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# Aspects of the biology of northern shrimp *Pandalus borealis* on the Scotian Shelf

by

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Abstract

**Information from groundfish and shrimp trawl surveys, commercial samples, logbooks, an experimental trap fishery and published geological/oceanographic reports were used to determine some basic biological parameters on Scotian shelf shrimp stocks. The main concentrations of *Pandalus borealis* are found on the eastern Scotian Shelf, in the Louisbourg, Canso and Misaine Holes. Secondary concentrations are found inshore off southeastern Cape Breton (The Noodles), on the Scotian Slope near The Gully, in Roseway Basin, in the vicinity of the Fundian Channel and at the head of the Bay of Fundy. Shrimp in the Noodles appear to be relatively isolated, but some degree of exchange with the offshore concentrations takes place via larval drift and migrations of juveniles into deeper water. Most movement is more local: for example, inshore, larger animals move between Chedebucto Bay and the Noodles; offshore, shrimp move into deeper water as they grow; larger animals congregate on the southern edge of the holes. Shrimp on the Scotian Shelf, as elsewhere, undergo an annual reproductive cycle with spawning (egg extrusion) in the late summer-early fall and hatching in the late winter-early spring. Local differences in this cycle are evident, particularly between the inshore and offshore areas. Year class strength varies considerably between the offshore holes. Growth rates appear to be slightly slower on the Scotian Shelf compared to Newfoundland stocks. Growth rates were slightly faster in Louisbourg Hole, which tends to have warmer temperatures.**

Resumé

L'information de relevés au chalut du poisson de fond et de la crevette, d'échantillons commerciaux, de registres de bord, d'une pêche expérimentale à la trappe et de rapports géologiques et océanographiques publiés a servi à déterminer certains paramètres biologiques fondamentaux des stocks de crevettes du plateau néo-écossais. On retrouve les principaux bancs de *Pandalus borealis* dans le secteur est du plateau, notamment les fosses Louisbourg, Canso et Misaine. Des bancs secondaires sont retrouvés dans les eaux côtières du sud-est du Cap-Breton (The Noodles), sur la pente du plateau près de Le Goulet, dans le bassin Roseway, dans les environs du chenal Fundian et à l'embouchure de la baie de Fundy. Les bancs The Noodles semblent relativement isolés, bien qu'un certain échange avec les bancs hauturiers se produisent par le truchement de la dérive des larves et de la migration de juvéniles vers les eaux profondes. La plupart des déplacements sont plutôt de nature locale; par exemple, dans les eaux côtières, les grosses crevettes se déplacent entre la baie Chédaboucto et The Noodles; dans les eaux hauturières, les crevettes se dirigent vers les eaux profondes lorsqu'elles grossissent, tandis que les grosses crevettes forment des bancs sur le bord sud des fosses. Les crevettes du plateau néo-écossais, comme ailleurs, se reproduisent tous les ans; la ponte a lieu vers la fin de l'été et au début de l'automne, et les oeufs éclosent vers la fin de l'hiver et au début du printemps. Le cycle reproducteur n'est pas le même partout, les secteurs côtiers et hauturiers montrant des différences marquées. L'abondance des classes d'âge varie considérablement dans les fosses hauturières. Les taux de croissance semblent être légèrement plus faibles sur le plateau que pour les stocks de Terre-Neuve. Par contre, ils étaient légèrement plus hauts dans la fosse Louisbourg, où la température de l'eau a tendance à être légèrement plus élevée.

## INTRODUCTION

On the Scotian shelf, the northern pink shrimp *(Pandalus borealis)* is the object of a recently established offshore trawl fishery (1995 catches 3100 mt) and a developing inshore trap fishery (Koeller 1995, 1996a). Its biology has not been well documented in this area, although it is relatively well defined in other areas where the species is of commercial importance (Shumway et al. 1985). The object of this paper is to synthesize available and new biological data on Scotian shelf shrimp stocks in order to provide some of the information necessary to manage the fisheries in the area.

Previous studies of migrations, reproductive cycles, growth and other biological aspects from widely distributed locations including the Northwest Atlantic are summarized in Shumway et al (1985) and provide a basis for comparing and interpreting findings on the Scotian Shelf. Of particular interest in this regard are shrimp stocks in the Gulf of Maine and the Newfoundland Shelf which, in addition to being relatively well studied, bracket the Scotian Shelf geographically and in terms of important environmental variables, especially temperature. *Pandalus borealis* is a circumpolar species and is most abundant north of 46°N. South of this parallel i.e. on the Scotian Shelf and in the Gulf of Maine, it is approaching its distributional, and by inference, its physiological and ecological limits. The Gulf of Maine population size fluctuates greatly and is highly dependent on water temperatures (Dow 1981), colder water being associated with population increases, as would be expected for a circumpolar species. Inshore migrations, while reported elsewhere, appear to be pronounced in the Gulf of Maine where older animals, particularly ovigerous females, move inshore into colder water in winter (Shumway et al 1985). Reproductive cycles are well defined for many areas, including those representing environmental extremes. *P. borealis* in all areas spawn once per year, extrude their eggs in the summer/fall and carry them over the winter, with hatching occurring in the spring/summer months (Shumway et al 1985). The time between extrusion and hatching varies with local water temperatures, and is shortest in warmer water such as the Gulf of Maine where eggs are extruded later in the fall and are hatched earlier in the spring than in colder, northern areas. Growth rates are also temperature dependent and are greatest in the southern stocks. The preferred temperature range for *P. borealis* is 0-5°C, but exposure to temperatures below -1°C are lethal (Shumway et al 1985). Other factors which are important in determining distribution include bottom type, depth, and salinity. *P. borealis* prefers soft mud or silt substrates with a high organic content that provide a food source. Preferred depth range is between 50 and 500m, but this varies considerably with latitude and season. The species is considered stenohaline and prefers fairly high salinities, although it has been reported in salinities as low as 23.4‰. Ecologically, northern pink shrimp play an important role in the food chain. They have been identified as a major food source for cod, flatfish, silver hake, redfish and Atlantic halibut (Shumway et al 1985), all of which are of commercial importance on the Scotian Shelf.

## METHODS

Information on the physical environment on the Eastern Scotian Shelf was obtained from several sources. Bathymetric information is available as digitized depth contours from the Canadian Hydrographic Service. The distribution of shrimp habitat can be inferred from surficial geology maps of the ocean floor published by the Atlantic Geosciences Centre (Dep. Energy, Mines and Resources). Information on water currents were obtained from the publications cited. Bottom temperature in areas of shrimp distribution were obtained during DFO shrimp surveys using a reversing thermometers or expendable bathythermographs at the randomly chosen fishing stations. In 1995 temperatures were determined during an industry survey with MINILOG continuously recording electronic temperature probes (Vemco Ltd.) mounted on the trawl doors. Bottom temperature at any location was determined by averaging all temperatures recorded at 20 second intervals during the fishing set. In 1994/95 temperatures were also recorded continuously between November 1994 and March 1996 in Chedebucto Bay at a depth of 100 meters using MINILOG recorders. Probes were attached to shrimp traps and retrieved after several months to download recorded data (recording frequency 30-60 min) and reinitialize recording. This data was summarized as average daily temperatures.

Information on shrimp distribution was obtained from DFO groundfish surveys (Halliday and Koeller 1981) conducted on the entire Scotian Shelf from 1970 to the present, DFO shrimp surveys conducted twice per year (spring and fall) on R.V. *E.E. Prince* from 1982 to 1988 (Mohn and Etter 1988), and industry surveys conducted in 1993 (Roddick 1994) and 1995 (Koeller 1996b). Groundfish surveys covered the entire Scotian shelf once per year (summer) from 1971-78 and 1985-95 and 3 times per year (spring, summer, fall) from 1979-84. In addition, spring coverage of the eastern Scotian shelf has been achieved annually since 1986. Although shrimp are retained by the groundfish survey trawl's small meshed liner (1/4" 1970-79, 3/4" subsequently) the main objective of these surveys was to obtain information on groundfish abundance. While large catches of shrimp were generally recorded, recording of smaller numbers was sporadic. Thus this information can be used to detect shrimp concentrations, but not their presence or absence. Information on the inshore distribution of shrimp was obtained from trapping surveys conducted in 1994-95 using Maine-style shrimp traps (Koeller 1995). This was the only source of inshore information since groundfish surveys do not sample areas inside the 50 fathom contour in most areas and shrimp surveys covered only the offshore "shrimp holes".

Biological information collected on individual shrimp included carapace length, sex, reproductive condition and egg developmental stage. Samples were collected during all surveys and from the commercial fishery, including the offshore trawler fleet and the inshore trap fishery. In general, where possible each sample consisted of a minimum of 500 animals to ensure adequate representation of the catch and separation of life history stages. For surveys, one sample was collected and processed at every random trawl location to ensure equal representation of the entire surveyed area. Commercial samples from the trawler fleet were collected to provide adequate temporal and spatial coverage of the Shrimp Fishing Areas (SFA's) and times. In general, at least 1 sample per fishing area per month was collected throughout the fishery. Samples from the inshore trap fishery were collected at approximately 2 week intervals, sampled randomly from an entire day's catch.

## RESULTS

### Environmental

The study area, including bathymetry, Shrimp Fishing Areas (SFAs) and place names used in the text, is shown in Figure 1. Shrimp distribution maps published in stock assessment research documents usually show only the 100 fathom contour (e.g. Labonté 1980, Mohn 1988, Roddick 1995), as in Figure 1. This is because DFO shrimp survey biomass estimates are based on aerial expansions of stratified mean swept areas, where 3 strata are defined as the areas deeper than 100 fathoms in the three offshore shrimp holes, i.e. Canso, Misaine and Louisbourg. A similar depth-stratified scheme is used for DFO groundfish surveys. The 100 fathom contour gives the impression of numerous isolated holes and masks the complexity of interconnected subglacial river valleys revealed in recent digital renderings of the accumulated bathymetric database (Loncarevic et al 1992). The physical interconnections below 100m between the three main holes, the inshore area between Canso town and Scaterie Island, the Continental slope and the Laurentian channel are apparent in Figure 2.

Surface water in the area is transported in a southwesterly direction by the Nova Scotia current (Figure 3). This current originates from freshwater runoff in the Gulf of St. Lawrence (Sutcliffe et al 1976), and is strongest in late summer-early fall. During late spring and early summer, when the Nova Scotia current is weakest, surface water from as far as 25 miles from shore can be moved toward the coast of Nova Scotia and Cape Breton Island by onshore winds. Bottom water movements toward shore have also been observed in the area (Trites 1979).

The distribution of fine mud, termed LaHavre clay, tends to concentrate in areas deeper than 100 fathoms (183m) in the offshore holes (Figure 3). In the inshore areas it is more widespread in shallow water, including up to 20 fathoms (37m) in Chedebucto Bay. The relatively large amount of inshore shrimp habitat, as depicted by the distribution of LaHavre Clay, is unique to this part of the coast. Southwest of

Canso and within 15 miles from shore mud is restricted to small embayments. North of Scaterie, only one small patch of LaHavre Clay has been identified.

