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Temperature, catch rate, and catchability during the spring lobster fishery off eastern Cape Breton

by

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ABSTRACT

Seasonal changes in catchability (q) and temperature are investigated for the spring lobster fishery in eastern Cape Breton (Aspy Bay - Petit de Grat). Two approaches are used: analysis of spatial and temporal coherence in temperature and catch rate; and analysis of seasonal tag returns. Lobster catch rate trends along the northeast Cape Breton (Aspy Bay - Main-a-Dieu) were similar with relatively large declines occurring over the season. Catch rates along the Atlantic coast of Cape Breton (Louisbourg-Petit de Grat) were flat or showed a much lower rate of decline. Temperature variability along the northeast coast was highly coherent between stations for periods > 2 days and wind-dependent. In agreement with Ekman theory, winds from the south produced upwelling (and lower temperatures) while winds from the north resulted in downwelling (and higher temperatures). No significant relationships between temperature and catch rate were found but further analyses are required to confirm this. Tagged lobster recaptures showed no trend relative to the capture of untagged lobsters in most cases, suggesting the q of unmarked lobsters could be inferred from that of tagged lobsters. Seasonal catchability did not increase with temperature, probably because lobsters become less catchable as they prepare to molt. The increased catchability with increasing seasonal temperature shown in an earlier study (Paloheimo 1963) may be due to an artifact of tagging.

RESUME

Les variations saisonnières de la vulnérabilité à la pêche(q) et de la température ayant pu affecter la pêche du homard de printemps de l'est du Cap-Breton (baie Aspy - Petit de Grat) font l'objet d'un examen. Deux méthodes sont utilisées : l'analyse de la cohérence spatiale et temporelle de la température et du taux de capture et l'analyse des étiquettes remises pendant la saison. Les tendances du taux de capture du homard le long de la côte nord-est du Cap-Breton (baie Aspy - Main-à-Dieu) ont été semblables et présentaient des baisses relativement importantes en cours de saison. Les taux de capture de la côte atlantique du Cap-Breton (Louisbourg - Petit de Grat) étaient uniformes ou présentaient une baisse de beaucoup inférieure. La variabilité de la température le long de la côte nord-est présentait une forte cohérence entre les stations pour les périodes supérieures à 2 jours et étaient en fonction du vent. Conformément à la théorie de Ekman, les vents du sud produisaient une remontée des eaux (et un abaissement de la température) tandis que les vents du nord provoquaient une plongée des eaux (et un accroissement de la température). Aucune relation significative entre la température et le taux de capture n'a été notée, mais celà devra être confirmé par des analyses plus poussées. Les recaptures de homards marqués n'ont généralement permis de déceler aucune tendance par rapport à la capture des homards non marqués, ce qui porte à croire que la valeur q des homards non marqués pourrait être déduite de celle des homards marqués. Le taux de vulnérabilité saisonnier n'a pas augmenté avec la température, sans doute parce que les homards deviennent plus difficiles à capturer lorsqu'ils se préparent à muer. L'accroissement de la vulnérabilité avec la température en cours de saison démontré par une étude antérieure (Paloheimo, 1963) pourrait s'expliquer par un artéfact dû au marquage.

INTRODUCTION

Catch rate (catch-per-trap-haul in trap fisheries) is a function of abundance and catchability (q), where q is defined as the probability of an animal being captured by a randomly applied unit of effort (Paloheimo 1963). Lobster catchability is affected by numerous biological and environmental factors (Miller 1990). Biological factors include animal size, sex, molting activity, intra- and inter-specific interactions; some key environmental factors are temperature, diurnal and lunar cycles, current strength and water turbidity. Temperature generally increases activity, which may lead to higher catchability (McLeese and Wilder 1958, Paloheimo 1963, Morgan 1974).

Although comparisons of annual mean catch rate may be affected by interannual variability in catchability, mean annual catch rate appears to be a useful index of abundance for some stocks since catch rate has covaried with landings (Miller et al. 1987, Tremblay and Eagles 1996). Any effect of temperature on annual differences in catchability was too small to detect from analysis of large-scale trends in lobster landings and temperature (Drinkwater et al. 1996).

Another use of catch rate data is in estimating biomass and exploitation with fishing-success methods (Ricker 1975). The reliability of these techniques (e.g. Leslie method) for stocks that are fished by traps is questionable because of some of the assumptions (Miller and Mohn 1993). Of particular concern is the assumption of constant catchability. When catchability changes seasonally, estimates of stock size and exploitation may be invalid. A potentially important source of seasonal changes in catchability is temperature. An increase in catchability with temperature during spring lobster fisheries was reported by Paloheimo (1963). An opposing factor with the potential to decrease catchability is molting activity, the timing of which is temperature related.

For several years "index" fishers in coastal Nova Scotia have maintained logs of fishing catch and effort (Tremblay et al. 1992). Recently some of the index fishers have also been provided with temperature recorders to place on traps. These data provide an opportunity to investigate the relationship between temperature and catch rate. A similar effort for the eastern shore of Nova Scotia (Koeller MS) reported a positive effect of temperature on catch rate in some years, but noted that catch rate was also affected by such factors as local changes in fishing effort.

In this paper we focus on the spring lobster fishery off eastern Cape Breton (Fig. 1). The objectives are twofold: (i) to evaluate the spatial and temporal coherence in temperature and lobster catch rates; (ii) to examine seasonal changes in lobster catchability, through the analysis of mark-recapture data.

METHODS

Catch rates and temperature

Lobster landings in kg and number of trap hauls for each day fished were obtained from the logs kept by index lobster fishermen (Tremblay and Eagles 1996) at 8 fishing ports along the east and south coasts of Cape Breton between 11 May and 15 July, 1996. The ports from north to south were Dingwall (Aspy Bay), Little River, Point Aconi, Glace Bay, Main-a-Dieu, Louisbourg, L'Ardoise and Petit de Grat (Fig. 1). These sites cover two Lobster Fishing Areas (LFA 27 and 29) with overlapping 9 week seasons. The landings and number of traps were combined to determine catch rates in kg/trap haul. Continuous temperature records were obtained for each site at two depths, one shallow (10-15 m) and another deeper site (18-22 m) from 28 May to 8 July. They were measured with a VEMCO minilog thermistor, sampling at a frequency 1 to 2 hours. The data were linearly interpolated to values on the hour (i.e., 1:00, 2:00, etc.). Hourly wind data were obtained from the Atmospheric Environment Service, for Sydney airport and Hart Island near Canso. Winds were converted to stress using the formulation of Large and Pond (1981). Wind stress is the force applied to the sea surface by the wind.

Correlation analyses were used to investigate the relationship between lobster catch rates at different sites and with temperature. Catch rates and temperatures at each site were first differenced (e.g. catch rate on day 2 - catch rate on day 1) to remove trends and then used in the correlation analysis. Spectral analysis techniques were used to investigate the relationship between temperature and wind stress. Spectra of the temperatures and winds were calculated from the hourly values. The records were divided into m blocks of 256 points with 50% overlap. The mean and trend were removed from each block and the data were tapered using a Hanning window (Bloomfield 1976). Multivariate frequency-response analysis (Jenkins and Watts 1968) was used, which is the frequency-domain analogue to time-domain regression for a multiple input-single output model. In this study, temperature was modeled as a function of the wind stress components, τ_x and τ_y. For further details see Drinkwater (1994).

Seasonal changes in catchability

To investigate seasonal changes in catchability, we use the data from mark-recapture studies. Using this approach, Paloheimo (1963) reported a strong positive dependence of catchability on temperature (Fig. 2). In this study we examine mark-recapture data from studies of growth and movement in several areas of northeast Cape Breton conducted between 1993 and 1996 (Table 1). Lobsters were tagged with polyethylene streamer tags, which appear to be retained at a higher rate than sphyrion tags (Moriyasu et al. 1995).

Catch (C), the number of legal-sized lobsters landed, is related to the number of lobsters on the bottom (N), catchability (q), and effort (f, number of trap hauls) as follows:

$$C_t = N_t\,(1 - e^{-qf_t})$$

or $$q_t = -\{Ln(1-C_t/N_t)\}/f_t$$

If q is small and time intervals are short, catch is estimated as:

$$C_t = N_t q_t f_t$$

Tag returns can be used directly in evaluating seasonal changes in q by substituting C and N with the marked population:

$$q_t = -\{Ln(1-R_t/M_t)/f_t$$

where R_t is the number of marked lobsters returned and M_t is the total number of marked lobsters remaining in the water at the start of period t.

Here we use catch and effort data from 2-6 fishing logs in the area where the tagging took place, and assume these logs are representative of the seasonal trend of all fishers. Since we were not interested in comparing the q estimates of different areas, it was not necessary to scale the fishing log data up to the full tagging area.

To investigate whether the relative catchability of tagged lobsters was the same as untagged lobsters we calculated the ratio of recaptures (M) to the landed catch (C) by log keepers. Catch weights were converted to numbers through division by the average weight of lobsters landed at the port. Average weights were obtained by converting average lengths from Tremblay and Eagles (1996) using the length-weight regression in Campbell (1985). The M_t/C_t ratio was estimated for 3 day intervals (whether the interval contained 2 or 3 fishing day records) during the fishing season. Paloheimo (1963) reported that lobsters tagged just prior to the spring fishing season off southeast Cape Breton became relatively more catchable as the season progressed. Our study differed in that most lobsters were tagged in the summer or fall preceding the spring fishing season of the following year (Table 1).

