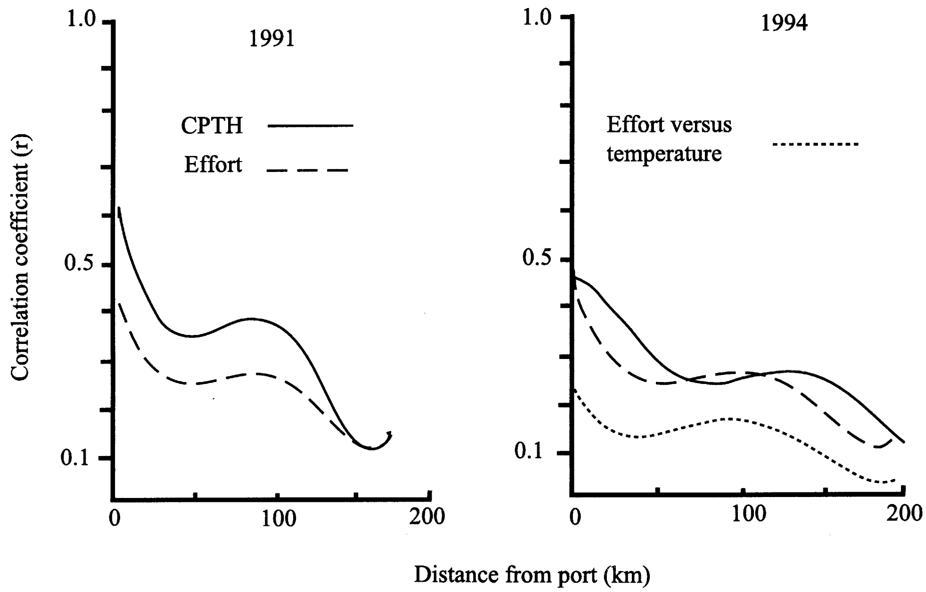

Figure 7

Fourth order polynomials as shown in the bottom of Figure 5, but for catch per trap haul and trap hauls separately, for the years in which significant correlations of daily temperature and catch per trap haul were found at Port Bickerton (1991, 1994). Also shown is the polynomial curve for individual fishermen's daily effort versus daily average temperatures in their area in 1994. Individual points have been omitted for clarity, but their distribution is similar to the bottom of Figure 5.

ning of DFO's lobster logbook program. Their continuing efforts increase the value of this database each year. The cooperation of Randy Baker, Sean Smith, and fishermen of the Fishermen's and Scientists' Research Society is gratefully acknowledged for access to additional data for the 1994 season, including temperatures. Ed Verge provided historical temperature data collected by the Physical and Chemical Sciences Branch, DFO, and Ron Duggan summarized much of the data for analysis. Bob Roger and Steve Smith provided statistical advice, and John Tremblay and Doug Pezzack reviewed early versions. I am particularly indebted to three anonymous reviewers whose suggestions significantly improved the manuscript.

Literature cited

Aiken, D. E., and S. L. Waddy.
1986. Environmental influence on recruitment of the american lobster (*Homarus americanus*): a perspective. Can. J. Fish Aquat. Sci. 43:2258–2270.

Campbell, S., D. J. Noakes, and R. W. Elner.
1991. Temperature and lobster, *Homarus americanus*, yield relationships. Can. J. Fish. Aquat. Sci. 48:2073–2082.

Drinkwater, K. F., G. C. Harding, W. P. Vass, and D. Gauthier.
1991. The relationship of Quebec lobster landings to freshwater runoff and wind storms. Can. Spec. Pub. Fish. Aquat. Sci. 113:179–197.

Drinkwater, K. F., G. C. Harding, K. H. Mann, and N. Tanner
1996. Temperature as a possible factor in the increased abundance of American lobster, *Homarus americanus*, during the 1980s and early 1990s. Fish. Oceanogr. 5(3/4):176–193.

Harding, G. C., K. F. Drinkwater, and P. Vass.
1983. Factors influencing the size of the American lobster (*Homarus americanus*) stocks along the Atlantic coast of Nova Scotia, Gulf of St. Lawrence, and Gulf of Maine: a new synthesis. Can. J. Fish. Aquat. Sci. 40:168–184.

Hudon, C.
1994. Large-scale analysis of Atlantic Nova Scotia American lobster (*Homarus americanus*) landings with respect to habitat, temperature, and wind conditions. J. Fish. Aquat. Sci. 51:1308–1321.

McCleese, D. W., and D. G. Wilder.
1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Board Canada 15(6):1345–1354.

Miller, R. J., D. S. Moore, and J. D. Pringle.
1985. Overview of the inshore lobster resources in the Scotia-Fundy Region. Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) Res. Doc. 85, 20 p.

Pezzack, D. S.
1992. A review of lobster landing trends in the northwest Atlantic, 1947–86. J. Northwest Atl. Fish. Sci. 14:115–127.

Pringle, J. D., and R. E. Duggan.
1984. Latent lobster fishing effort along Nova Scotia's Atlantic Coast. Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) Res. Doc. 84/56, 23 p.