Temperature regimes in the three main holes and the Noodles are given in Figures 4 . Temperatures averaged 3.5°C in the main holes from 1982-95, which suggests that this water is a mixture of the warm slope (generally >5°C) and cold intermediate (<5°C) water described by Smith et al (1978). There was little evidence of strong seasonal changes (i.e. spring to fall) in the deep holes since a repeated pattern such as colder spring and warmer fall temperatures would have been evident in the surveys between 1982-1988 (Figure 4). Monthly means (1919-1982) at 200 m in this area also show relatively little intra-annual variation (range 1.7-3.1°C) but a considerably lower overall mean temperature of 2.5°C (Drinkwater and Trites 1987). There are clear longer term trends which are similar in all three holes i.e. an increase from spring 1982 to fall 1984, a subsequent decrease to spring 1997, an increase until fall 1988, followed by a decrease to the present. The cooling trend in near bottom water on the eastern Scotian shelf from the late 1980's to the mid 1990's has also been noted by Page and Losier (1994). A persistent feature in Figure 4 is the warmer water in the Louisbourg Hole. This area had the warmest mean water temperatures in all surveys except spring 1986, when the Canso Hole had an unusually warm mean temperature. Distribution of temperatures that year shows that this warm water (maximum 7°C) concentrated in the western part of the Canso Hole and may represent an intrusion of warm slope water which had entered the Scotian Shelf from the southwest through the Scotian Gulf. However, it unlikely that the persistent warmer water in Louisbourg hole represents a similar intrusion of Scotian slope water from the Scotian Gulf or the Gully since this would also have resulted in warm water in the Canso and Misaine Holes. A more likely source of the warmer water in Louisbourg hole is the Laurentian Channel (1919-1982 average annual temperature at 200 m = 4.8°C, Drinkwater and Trites 1987).

In contrast to the relatively constant offshore environmental conditions, inshore temperatures fluctuate seasonally (Figure 5). Temperatures on the inshore shrimp grounds in Chedebucto Bay (100m) are warmest in the late fall when they can approach 5°C (mean 2.8 and 3.2°C for December 1994 and 1995, respectively) and coldest in the early spring when they approach -1.0°C at times (mean 0.5 and 1.1°C for March 1995 and 1996, respectively). The inshore is also characterized by short-term swings in temperature which can increase or decrease temperatures by as much as 4°C in a matter of days. In general these short term changes decrease temperatures in the winter and increase temperatures in the fall, presumably due to wind induced mixing of the surface and deeper layers. These changes are absent in the summer when winds are light and the water is thermally stratified.

Distribution

Cumulative plots of station locations during the 26 years of DFO groundfish surveys is given in Figure 6. Spatial coverage is excellent from 50 to 200 fathoms (91 to 366m) and temporal coverage included 26 summer, 17 spring and 6 fall surveys. Cumulative plots of all shrimp catches recorded during these surveys (Figure 7) clearly outline the large offshore concentrations on the eastern Scotian Shelf and the smaller inshore concentration in the vicinity of the Noodles. Smaller, less coherent concentrations are evident in the Gully and the adjacent Scotian Slope, the 3 large basins on the central Scotian Shelf, especially Roseway Basin, the Georges Bank/Fundian Channel/southwest Brown's Bank area, and in the Bay of Fundy. A detailed plot of the eastern Scotian Shelf, including sets for which there were no shrimp recorded (Figure 8) shows that the concentration in the Noodles is isolated from the main concentrations to the south and northeast. However, it is possible that shrimp were present in smaller quantities in the large area between these concentrations, but were not recorded.

Inshore distribution from shrimp trap catches i.e. in areas not covered by the groundfish surveys, is given in Figure 9. Despite over 3600 trap hauls completed during an experimental trap fishery between July, 1995 and February 1996, there were no catches of *P. borealis* in areas other than in Chedebucto Bay and on the northwest edge of the Canso Hole. The area between Scaterie and Northern Cape Breton i.e. Sydney Bight, was not fished with trap gear, but was relatively well covered by groundfish surveys (Figure 6) which show no shrimp concentrations in this area. Thus, results from both inshore trap and offshore trawl surveys indicate that inshore shrimp concentrations are restricted to the shoreline closest to the offshore concentrations, ie. the area between Whitehead on the eastern shore, and Scaterie Island.

Distribution by depth and temperature from DFO shrimp surveys is given in Figure 10. These data are not particularly informative because of the restricted survey area (i.e. > 100 fathoms) and the resulting narrow dynamic range with which to determine temperature and depth preferences. Most large catches occurred between 100 and 150 fathoms. However, significant catches were recorded in water as shallow as 60 and as deep as 200 fathoms. Similarly, most catches were made between 1 and 5 °C, but significant catches still occurred as low as 0.3 and as high as 6°C. The highest catches appeared to occur between 0.5 and 3°C. Distribution by depth and carapace length (Figure 11) indicates differential size distribution by depth in both spring and fall, with smaller animals found in the shallower depths. The slopes of the regression lines between spring and fall in the accumulated data are not significantly different. This suggests that differential size distribution by depth is more of an ontogenetic, rather than a seasonal phenomenon. The steeper slope of the line in the fall may reflect slightly more movement during the summer growing season.

Distribution of sizes and life history stages by area

Mean carapace lengths by SFA during the 1980's (Figure 12) indicate that the Louisbourg Hole (SFA 13) generally had the largest animals, both spring and fall, until 1987 when the Misaine Hole (SFA 14) animals were larger. This apparently persisted until 1995, when Louisbourg hole again had the largest animals. Also apparent in Figure 21 is the relatively small size of the animals in the Noodles in 4 of the 5 years in which this area was sampled. A more detailed picture of distribution by size in the Canso/Misaine Holes area can be obtained from "counts" (number of animals per pound) reported in logbooks by the trawler fleet (Figure 13). This indicates an accumulation of larger animals (i.e. lower counts) in the Big Hole area. These results corroborate anecdotal information obtained from fishing captains, who indicated that the Big Hole has been intensely fished during the last two years because of a combination of relatively high catches, low counts, and short distances from landing ports. Larger animals in Louisbourg Hole have also been noted by some fishing captains (R. Schrader, personal communications). In addition, many captains indicate that shrimp are larger in the southern edge of the holes. Plots of commercial counts/pound by Latitude in the Canso/Misaine Holes area (Figure 14) do not show a strong north/south trend, however, the regressions for all 3 years are significantly greater than zero (P>0.0001). The lack of a strong trend may be due to inaccuracies in reporting positions, and to the fact that many commercial sets are many hours long and can cover a large part of any hole. A more informative picture of distribution by size categories is seen in a cross section of survey trawl samples taken in June 1995 from within 2 miles of shore in Chedebucto Bay to the southern edge of the Big Hole (Figure 15). In June, shrimp in Chedebucto Bay consisted mainly of males and smaller animals, with very few transitionals and females. Catches in the experimental trap fishery, which exploits mostly transitionals and females, had dropped to zero at this time, apparently due to emigration of these animals from the area. Very low i.e. approaching lethal, water temperatures (Figure 5) coincide with the drop in trap catches and probably precipitated this emigration. Transitionals and females, probably originating from Chedebucto Bay, increased in proportion further from shore and reached a maximum in the mid Noodles area (Figure 15). Still further from shore, transitionals and females drop off again until midway between the Noodles and the Big Hole where juveniles and immature males predominate. In the Big Hole itself shrimp increased in size from north to south, as predicted by anecdotal information. The north was dominated by juveniles and immature males, while the south consisted mainly of males and females, but all stages were present in all areas. Juveniles, immature males and males were larger in the mid part of the hole, suggesting that smaller animals also move south, but not as far as transitionals and females.

Reproductive cycle

The percentage of animals with head row, percentage of females bearing eggs, and the egg maturation index for bimonthly periods from November 1994 to November 1995 for Chedebucto Bay and the offshore holes is given in Figure 16. Sampling for an entire year clearly shows a single spawning per year which differs slightly for inshore and offshore animals. Egg extrusion began at about the same time both inshore and offshore in late June-early July 1995. Offshore, extrusion was completed by August, while inshore this continued until September. There was a large difference in the percentage of ovigerous females between areas in both years. Offshore, more than 90% of all females became ovigerous during both years. Inshore, only about 70% were ovigerous in 1994-95, and this dropped to a maximum of only 40% in 1995/96. Inshore, the percentage of ovigerous females changes during the ovigerous period. For example, the percentage increased during the fall/winter 1994/95 until just prior to egg release, and decreased during the same period in 1995/96. These changes were not due to extrusion and egg release, respectively, since eggs continued to mature steadily during the former period and were not mature enough for release in the latter period. Within and between year changes in the percentage of ovigerous females inshore are probably due to local movements, however, the role of the trap fishery in the decrease in the percentage of ovigerous females between years should not be overlooked. Another notable difference between inshore and offshore is the earlier release of eggs inshore. This occurred in February 1995 inshore but not until April-May offshore. The earlier release of eggs inshore is mirrored in the appearance of head roe (Figure 16, top).

The percentage of each life history stage, including females which had not spawned previously (primiparous) and those which had (multiparous) is given in Figure 17 for both areas. This figure must be interpreted with caution because of the greatly differing selectivity patterns of the sampling gears used between inshore (traps) and offshore (trawls). Thus the larger percentage of juveniles, immature males and males in the offshore throughout is due to the smaller selectivity pattern of shrimp trawls, while traps generally retain mainly transitionals and females (Koeller et al 1995). Inshore, notable changes in population structure included an increase and subsequent decrease in multiparous females in the late fall-winter 1994-95 which was probably due to immigration-emigration of ovigerous females as noted above. Also apparent are sequential and corresponding changes in the percentage of successive stages which may be due to growth. Thus, decreases in males from November to June coincide with increases in transitionals, and a decrease in transitionals during June-July is followed by an increase in females. A concurrent decrease in transitionals and increase in females is also evident offshore. Inshore, the large increase in males beginning in June is probably due to growth of younger stages into sizes which enter traps. A notable difference between the inshore and offshore is the slow but steady increase in multiparous females throughout the spring, summer and fall inshore, which may be due to continuous immigration during this period, and the sharp increase in multiparous females in July offshore due to egg extrusion.

Year-class strength

A variation of deviation analysis (Skúladóttir 1979) was used to facilitate comparison of year-class strengths between SFA's, as well as identify above average year classes from 1982-88 (Figure 18). Most, but not all identified year classes (i.e. 1979, 80, 81, 83, 85) appeared in all three areas. In addition, some year classes were stronger in some areas, and appeared or disappeared at different times. Thus, the 1979 year class was prominent in SFA 14 but hardly identifiable in other areas. The 1980 year class was strongest in SFA 13 but relatively weak in the other areas. The 1983 year class was strongest in SFA 14, followed by SFA 13 and 15. The 1985 year class appeared first in SFA 15 during spring 1986, was not prominent in SFA 13 until spring 1987, and was hardly identifiable in SFA 14. The 1981 year class was strong in all three areas and was used to determine growth rates during the 1980's (see below). Also evident in all areas was the joining of the 1981 and 1980 year-class modes after 1984 due to "bunching up" of year-classes at older ages, a feature of shrimp length frequencies which complicates identification of year-classes (Fréchette and Parsons 1983).

Growth

Growth between 1982-88 was determined by averaging the positive deviations of the 1981 year-class from deviation analysis, independently for each SFA. Another estimate was obtained from the 1995 survey samples by separating length frequencies into life history stages, with the difference between successive stages (i.e. juveniles, immature males, males, transitionals, primiparous females and multiparous females) assumed to represent a year's growth. Results from both methods are relatively similar during the first two years of growth (Figure 19), but after this the deviation method produced lower growth. This may be due to higher growth rates during the early to mid 1990's relative to the 1980's, or to a problem with one or both of these methods. The deviation method would be more representative of actual growth if not all males become transitionals, and not all transitionals become females in the same year. The stage separation method indicates higher growth rates offshore than inshore. The deviation method indicates higher growth rates in SFA 13 relative to the other two areas after the fourth year, which may be due to the warmer temperatures in this area (Figure 4). Growth rates in Figure 19 (top) determined by either method are between those recorded for the Gulf of Maine and Newfoundland, as might be expected in an area with intermediate environmental conditions. Unfortunately, the rate of growth on the Scotian Shelf during the first year could not be determined from available data, and the mean size of the smallest mode is questionable because of gear selectivity. Only Parsons et al (1986) have determined growth of larvae and juveniles during the first year, so their 12 month estimate must be considered accurate. Because growth on the Scotian Shelf after the first year is the same or slower than the Newfoundland stocks, it seems unlikely that growth during the first year was over twice as fast. Consequently, it is probable that the first identifiable mode in the survey data represents two, not one, year old animals. This would produce growth curves as depicted in Figure 19 (bottom), indicating that growth on the Scotian Shelf is slower than on the Newfoundland Shelf. In this case, the nominal year-classes identified in Figure 18 and mentioned in the text are 1 year less than the actual year of birth.