Table 1. Lobster tagging studies in northeastern Cape Breton. N recaptures is the number of first-time recaptures during the return period. In 1994 most lobsters were returned to the water after the tag information was recorded. Ovig = ovigerous

Area	Tag Date	N tagged	Mean CL (mm) at tagging Males	Females	Ovig Fem	Return Period	N ecaptures
Little River	July 1993	179	68.4	65.9	78.9	May 15-Jul 15 1994	84
Little River	Sept. 1993	1200	80.6	72.7	80.4	May 15-Jul 15 1994	558
Little River	May 1994	138	65.4	65.4	78.0	May 15-Jul 15 1995	74
Aspy Bay	July 1995	399	67.5	67.1	80.8	May 15-Jul 15 1996	158
Glace Bay	July 1995	209	68.1	67.7	79.7	May 15-Jul 15 1996	57
Pt Morien	Oct. 1995	253	85.8	81.7	---	May 15-Jul 15 1996	104

RESULTS AND DISCUSSION

Spatial coherence of lobster catch rates

The time series of catch rates for Aspy Bay, Glace Bay and Petit de Grat show a distinct pattern (Fig. 3). At the most northerly location (Aspy Bay), catch rate declined gradually from a maximum at the beginning of the lobster season and displayed high amplitude haul-to-haul variability. Further to the south at Glace Bay, both catch rates and their seasonal decline were of lower magnitude. Indeed, the amplitude of the seasonal decline during the lobster season decreased almost linearly from Aspy Bay to Louisbourg. In contrast, at Petit de Grat (on the Atlantic coast) catch rates were comparatively low, showed no mean trend and exhibited lower amplitude haul-to-haul variability. Catch rates at L'Ardoise showed a pattern similar to those at Petit de Grat. Standardizing the catch rate to 1-day soaks dampened some of the peaks but did not change the patterns (Fig. 3).

High correlations of catch rates were observed between sites from Aspy Bay to Glace Bay ($r > 0.8$; Fig. 4). Correlations between these sites and those along the Atlantic coast declined gradually from Main-a-Dieu ($r \sim 0.7$) to Louisbourg ($r \sim 0.4$) to L'Ardoise and Petit de Grat ($r < 0.2$). Catch rates between these Atlantic sites are only weakly correlated (generally $r < 0.5$). When the analysis was repeated using the first differenced catch rates, the pattern was similar to that observed using the raw rates although correlations between sites from Aspy Bay to Main-a-Dieu decreased ($r = 0.6-0.8$; Fig. 5). This is because part of the correlation using the raw catch rates was due to the seasonal trend which is largely removed by the first differencing (Fig. 5). On the other hand, there was only a slight decrease in correlations amongst Louisbourg, L'Ardoise and Petit de Grat because of the smaller seasonal decline in catch rates at these sites.

Spatial and temporal variability of temperatures

To investigate the temperature variability, we restricted ourselves to the deeper temperatures since they were strongly correlated with the shallower records and tended to exhibit higher variance at all sites. During spring 1996, the rate of temperature increase was highest at the more northerly locations and lowest at Petit de Grat (Fig. 6). Temperature spectra generally show increasing variance towards lower frequencies, i.e. longer periods (Fig. 7). The largest amplitudes were at Aspy Bay and Little River. The amplitude depends upon two factors, the strength of the thermal stratification (vertical temperature gradient) and the position of the recorder relative to that gradient. The high variance at Aspy Bay for frequencies above 1 cpd is most likely due to tidal variability. We examined the spatial coherence in temperature using Aspy Bay as our reference. Coherence with the other sites shows highest values (>0.7) at the lowest frequency which corresponds to periods of 5-10 d (Fig. 8). High coherence at these frequencies occurred at all sites. Smaller peaks occur near periods of 1 d and 12 hours, corresponding to the main tidal frequencies.

Temperature-wind relationship

The relationship between temperature and wind was explored using spectral methods. Coherency analysis between temperatures and the two wind stress components (Taux, east/west component, positive eastward; Tauy, north/south component, positive northward) were carried out for all sites. The results for Little River were typical of the sites along the northeast coast of Cape Breton (Fig. 9). They show high coherence with the north-south component of the wind. Coherence was > 0.6 for periods above 2 days and reached a maximum of 0.9 at a period of 5 days. Coherence to Taux was low and not significant. This was expected since the north-south winds parallel the coastline at Little River and along-shore winds have been shown to control near-shore dynamics including fluctuations of the thermocline in numerous coast studies (Csanady, 1982). The phase information (the time between the wind and the temperature response) indicated that a positive wind stress (to the north) produced lower temperatures. This is consistent with Ekman dynamics, i.e. along-shore winds forcing surface waters to the right of the wind which replace or are replaced by deeper cooler waters. Thus winds from the south along Cape Breton produce upwelling. While most sites along the northeast coast of Cape Breton showed a similar response, not all did. Aspy Bay showed high coherence with both τ_x and τ_y components, perhaps due to the orientation of the local topography or geometry of the Bay.

Correlation between temperature and catch rates

We also examined the correlation between temperature and catch rates. The seasonal decline in catch rates is due primarily to removals by the fishery. Since we were particularly interested in the shorter period fluctuations, we first-differenced both daily mean temperatures and catch rates to remove the trends. If trap hauls were 2 days apart, differences in temperature were still calculated using only the previous day since the majority of the catch is believed to occur during the first day. Plots of the temperature and catch rates for Aspy Bay and Little River show some correspondence with many of the peaks in catch rate difference corresponding to those in temperature (Fig. 10). This indicates that catch rate increases as temperature increases. However, correlations are relatively low (r=0.25 for Aspy Bay and r=0.38 for Little River) and are not considered significant. However, we feel that further analysis is required to determine the possible effect of lags in temperature and to determine the correct averaging period for the temperature.

Relative catchability: within-season catch of tagged vs. untagged lobsters

For 5 of the 6 tag-recapture data sets there was no apparent trend in the ratio of number of recaptures to total catch (Fig. 11, 12). Assuming the number of tagged lobsters in the water (M) did not change as a result of migration, this indicates that the tagged lobsters behaved similar to the untagged lobsters for the most part, and the q of unmarked lobsters can be inferred from that of tagged lobsters. The exception was lobsters tagged in September 1993 and returned the following spring (Table 1), which became increasingly more catchable relative to tagged lobsters as the season progressed (Fig. 11b).

Paloheimo (1963) reported a similar but more marked effect of increasing relative catchability for 3 spring fisheries. He believed that the increase was because the tagged lobsters did not have enough time to mix with the untagged population before capture by the fishery. In his marking studies, the lobsters were tagged just prior to the fishing season. A lack of mixing is unlikely in our case since the lobsters tagged in September 1993 had about 8 months to mix with the untagged lobsters prior to recapture. We can only speculate on the basis for the relative increase in catchability for lobsters tagged in September 1993. It may be the result of migration--perhaps the September tagged lobsters contained a component that moves onto the grounds as the season progresses reaching a maximum in late summer.

There was one small data set to test whether the relative catchability of lobsters tagged just prior to the season would differ from the unmarked population. In May 1994, 138 sub-legal lobsters were tagged (Table 1). The main recapture period was the following spring (1995), after they had molted, but during the 1994 fishing season lobster fishers kept track of recaptures and then returned the lobsters to the water. A total of 48 tagged lobsters were recaptured at least once in 1994. Compared to 1995, when the lobsters had molted to commercial sizes, we would expect the 1994 return rate to be lower because commercial traps are designed to allow for escapement of sublegal sizes. The ratio of the number of recaptures to the estimated catch of sublegal lobsters trended upwards during the season (Fig. 13a), as was seen by Paloheimo (1963). The following year, these lobsters showed no tendency of increased catchability during the season (Fig. 11c) (but did exhibit unexplained autocorrelation). The increase in estimated catchability in Fig. 13a might also result from an increase in the rate of reporting of tagged sublegal lobsters as the season progressed. We have no reason to suspect this since the fisherman involved in this study seemed eager to participate. We suggest that when estimating catchability from mark-recapture studies, the time of tagging relative to the fishery is an important consideration.

Within-season catchability and temperature

There were no positive relationships between seasonal changes in q and temperature for the 6 data sets in Table 1 (Fig. 14, 15). In fact the catchability of lobsters tagged in Glace Bay in 1995 actually decreased with temperature (Fig. 15b). The May-July 1994 returns of sublegal lobsters tagged just prior to the season again differed, since catchability was positively related to temperature (Fig. 13b). Thus we obtained the same result as Paloheimo (1963) for lobsters tagged just prior to their recapture. The correlation between q and temperature would appear to be an artifact of the time of tagging.

The fact that catchability did not change, or actually decreased as the season progressed is probably related to lobsters preparing to molt. Studies of molt timing in Little River indicate that preparation for molting begins as early as June (Tremblay and Eagles MS). Several weeks before the end of the season there is a shift in the sex ratio in favour of females. Since males molt first it is inferred that the males become less catchable. Although the major molt generally does not occur until August, some lobsters have molted by mid-July, near the end of the fishing season. Thus the lack of a positive relationship between q and temperature indicates the presence of a confounding factor, that of molting.

Fishing-success methods for estimating biomass and exploitation rate assume constant catchability. If these methods are applied to spring lobster fisheries, consideration must be given to the potentially opposing effects of increased temperature (increased catchability) and the onset of molting activity (decreased catchability). Corrections for catchability changes, or removal of fishing data pertaining to the premolt period are possible options.

SUMMARY

1. Lobster catch rates trends were similar along the coast of northeast Cape Breton (Aspy Bay to Main-a-Dieu) but dissimilar to those along the Atlantic coast of Cape Breton (Louisbourg to Petit de Grat).
2. Temperature variability along the entire east coast of Cape Breton is highly coherent for periods of >2 days.
3. Temperature variability is strongly related to the wind, in the classical Ekman sense. Where the coastline runs north-south, winds from the south produced upwelling (and decreased temperature), winds from the north produced downwelling (and increased temperature).
4. No significant relationships between temperature and catch rate were found but further analyses are required to confirm this.
5. Tagged lobster recaptures showed no trend relative to untagged lobsters in 5/6 cases.
6. If lobsters are tagged just prior to recapture their catchability may differ from that of untagged lobsters.
7. Seasonal catchability did not increase with temperature, probably because lobsters become less catchable as they prepare to molt

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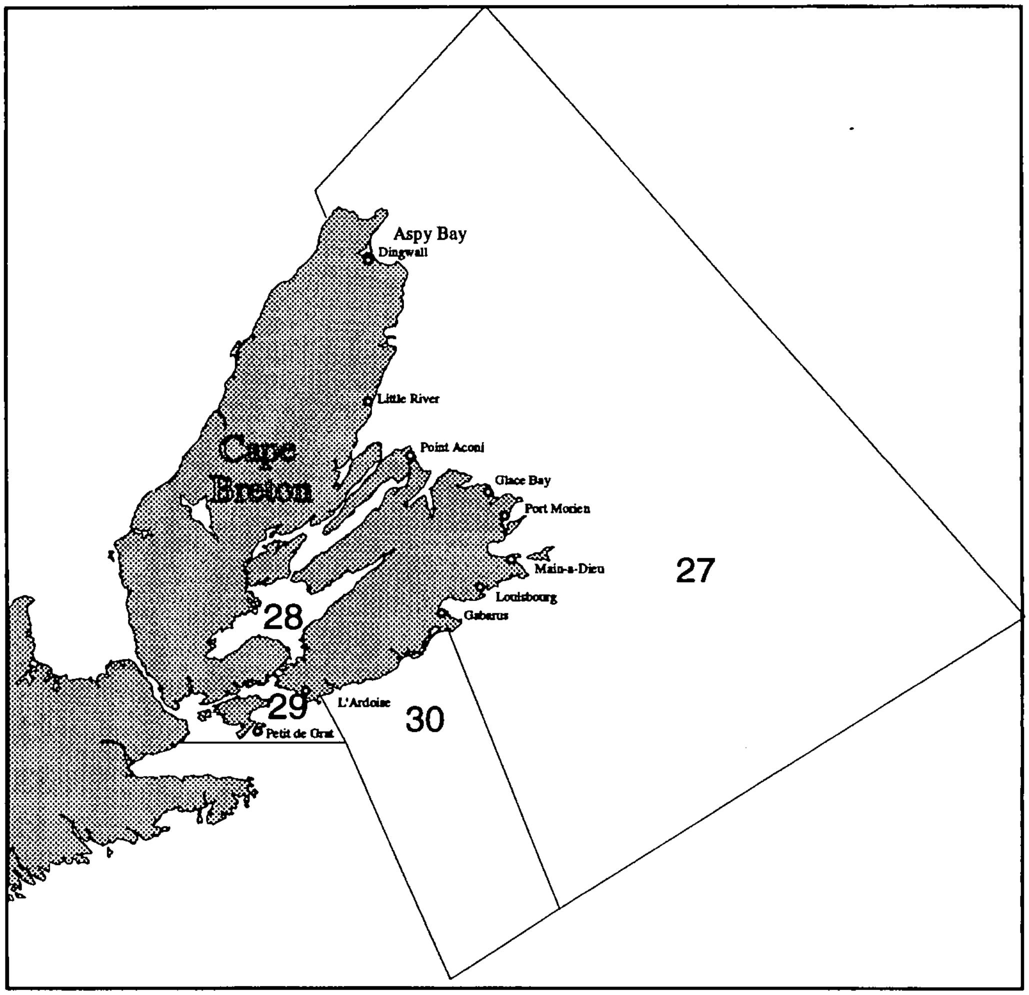


Figure 1. Map showing location of temperature records during the spring 1996 lobster fishing season. Lobster fishing areas 27-30 are also shown.

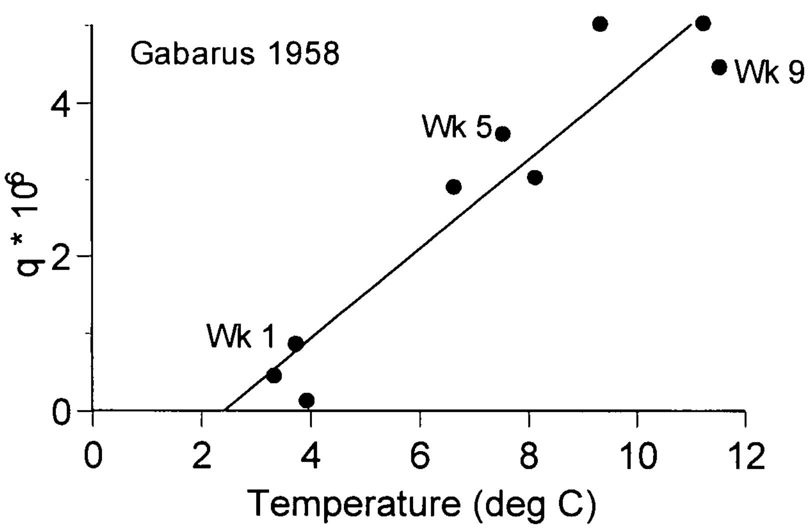


Figure 2. q versus weekly temperature for mark-recapture experiment reported in Paloheimo (1963). q calculated as: $q = -\{Ln(1-R_t/M_t)/f_t$, where R is number of recaptures, M is number of marked lobsters yet to be recaptured, and f is effort in number of trap hauls. Points representing weeks 1, 5, and 9 are labeled.

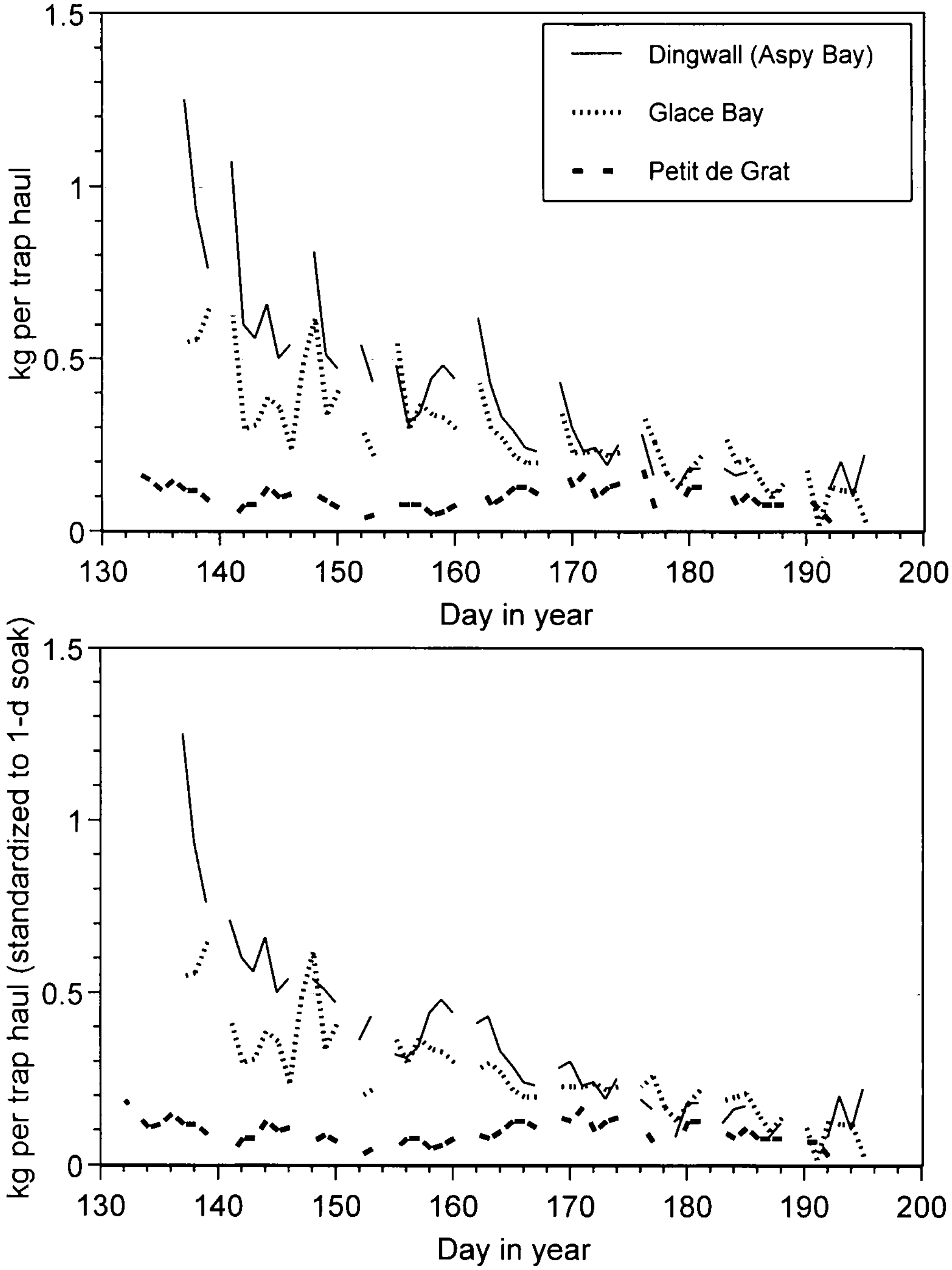


Figure 3. Catch rate (kg per trap haul) for Dingwall (most northerly location), Glace Bay, and Petit de Grat (most southerly location on Atlantic coast). Upper panel is raw catch data, lower panel shows catch rate standardized to a 1-d soak by multiplying by 0.7 those catch rates based on 2-d soak. Two or 3-day soaks (infrequent) occurred after days of no fishing due to weather or a Sunday.