Length-weight relationships are compared for the inshore and offshore in Figure 20 for November 1994, and April and May 1995. The slope of the regression for the inshore sample in November is significantly lower ($P>0.05$) than the offshore sample, but the data may not be directly comparable because inshore samples were measured only to the nearest 10th of a millimeter. The April samples were measured in the same manner (i.e. nearest 1/100th mm) and the slope of the regression lines from the inshore sample is also significantly lower ($P>0.05$). The difference in the slopes of the May samples was not significant. The lower slope for inshore animals suggests a poorer condition, which would be expected for animals with slower growth rates as described above.

<u>Changes in abundance</u>

Changes in shrimp density from spring to fall offshore, and trap catches from fall 1994 to winter 1995/96 inshore were examined for patterns which would indicate movements between these two areas (Figure 21). There were no recurring patterns in the offshore holes from 1982 to 1988 which would suggest large scale immigration/emigration. Long term abundance trends masked any interannual patterns, if present. The most remarkable event in Chedebucto Bay during the sampling period was the large decrease in catches during the spring of 1995 which has been attributed to emigration due to cold water temperatures as noted above, and competition with snow crabs (Koeller et al 1995). The larger shrimp returned again by late July-early August, when water temperatures were rising, decreased for a short period in October-November and appeared to increase throughout much of the winter, probably due to immigration, as noted above under "reproductive cycle".

## DISCUSSION

A <u>hypothetical</u> summary of *Pandalus borealis* movements on the Scotian Shelf, as deduced from the results presented above, is shown in Figure 22. This and other aspect of biology are summarized below.

Spawning is an annual event that occurs about the same time inshore and offshore i.e. beginning in late June-early July, with completion by August-September. Eggs are carried over the winter, and are released as larvae in late winter-early spring, depending on location. Egg release is earlier inshore where conditions (temperatures, food availability) favour egg development. Inshore migration of females may be advantageous because the resulting longer growing season before the first winter as juveniles increases survival. Females carry their eggs for about 7-8 months inshore and 8-9 months offshore. Shrimp larvae found offshore in the surface layers in spring are transported in a southwesterly direction by the Nova Scotia Current, but also inshore by wind driven currents during spring. Thus, some of the shrimp found inshore originate from offshore spawnings. Some offshore larvae are also moved further offshore at this time to settle on the Scotian slope or beyond where the species' wide depth range facilitates survival. The larger animals and lower catch rates in Louisbourg Hole result from warmer temperatures and a net transport of the population out of the area as larvae. In addition, some larvae are moved toward the southwest, where they contribute to the relatively small populations found in Emerald and LaHavre Basin. As animals grow they gradually move into deeper water - those originating from spawnings in Chedebucto Bay move offshore toward the Noodles, those originating from the Noodles move further offshore toward the Big Hole, and those originating in the offshore holes, including the Big Hole, move into deeper water there. Most movement occurs within the inshore and offshore zones, with relatively little movement between these areas because of a break in their preferred habitat of fine mud (La Havre Clay) with high organic content. Shrimp, especially the larger animals, also move seasonally in their immediate vicinity, in winter to shallower water, in spring to deeper water. Nearer to shore, as in the Canso Hole and in the Noodles, movement into shallower water will bring animals very close to shore, which happens in Chedebucto Bay and on the Eastern Shore off Whitehead. Local movements in the offshore holes revolve around the Big Hole, which forms a bathymetric crossroads for animals closely associated with the bottom. From the Big Hole, channels lead north toward the Noodles, south toward the Gully, and east and west toward the Canso and Misaine Holes. Shrimp can move toward the Big Hole from the Noodles, and the Canso and the Misaine Holes, resulting in an accumulation of larger animals in the Big Hole. Within the Big Hole, the largest shrimp move toward its southern edge , and some move further toward the Gully. Year class strength varies between the offshore holes depending on varying local factors which can affect larval survival. These include oceanographic conditions (temperature and currents) and predation. Year class strength also varies with time, presumably due to similar influences on survival. Growth rates also vary between areas and years, largely due to differences in temperature.

The above synthesis has a number of weaknesses which will require additional research to elucidate. The timing of key events in the reproductive cycle such as egg extrusion and egg release, while in general agreement with results from other areas (Shumway et al 1986) is based on only one complete and one partial annual cycle and does not account for interannual variability which may delay or accelerate events by several weeks or even months, perhaps differently in different areas from year to year. Inshore/offshore migrations as well as local movements between deep and shallow water, although relatively well documented elsewhere (Shumway et al 1986) are necessarily deduced indirectly using such methods as seasonal distribution maps, comparison of changes in abundance between areas, and interpretation of length frequencies, rather than direct methods such as tagging. Consequently the above interpretation of movements is hypothetical. The available data would not, for example, detect large movements of animals between the Noodles and the offshore holes between the spring, summer and fall groundfish surveys. Thus the degree of exchange between these areas, while probably small, remains open to question until additional survey coverage of inshore areas, and in the areas between the inshore and offshore holes, is conducted. Deviation analysis and stage separation produce different growth curves so the interpretation of these data requires refinement and comparison with other available methods (e.g. modal analysis). The unexpected slow growth of Scotian Shelf shrimp relative to the Newfoundland shelf is puzzling and requires verification. In the presence of significant fishing pressure, the interpretation of temporal changes in any population as a natural phenomena must always be approached cautiously. For example, while the lower percentage of ovigerous females in Chedebucto Bay is consistent with inshore migrations of ovigerous females and emigration of younger animals, it is also possible that this lower percentage is due to removal of ovigerous females by traps, especially since this percentage decreased further in the second year of the new fishery.

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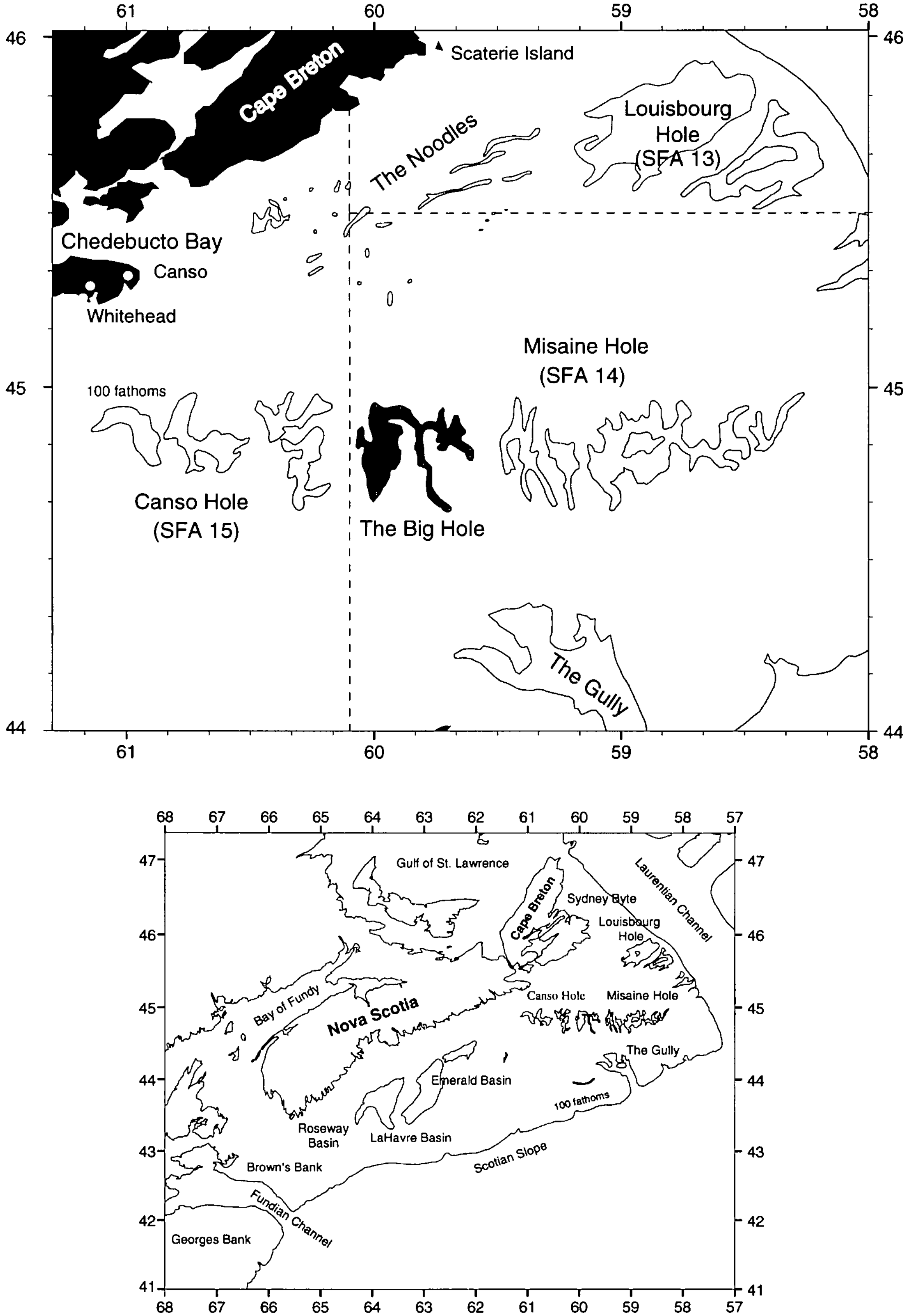



Figure 1. Shrimp Fishing areas on the Eastern Scotian Shelf and place names used in the text.