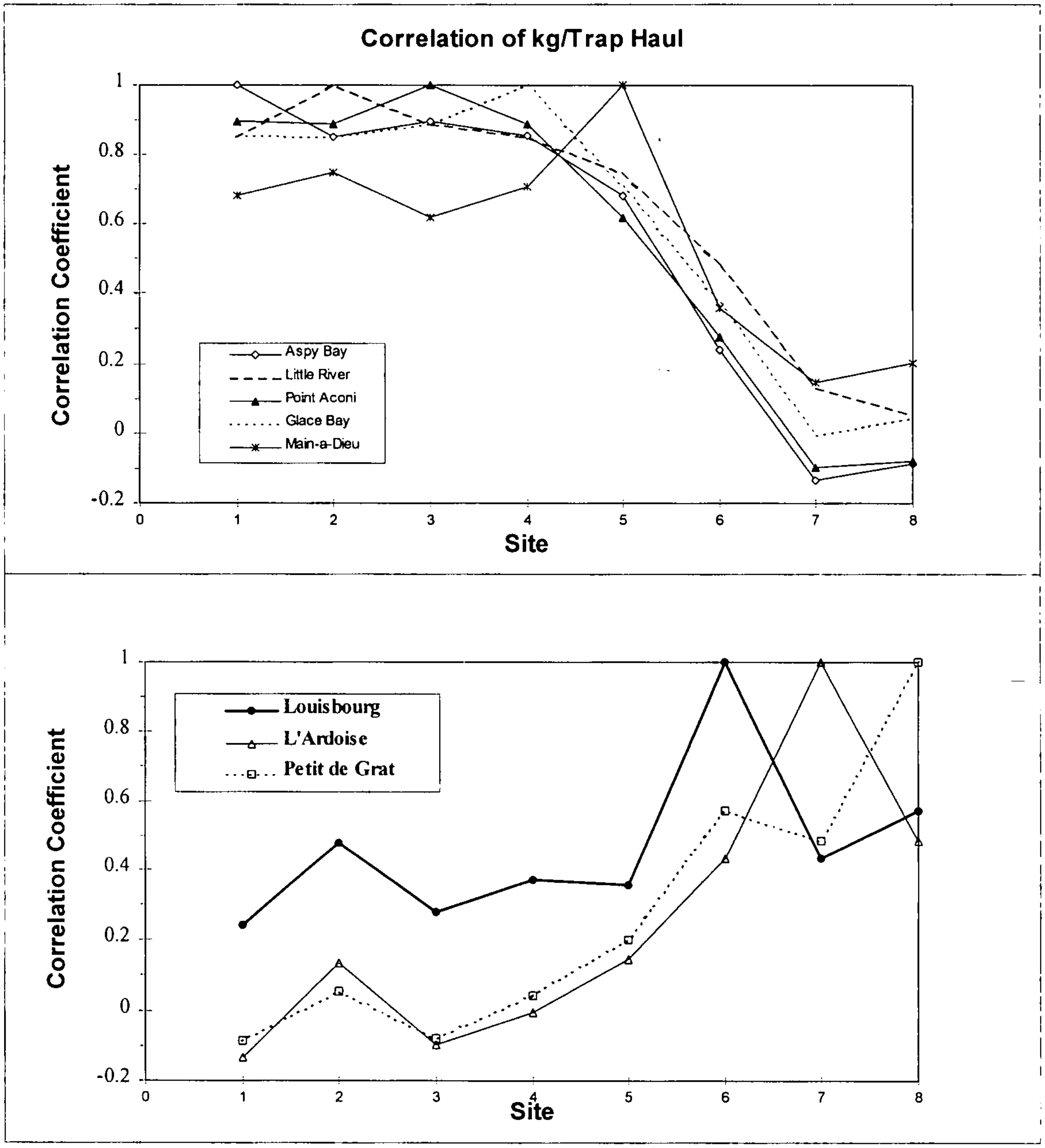
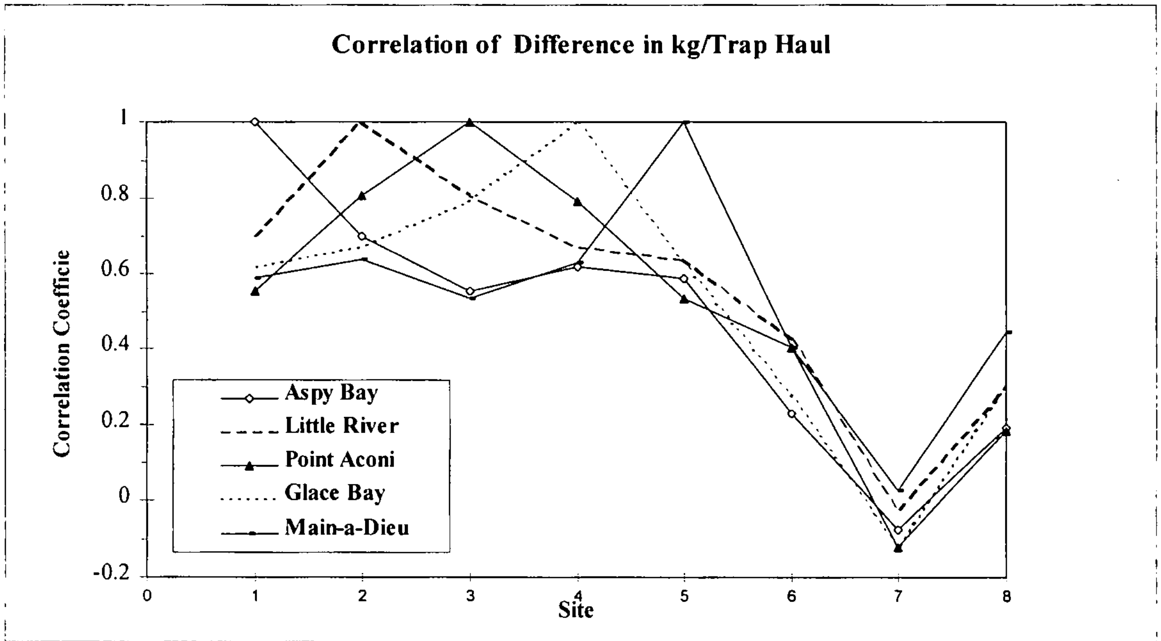


Figure 4. Correlations of catch/trap haul by site with each other site (1-Aspy Bay south to 8-Petit de Grat).



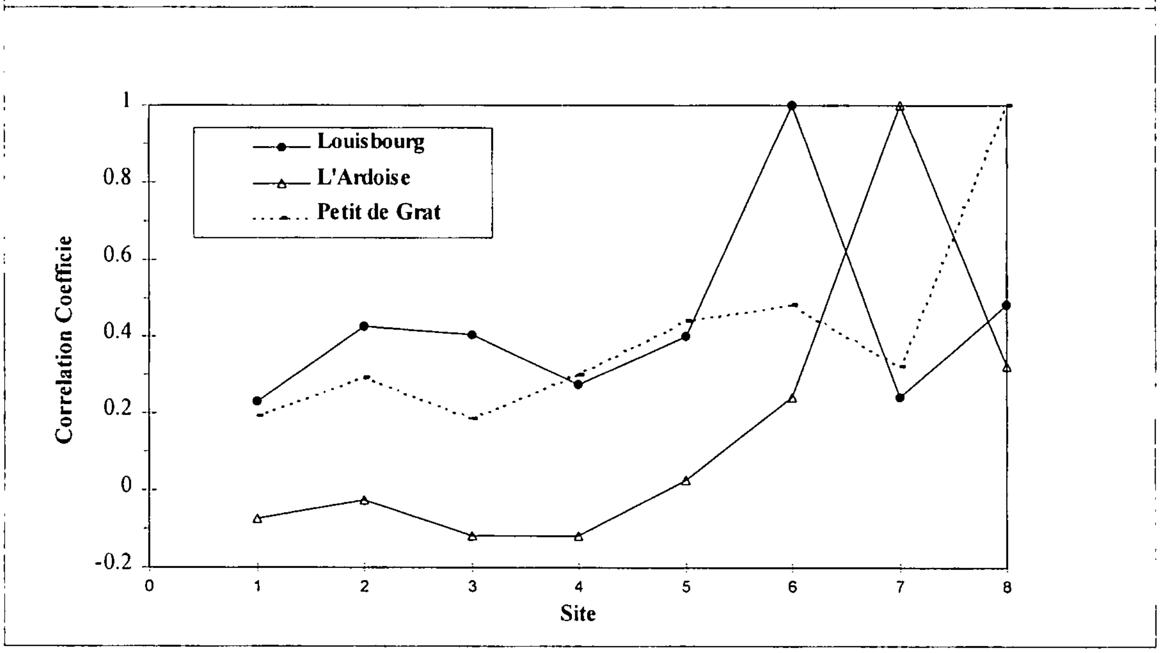


Figure 5. Correlations of first differences of catch/trap haul by site with each other site (1-Aspy Bay south to 8-Petit de Grat).

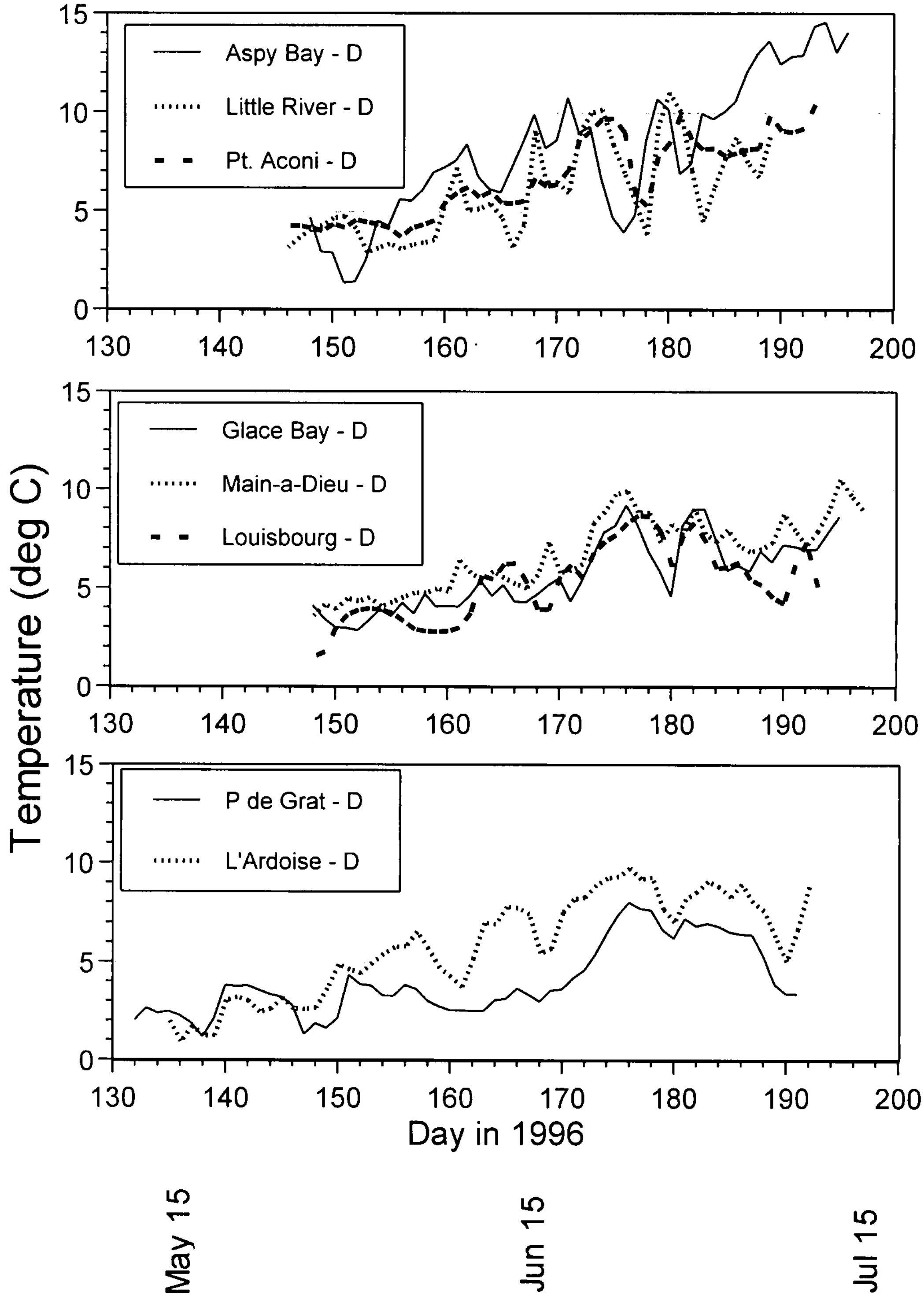
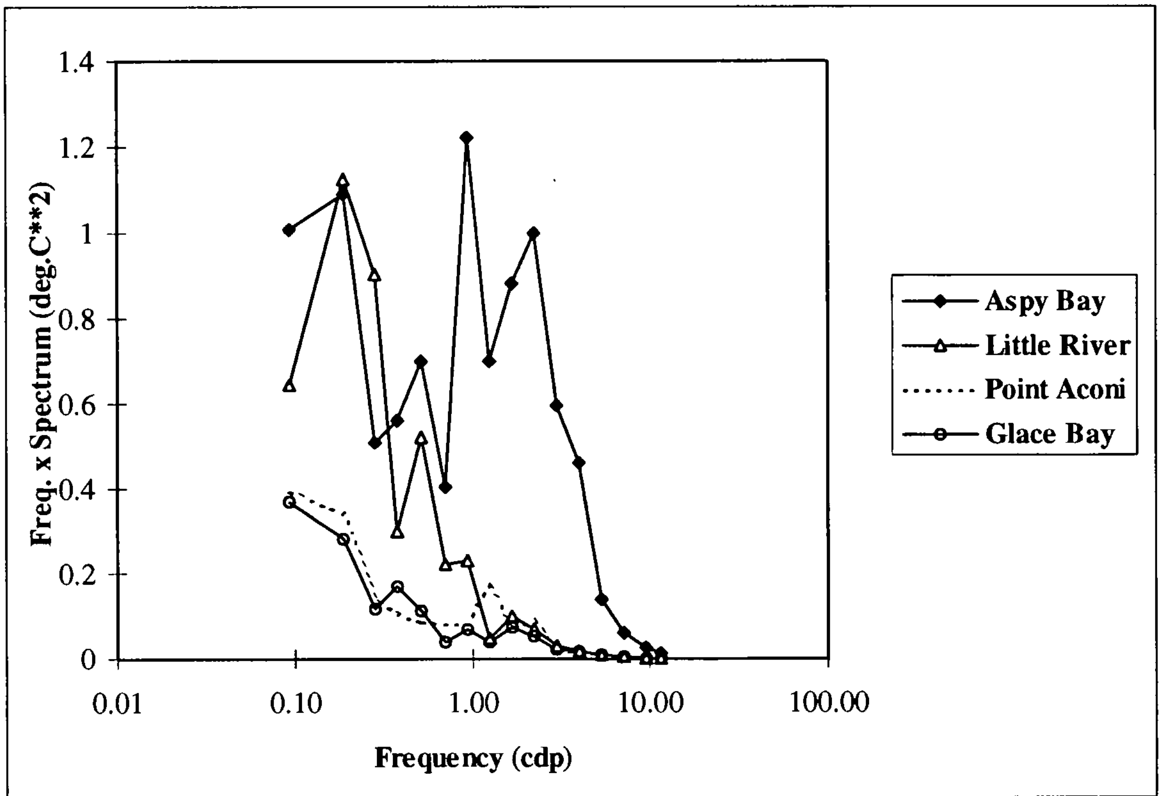


Figure 6. Temperatures measured at depths of 18-22 m during the 1996 lobster fishing season.



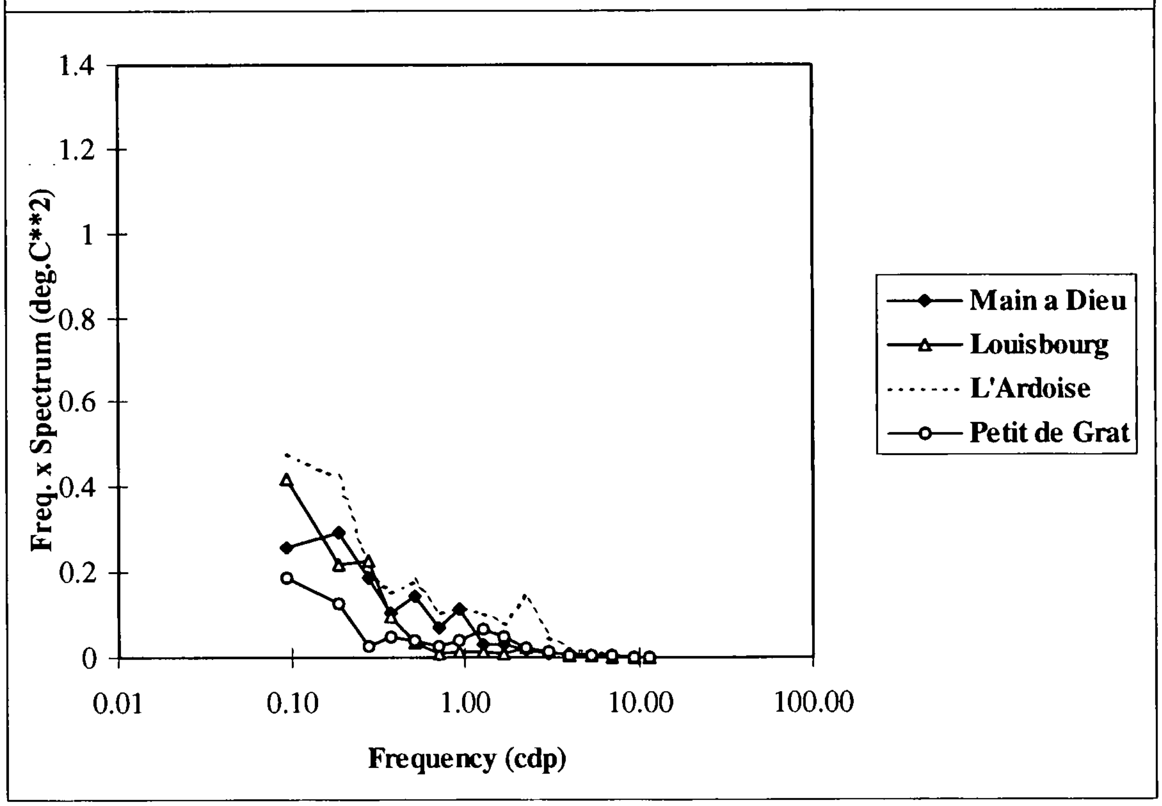
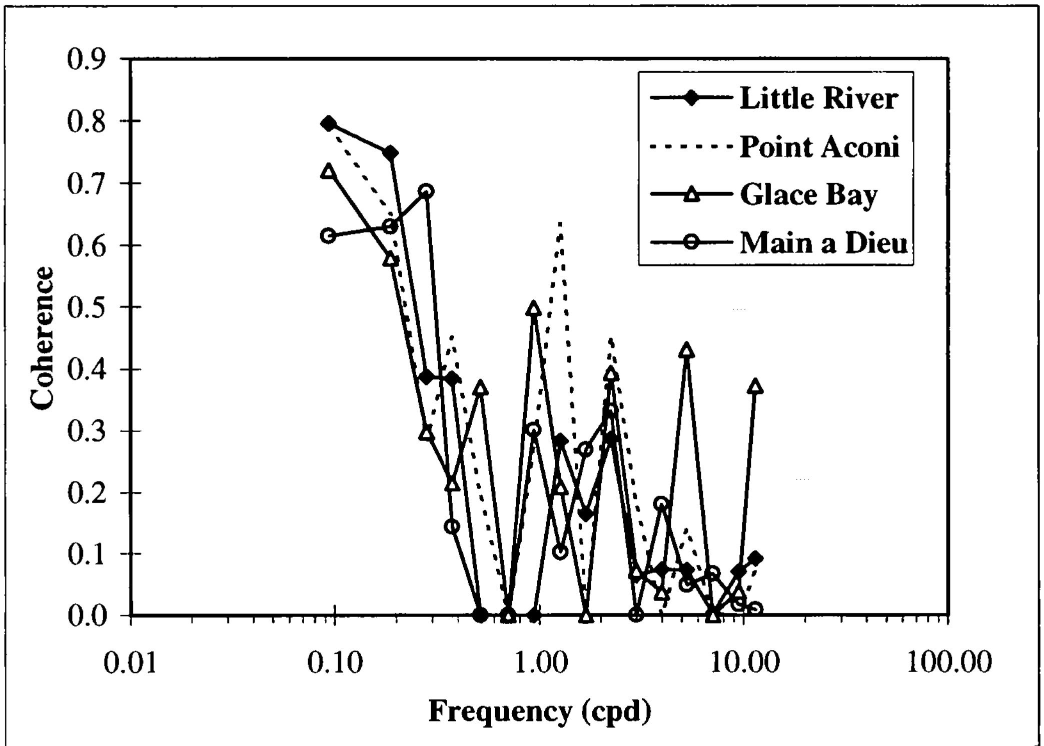


Figure 7. Temperature spectra for different sites during spring 1996. Depth was 18-22 m. cpd is cycles per day; a cpd of 0.2 corresponds to a period of 5 days.