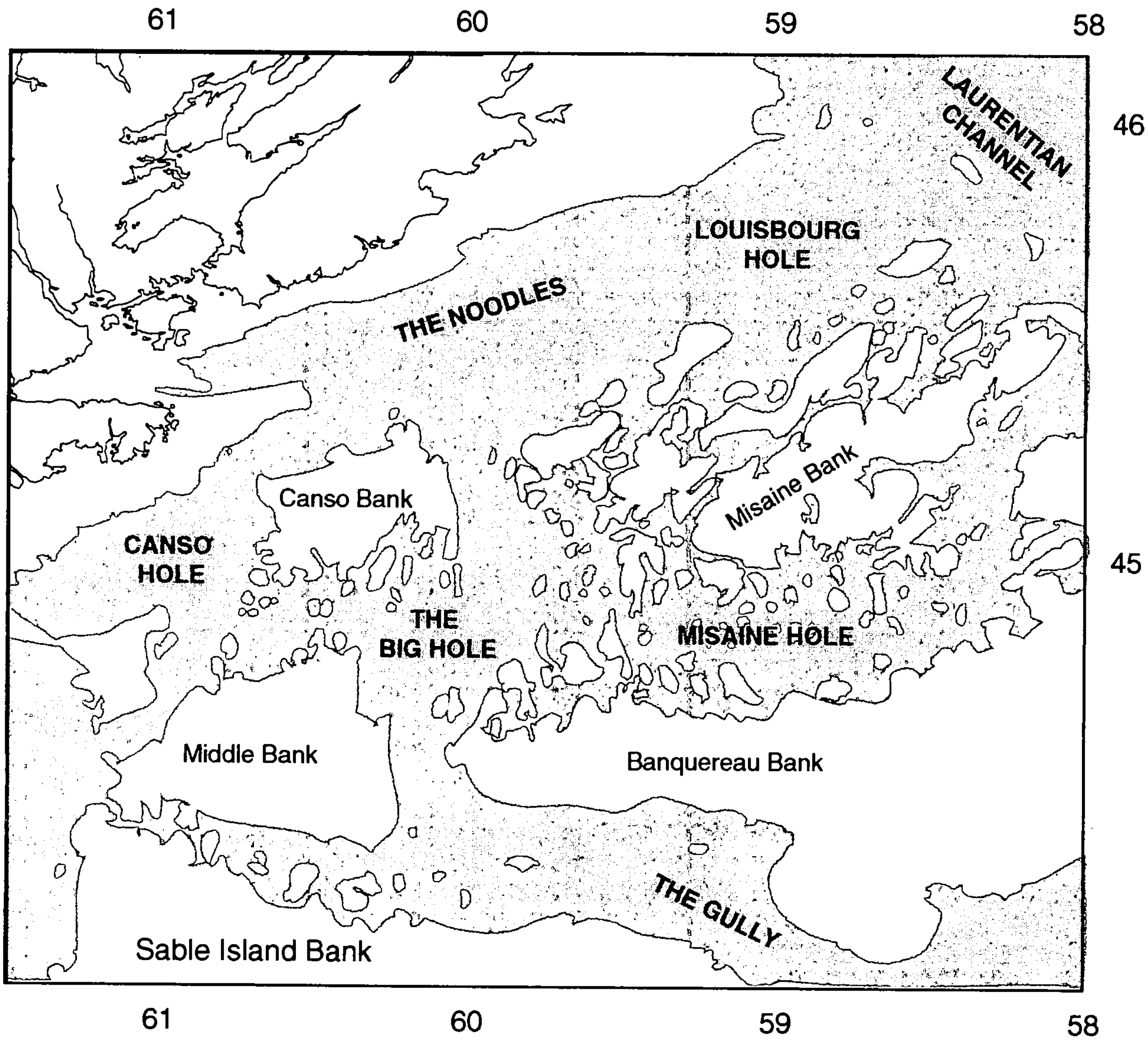



Figure 2. Eastern Scotian Shelf showing place names and areas deeper than 100 meters (shaded).

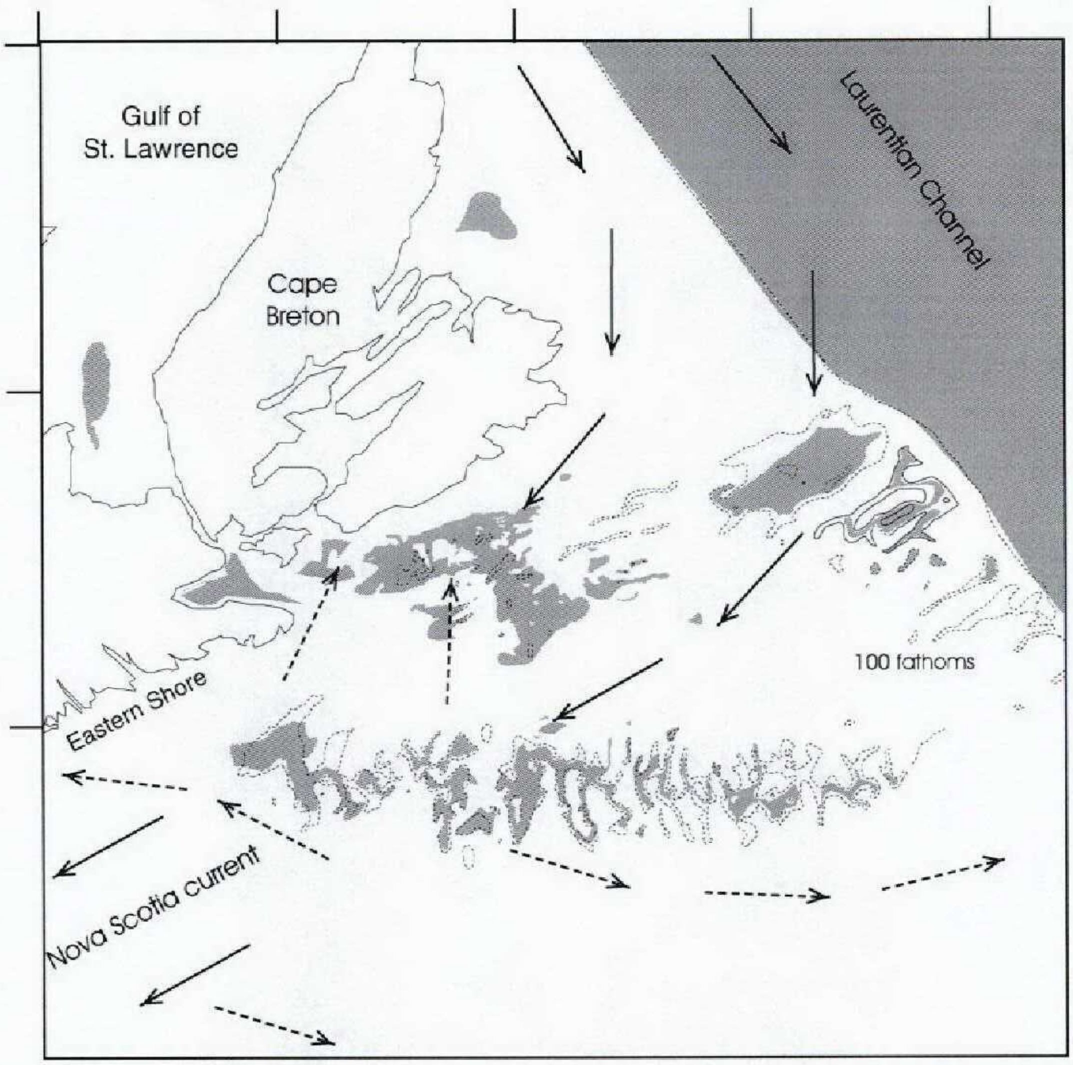



Figure 3. Residual (solid arrows) and wind-driven (dashed arrows) surface currents on the eastern Scotian Shelf. The distribution of fine mud, termed LaHavre clay on the Scotian Shelf and pelite in the Gulf of St. Lawrence, is also shown (shaded).

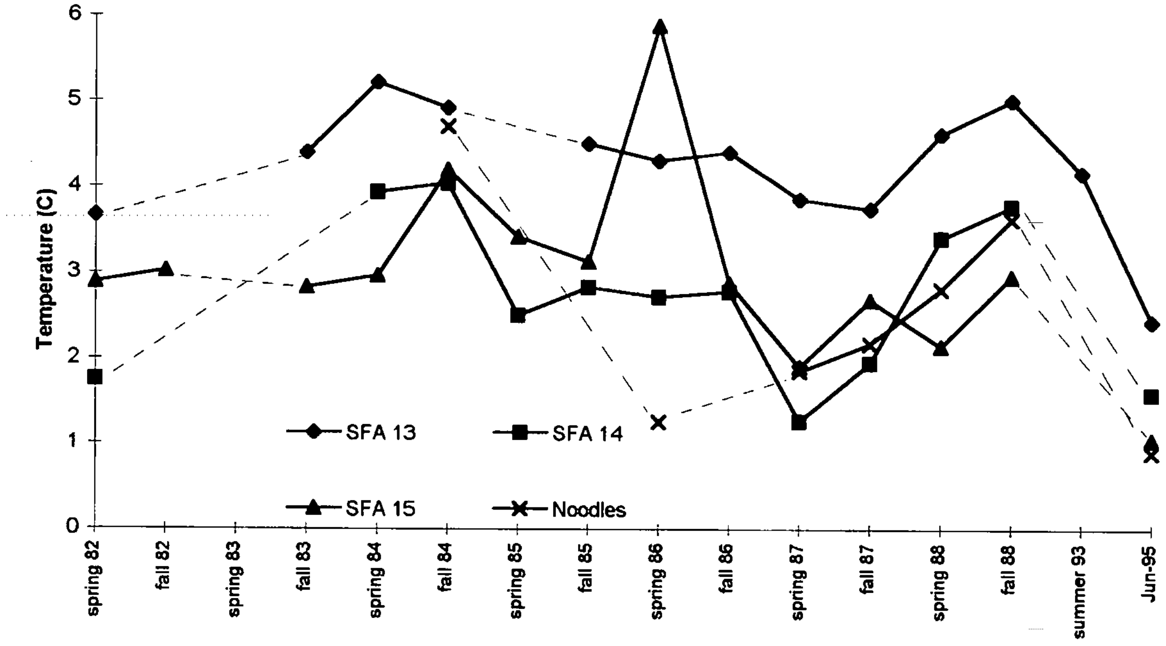



Figure 4. Spring and summer bottom temperatures in the offshore shrimp holes and in the Noodles from DFO shrimp surveys conducted between 1982 and 1995.

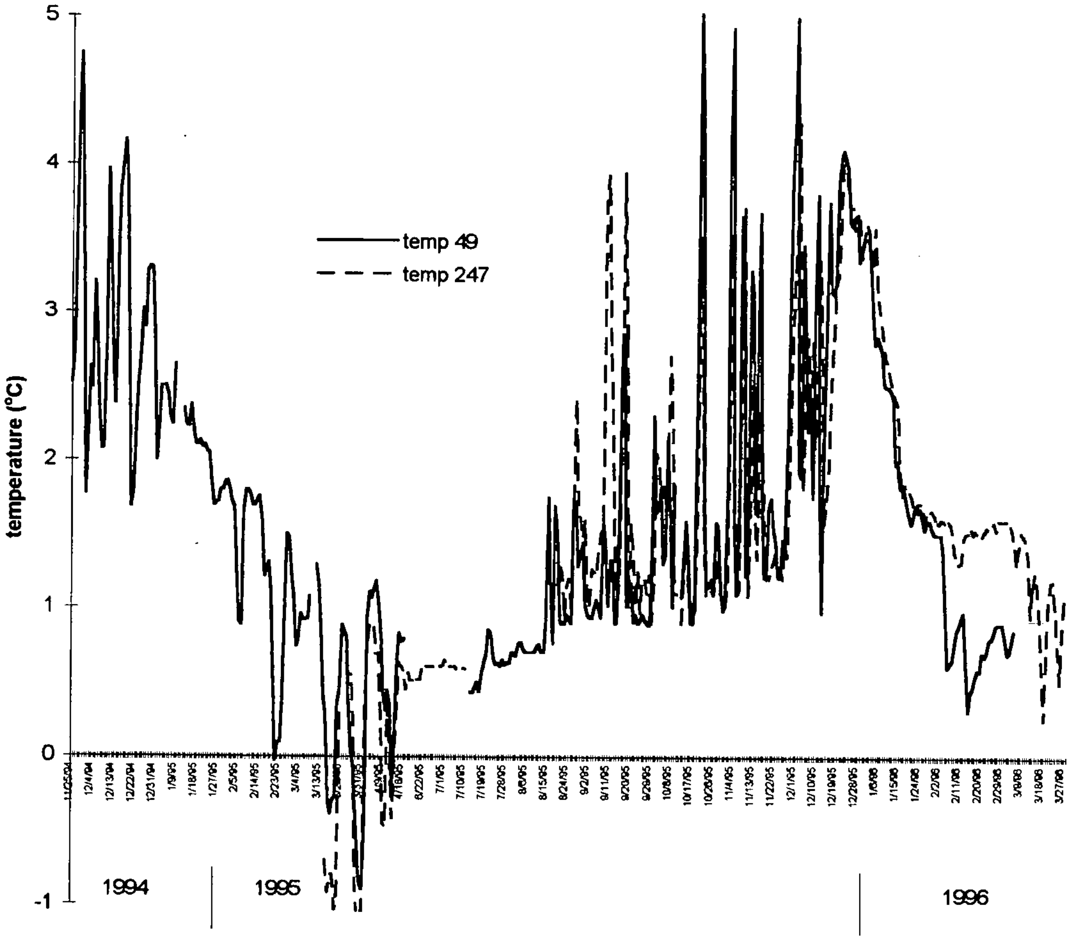



Figure 5. Mean daily temperatures at 100 m from two continuous recorders (#49 and 247) deployed on shrimp traps in Chedebucto Bay.