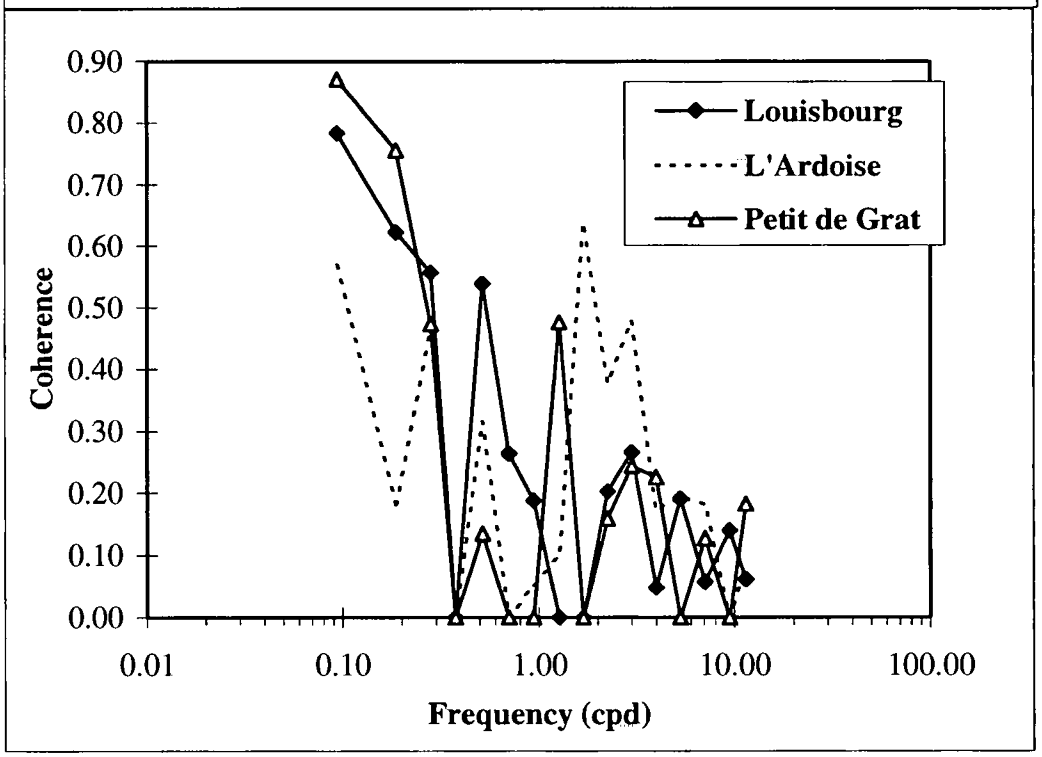


Figure 8. Coherence of temperature between sites relative to Aspy Bay.

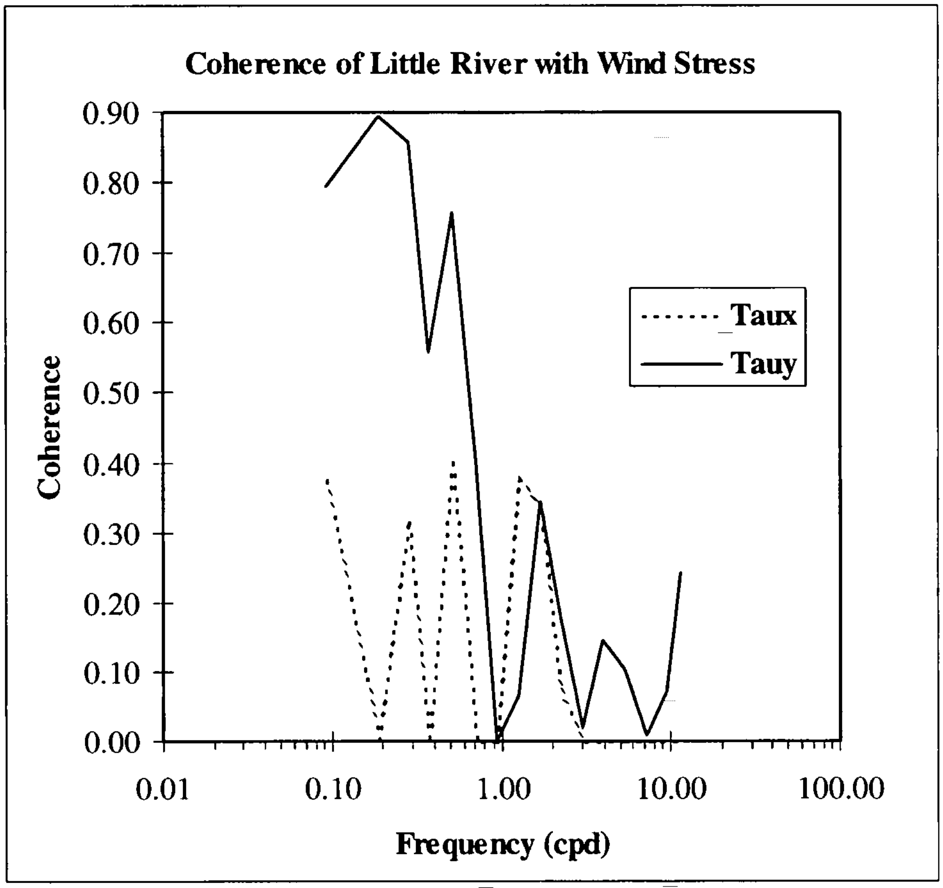
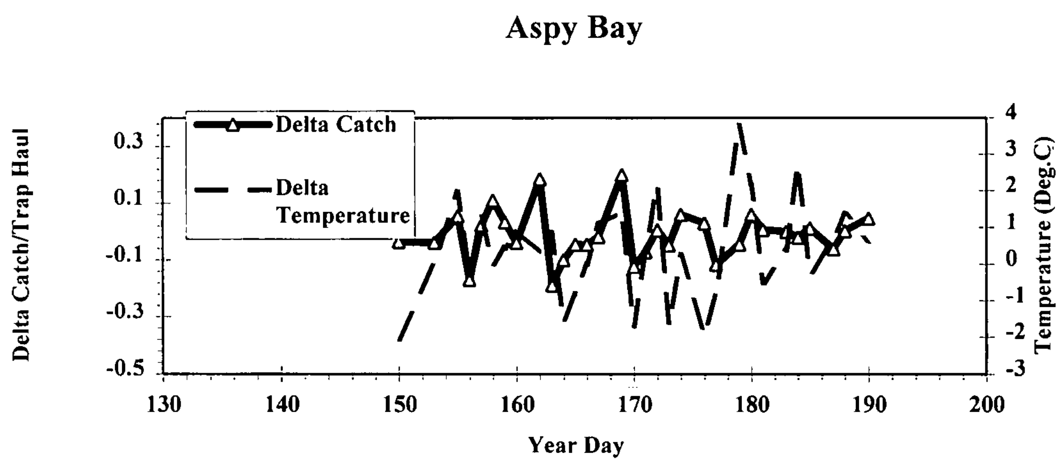


Figure 9. Coherence of Little River temperature with the Sydney wind stress components.



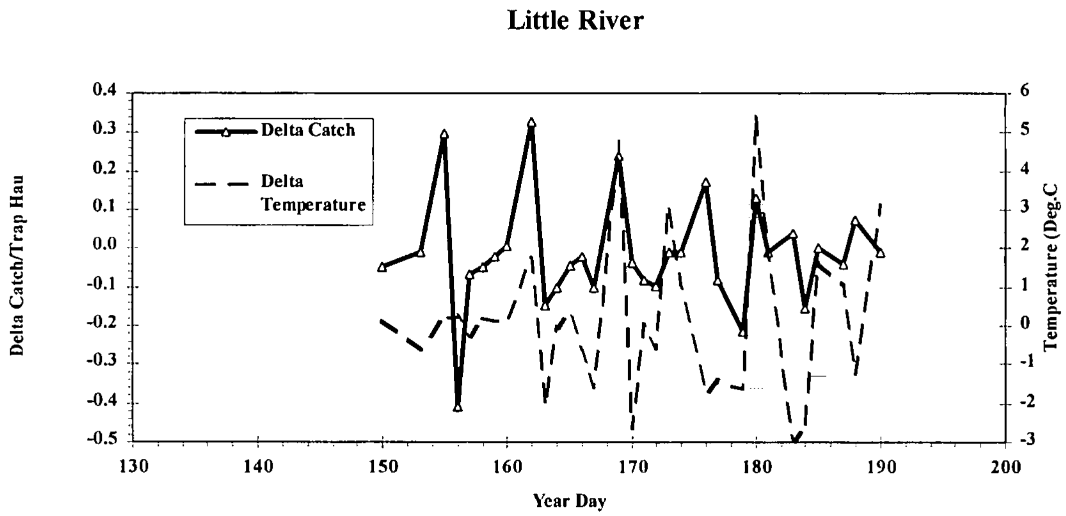


Figure 10. First difference (delta) of kg per trap haul and temperature for Aspy Bay and Little River.

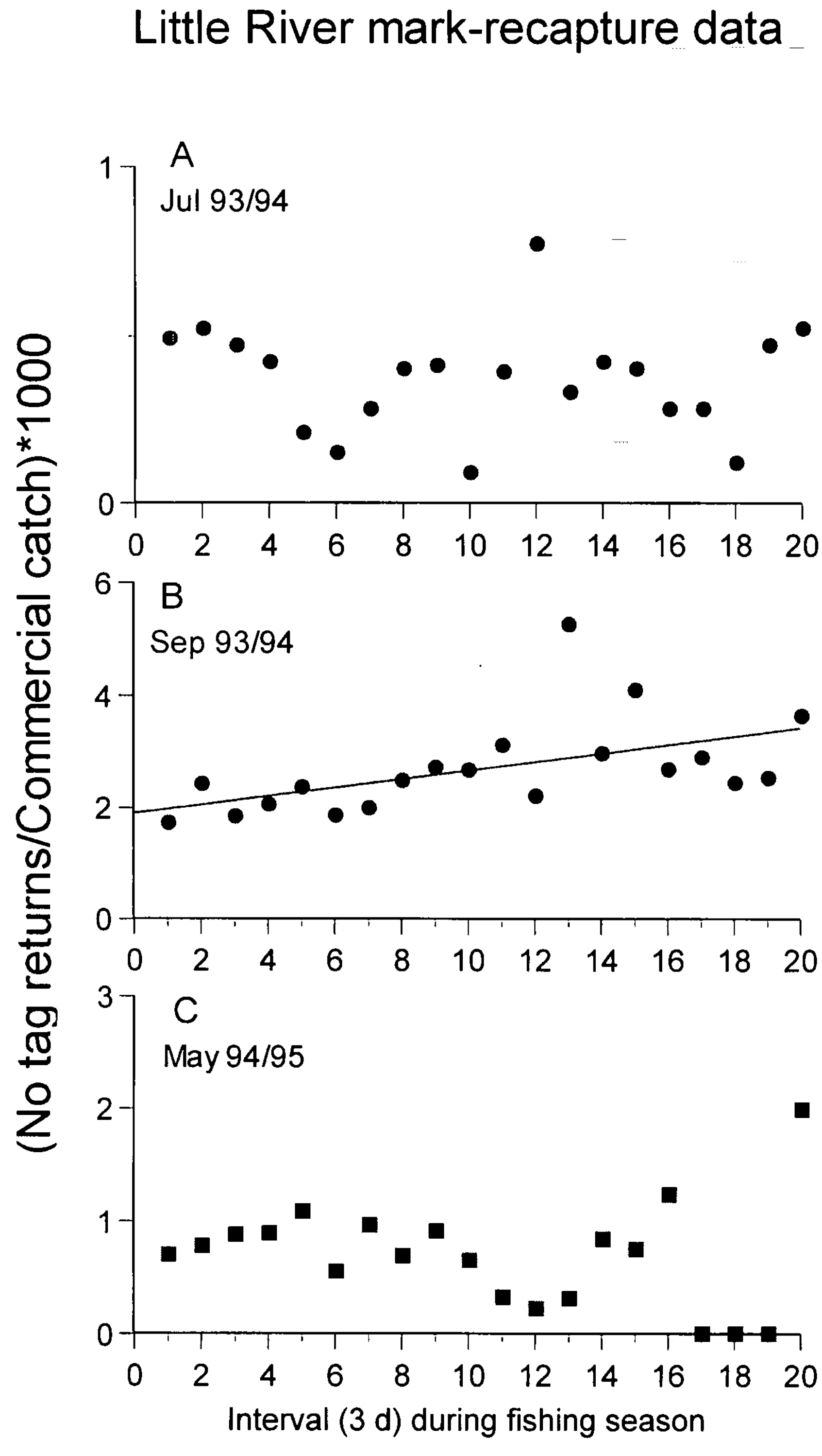


Figure 11. Relative catchability of tagged vs untagged lobsters for mark-recapture studies conducted at Little River. A: Lobsters tagged in July 1993 and recovered during the 1994 fishery; B: lobsters tagged in Sept. 1993 and recovered during the 1994 fishery ($r^2 = 0.29$, $p = 0.02$); C: lobsters tagged in May 1994 and recovered during the 1995 fishery.

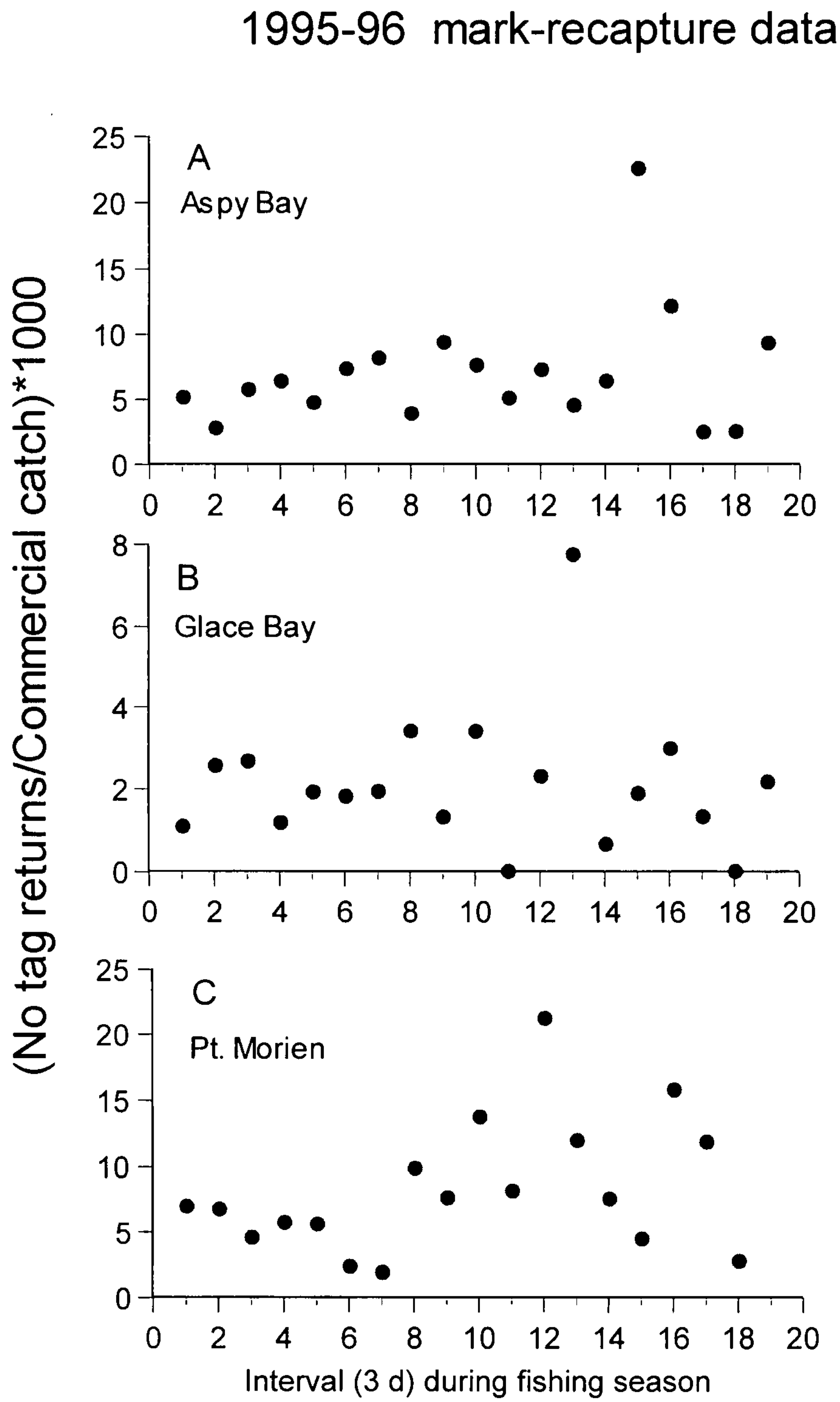
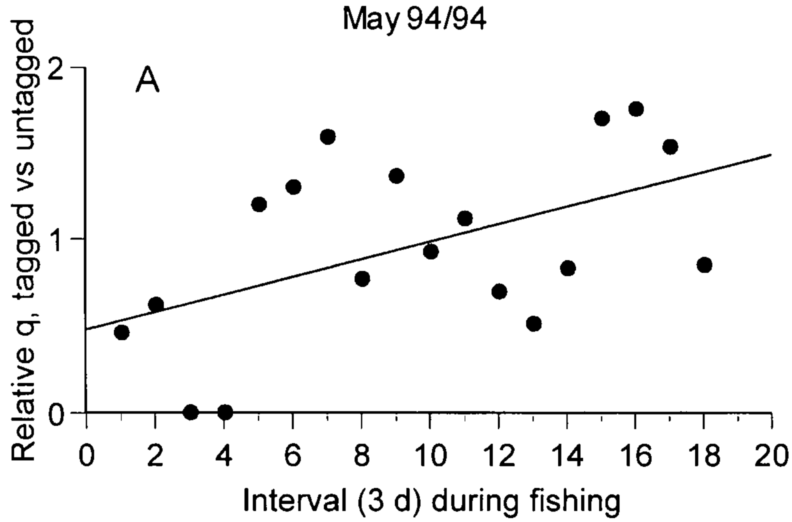


Figure 12. Relative catchability of tagged vs untagged lobsters for lobsters tagged in 1995 and recovered during the 1996 fishery. A: Lobsters tagged in Aspy Bay in July; B: lobsters tagged in Glace Bay in July; and C: lobsters tagged near Port Morien in October.