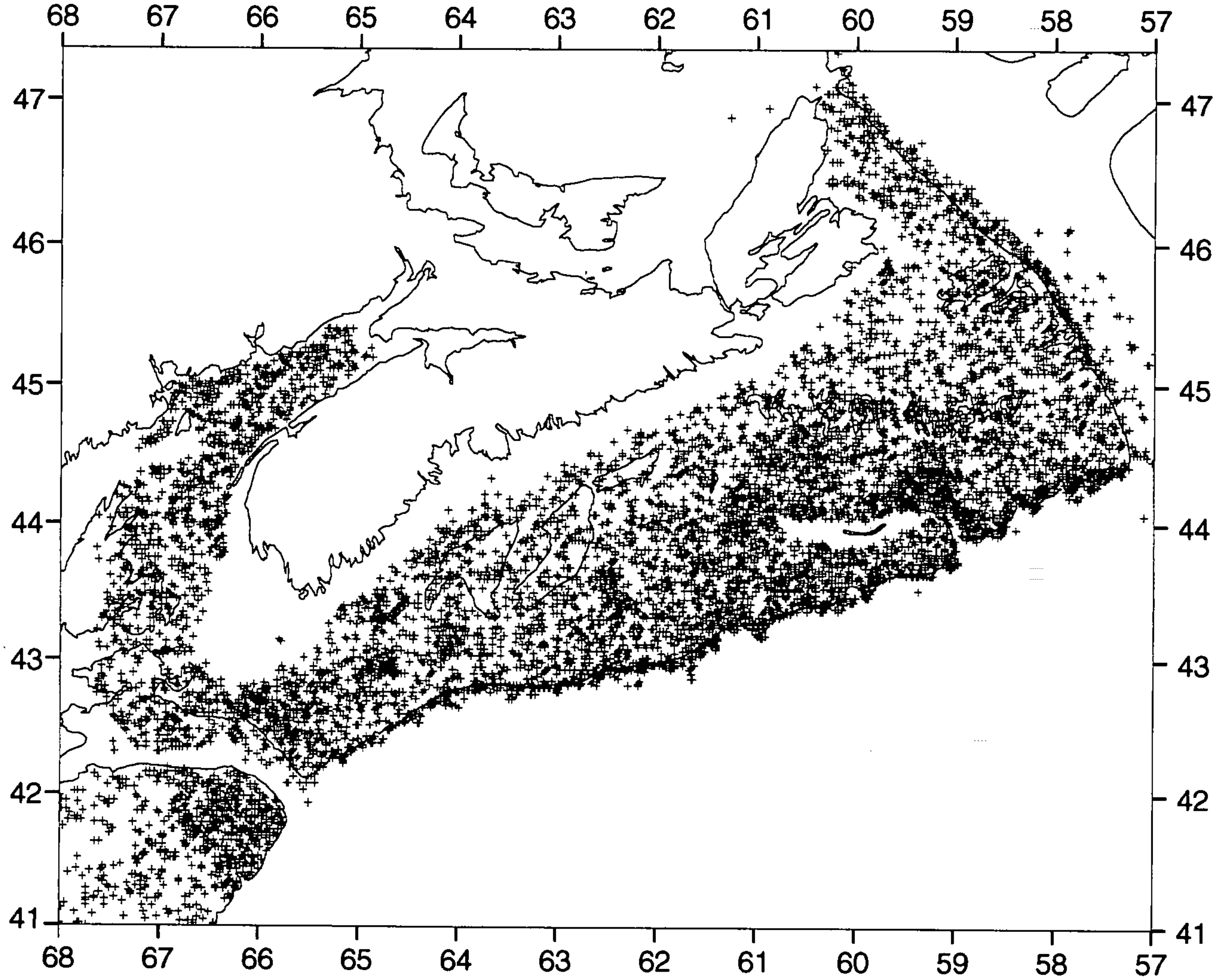



Figure 6. Locations of DFO random stratified groundfish survey sets completed between 1970 and 1975.

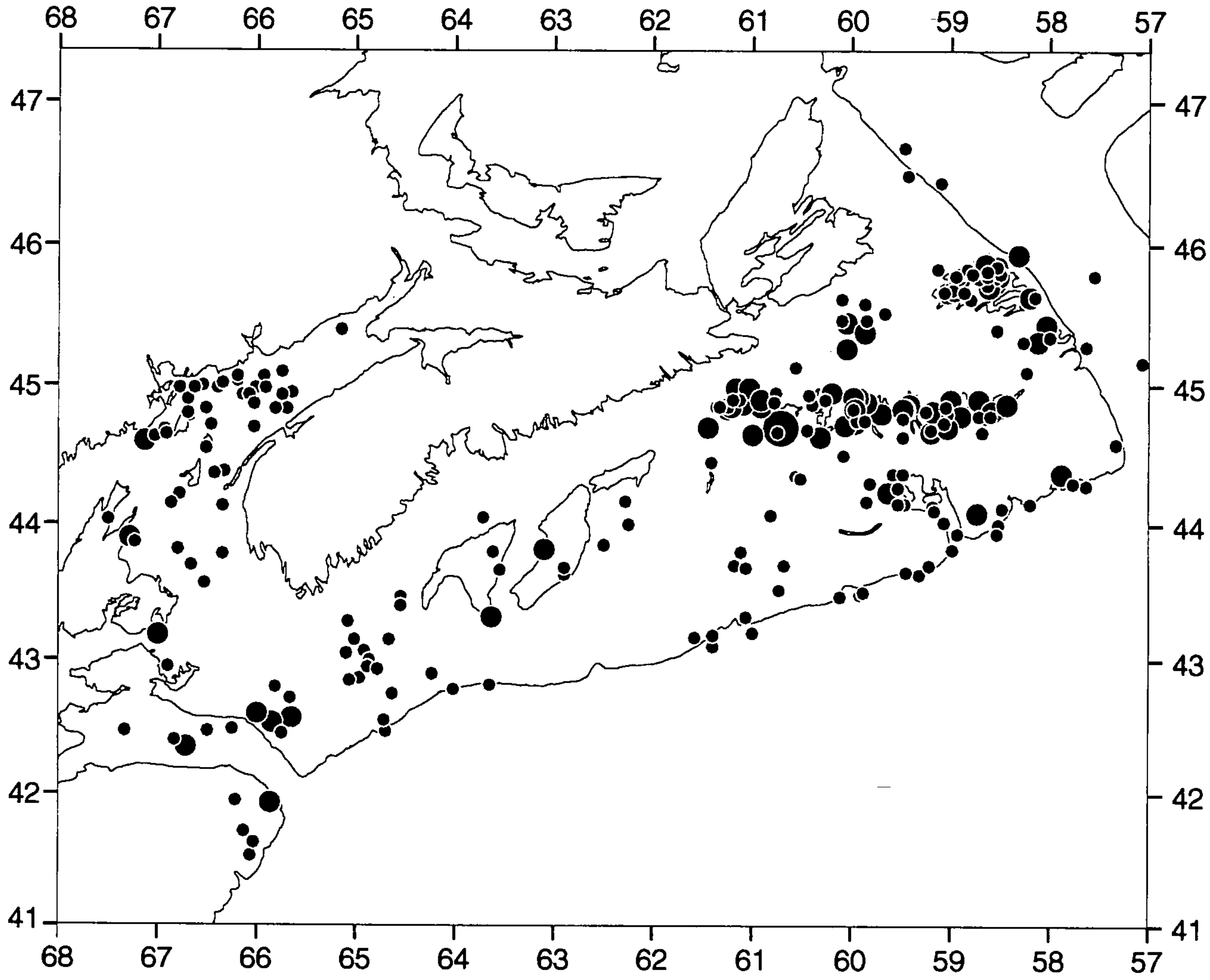



Figure 7. All shrimp catches recorded during groundfish surveys conducted from 1971-1995.

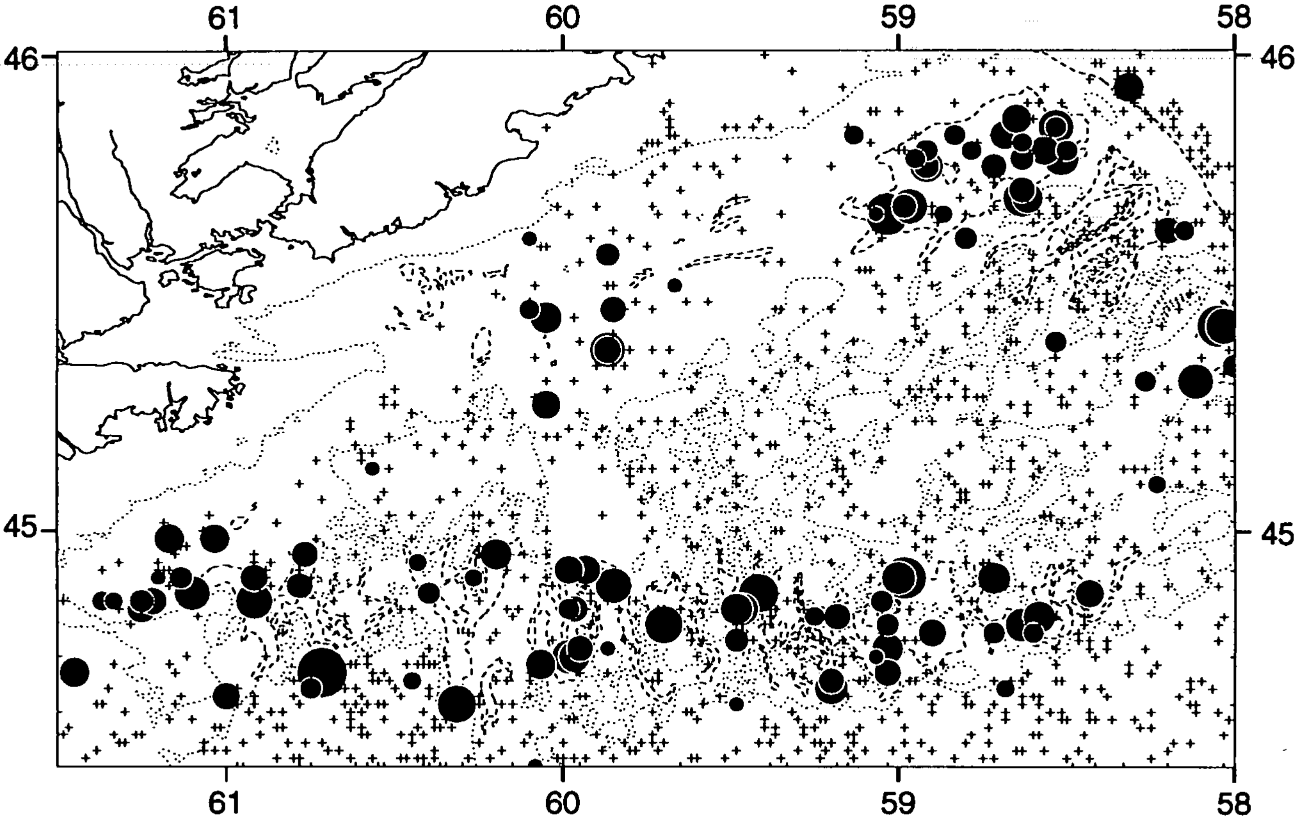



Figure 8. All shrimp catches from DFO groundfish surveys completed between 1971-1995, detail from Figures 6 and 7.

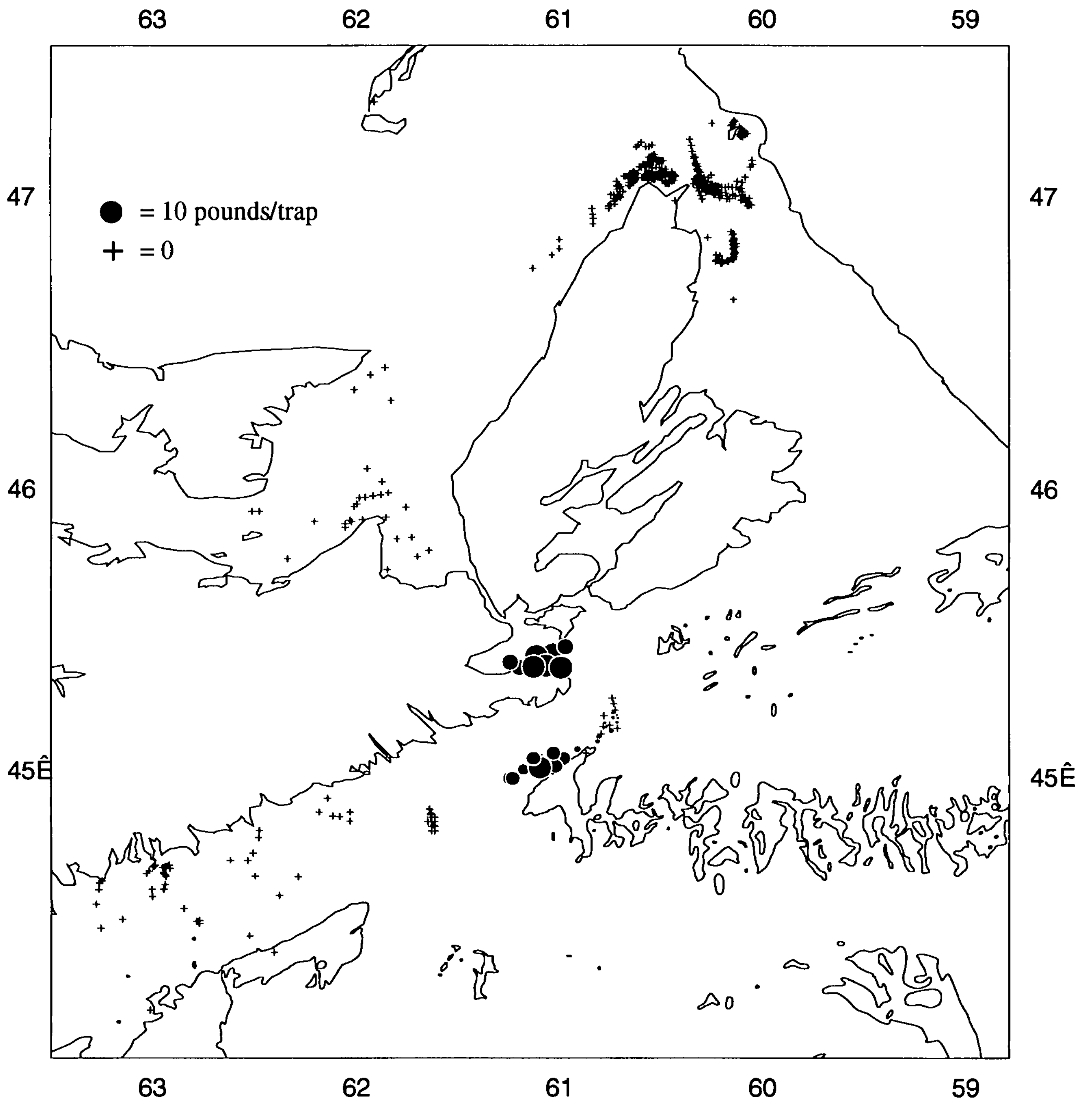



Figure 9. Location of shrimp traps and catches in eastern Nova Scotia during 1995 and early 1996.

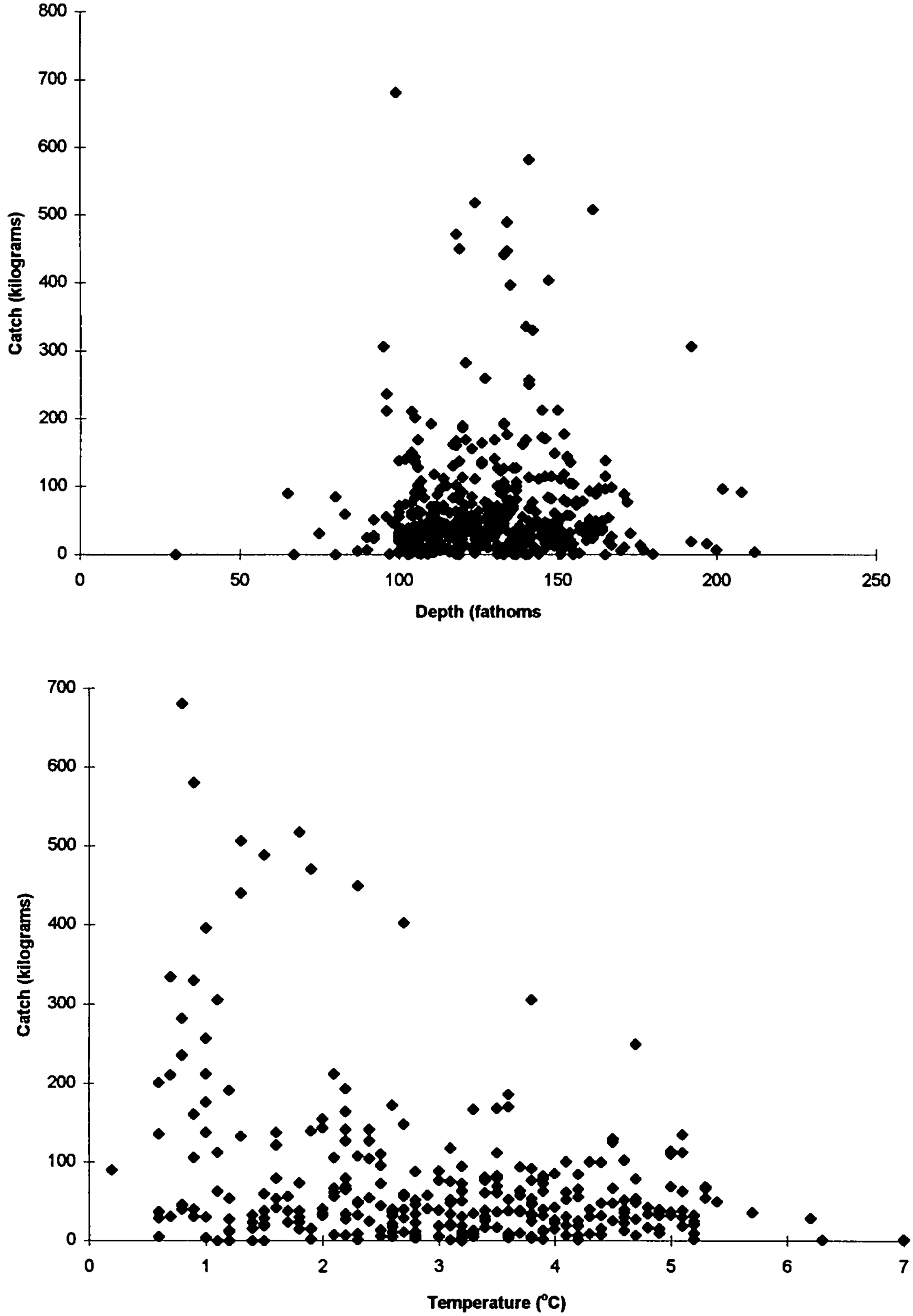



Figure 10. Distribution of shrimp catches by depth and temperature from DFO shrimp surveys 1982-1995.

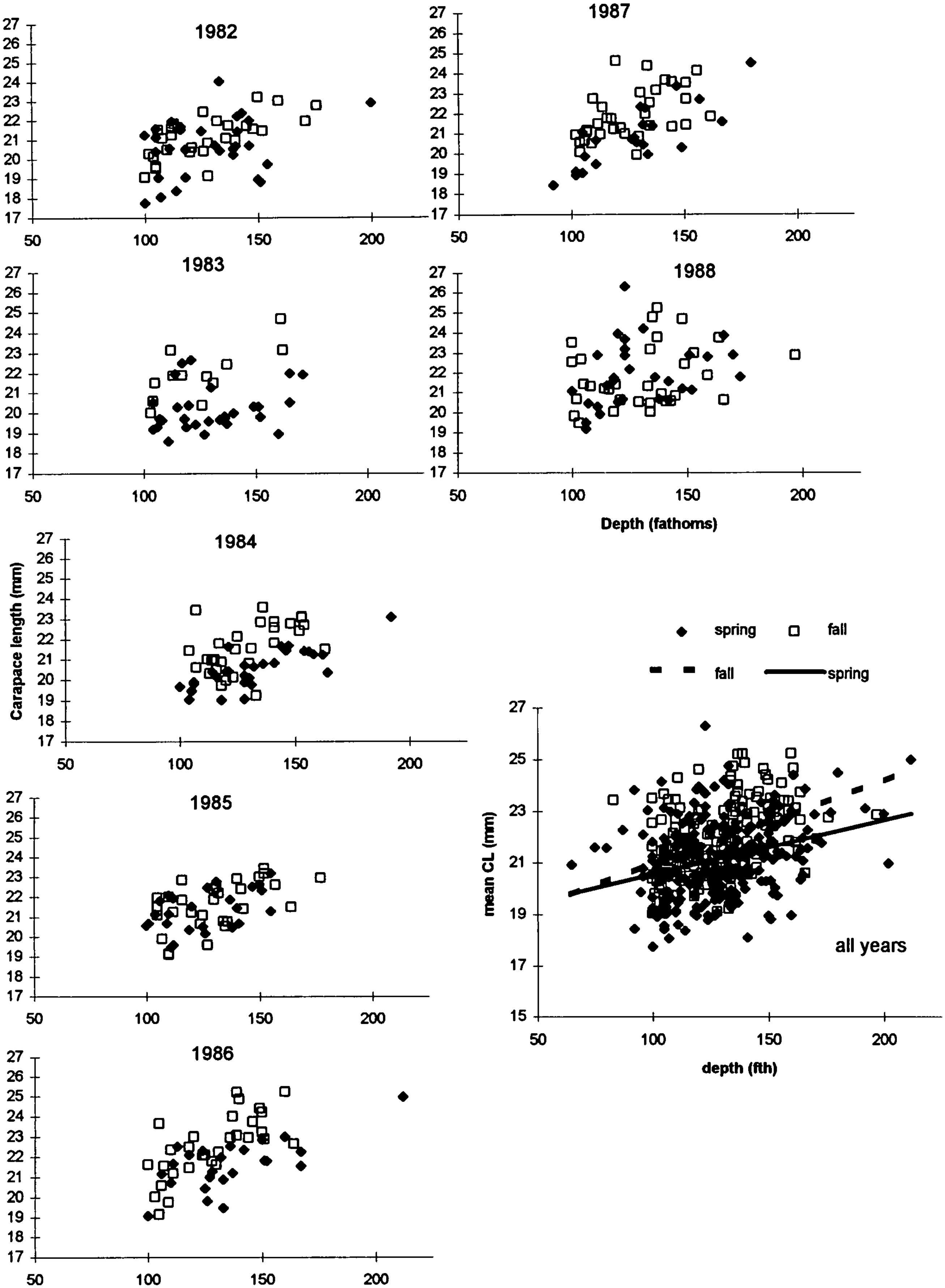



Figure 11. Distribution by depth and carapace length for each of the surveys conducted from 1982-88.