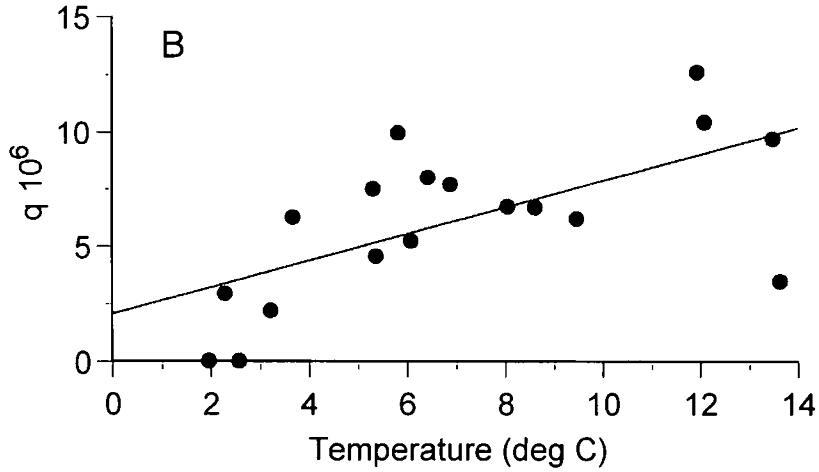


Figure 13. Lobsters tagged in May 1994 and recovered during the 1994 fishing season. A: Relative catchability over the season; B: q versus temperature. Each point represents a 3 day period. Relative q is significantly correlated with interval ($r^2 = 0.26$, $p = 0.03$), as is q with temperature in ($r^2 = 0.40$, $p = 0.005$).

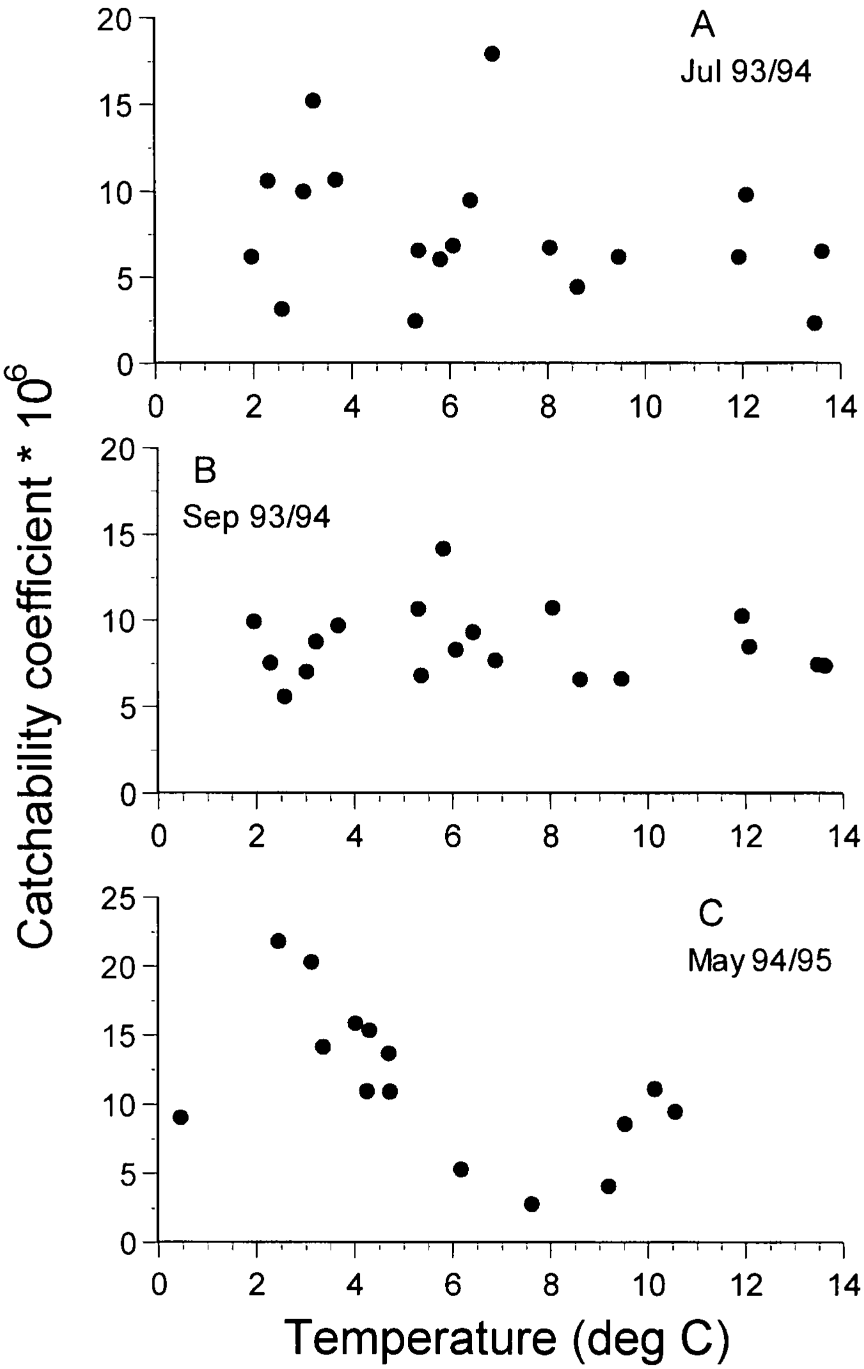


Figure 14. Catchability vs temperature for lobsters tagged at Little River. Each point represents one 3 day interval during the season. A: Lobsters tagged in July 1993 and recovered during the 1994 fishery; B: lobsters tagged in Sept. 1993 and recovered during the 1994 fishery; C: lobsters tagged in May 1994 and recovered during the 1995 fishery.

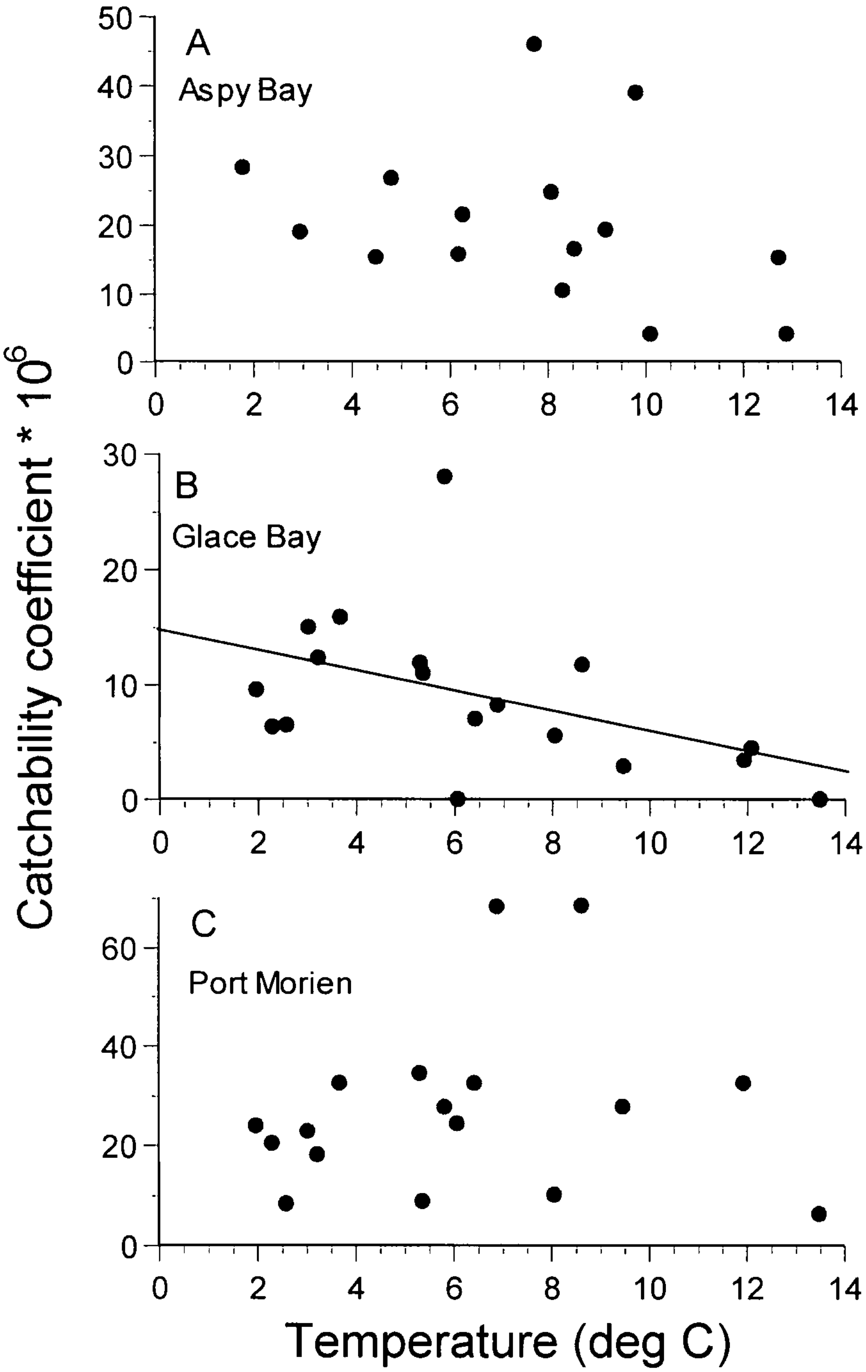


Figure 15. Catchability vs temperature for lobsters tagged in 1995 and recovered in 1996. Each point represents one 3 day interval during the season. A: Lobsters tagged in Aspy Bay in July; B: lobsters tagged in Glace Bay in July; and C: lobsters tagged near Port Morien in October. Regression line in B: $r^2 = 0.21$, $p = 0.06$.