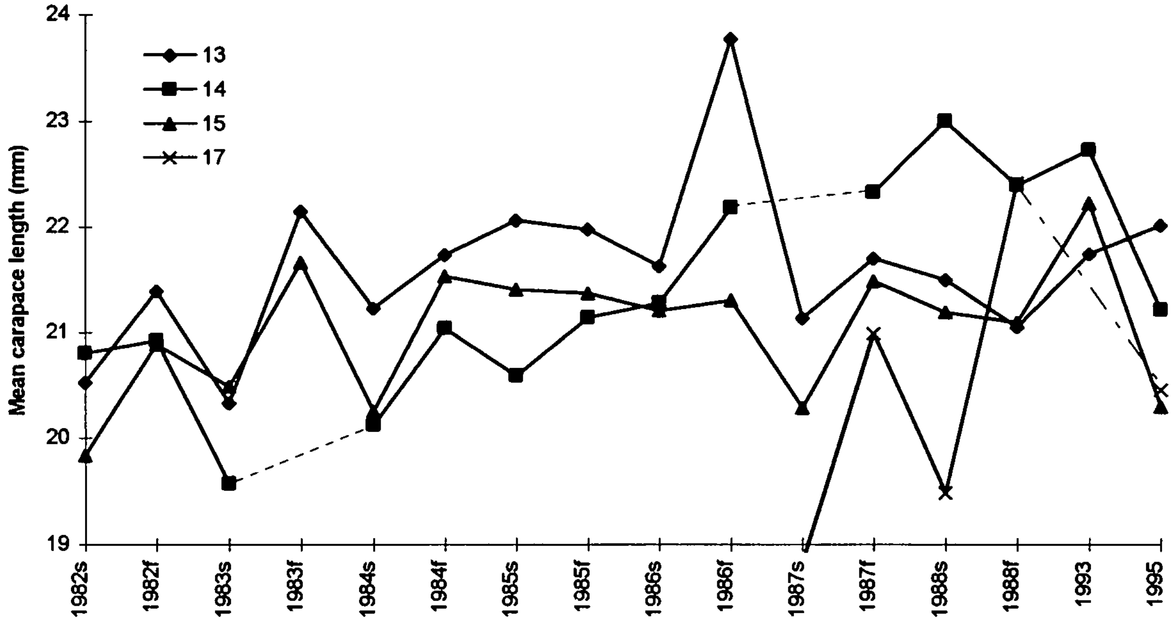



Figure 12. Mean lengths by SFA for spring (s) and fall (f) DFO shrimp surveys (1982-88) and industry surveys (1993,95).

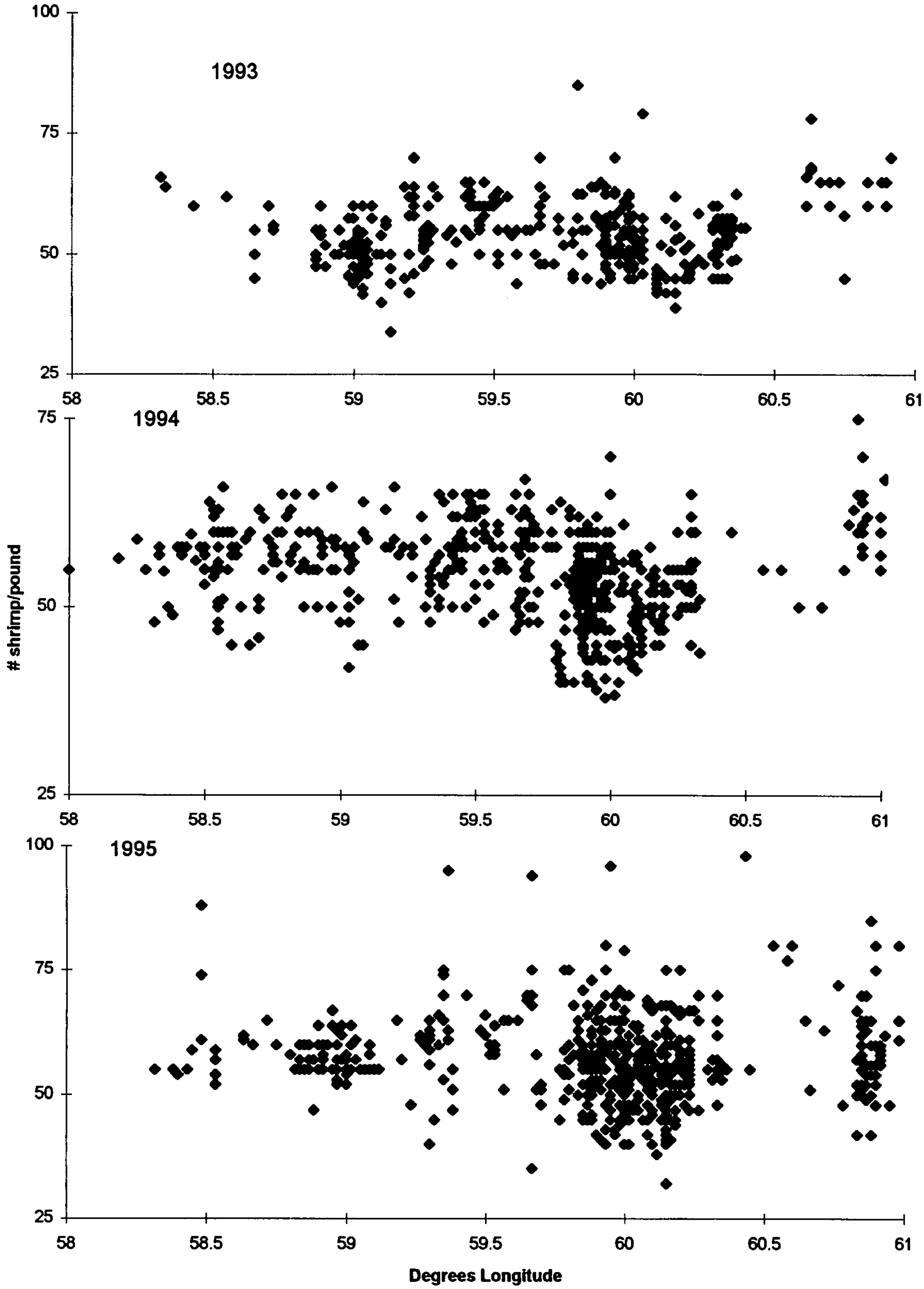



Figure 13. Distribution of counts per pound by longitude in Canso/Misaine holes from the commercial fishery

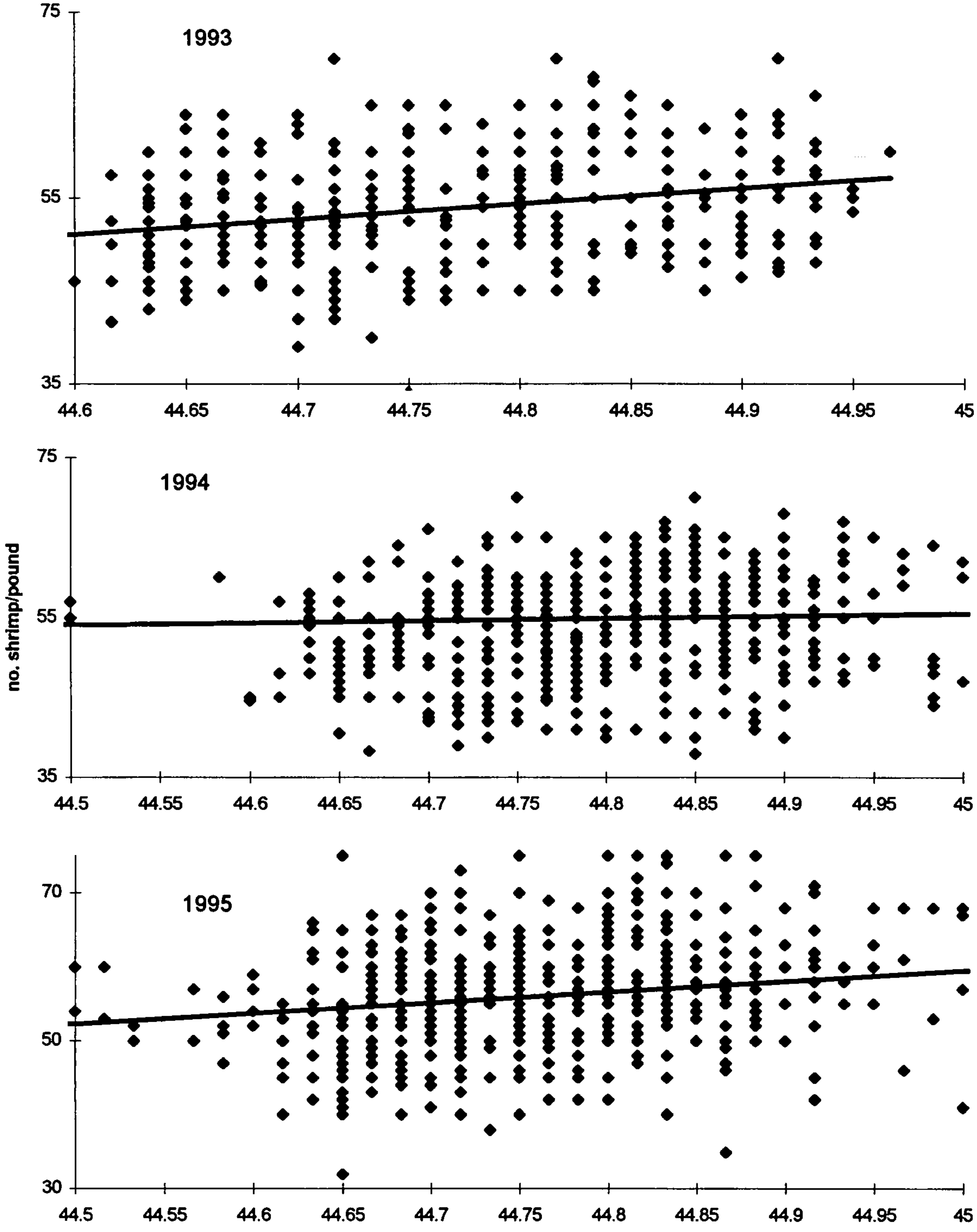



Figure 14. Distribution of counts per pound by latitude in Canso/Misaine holes from the commercial fishery

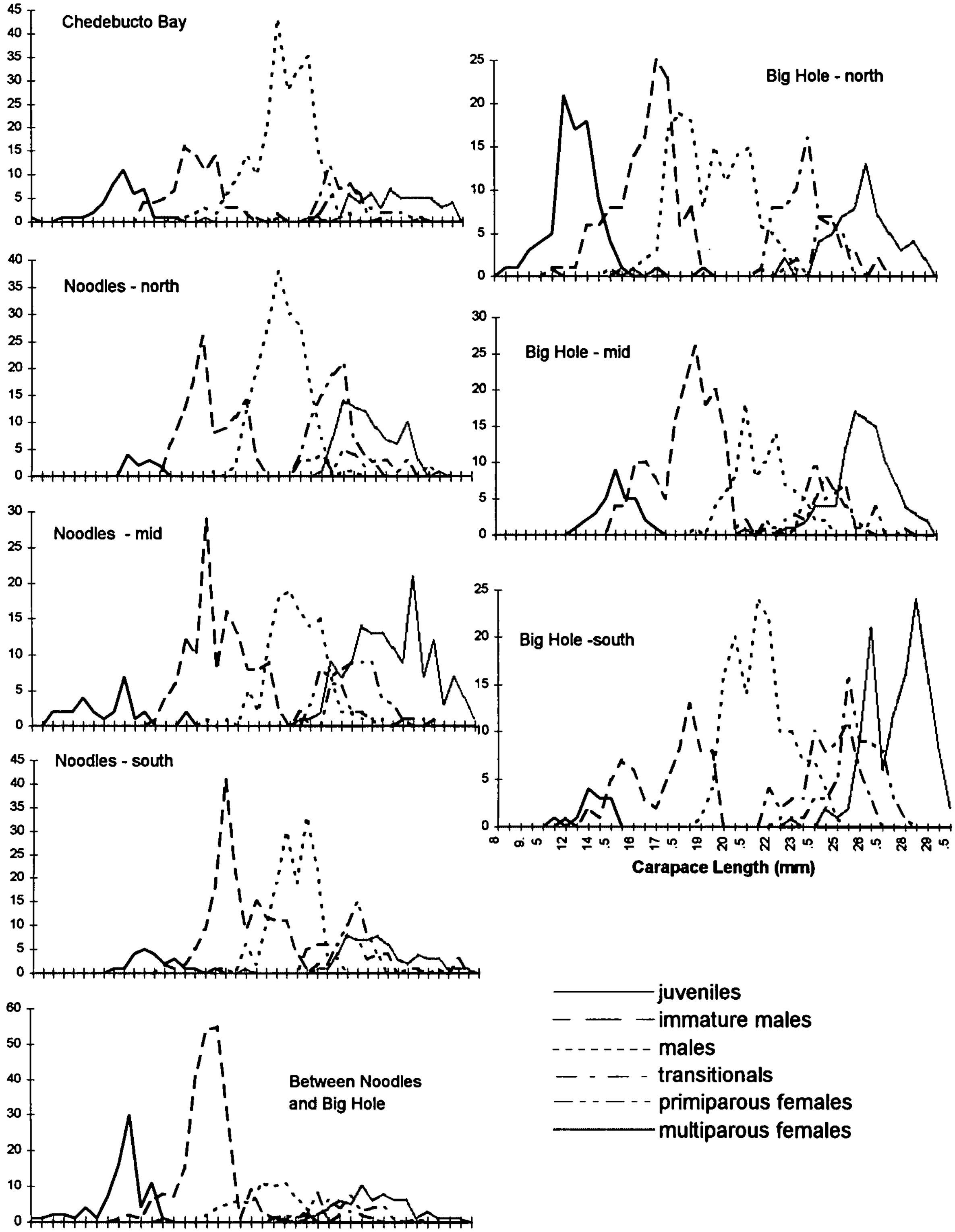



Figure. 15. Length frequencies by developmental stage from an inshore-offshore section of trawl sets completed in June, 1995.

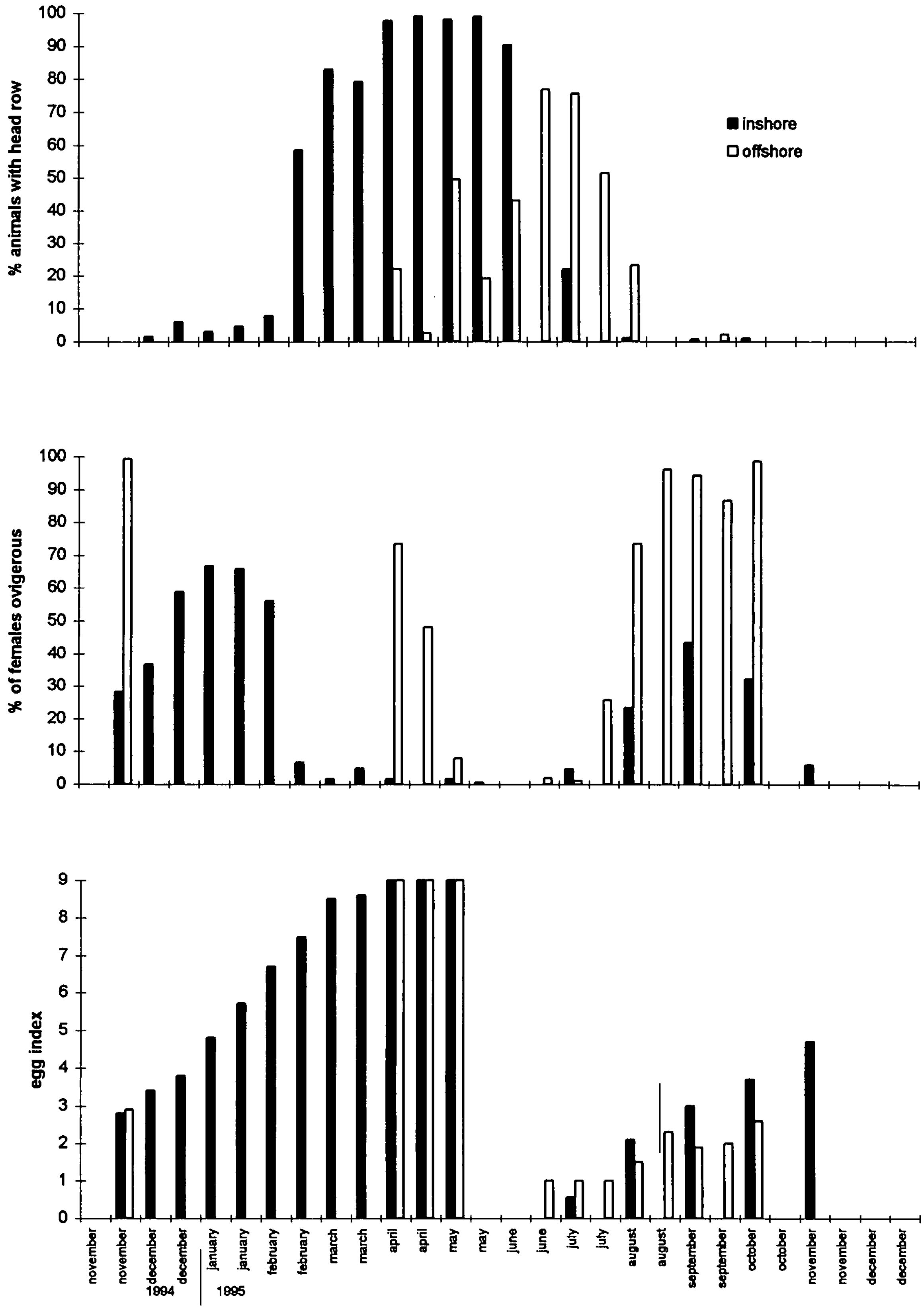



Figure 16. Reproductive cycle, including egg development in the carapace (top), ovigerous period (middle), and egg maturation (bottom) from bimonthly inshore (Chedebucto Bay) and offshore holes, November 1994 to 1995.

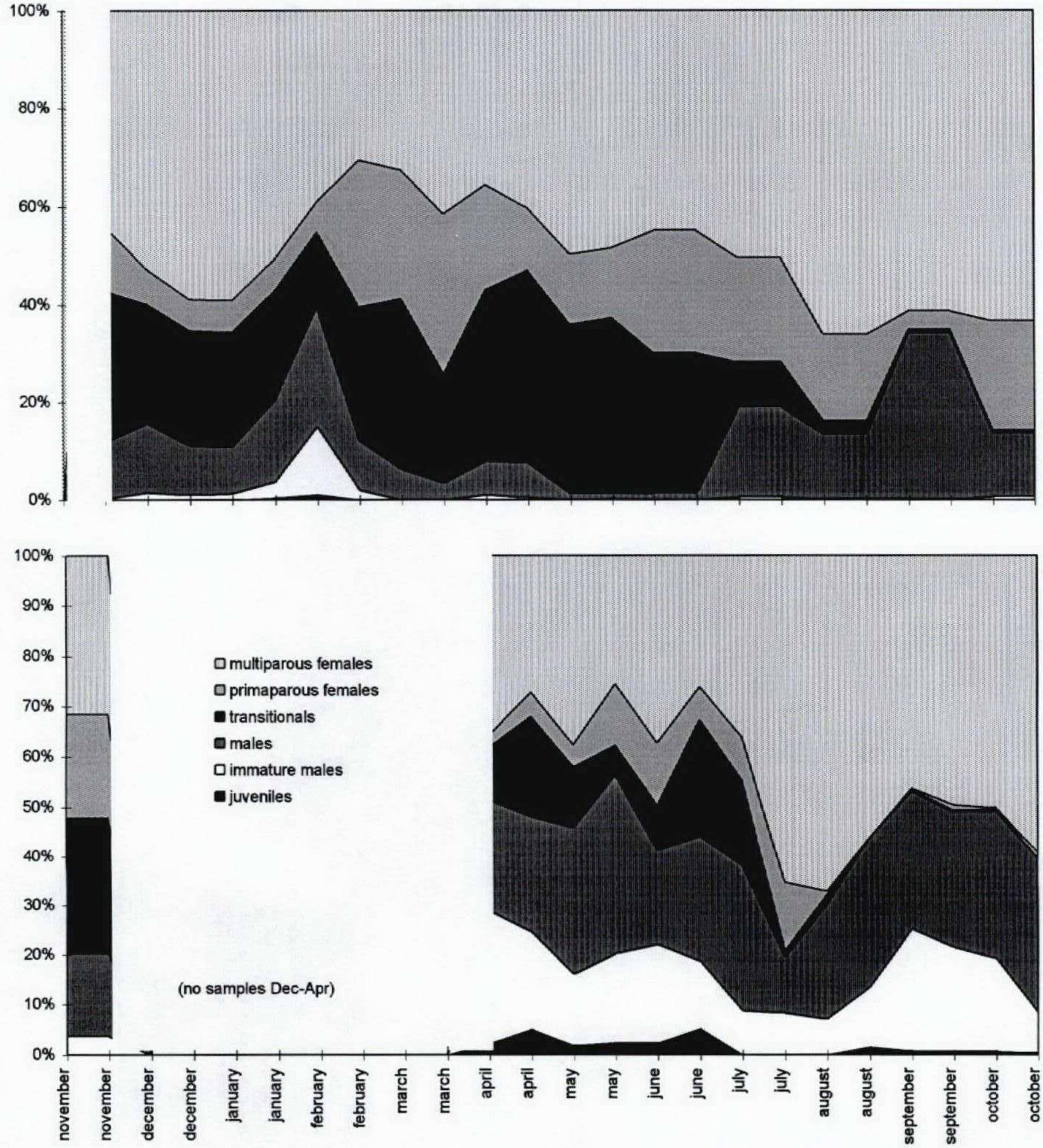



Figure 17. Percentage of each life history stage from inshore (top) and offshore (bottom) samples taken during 1994-95.

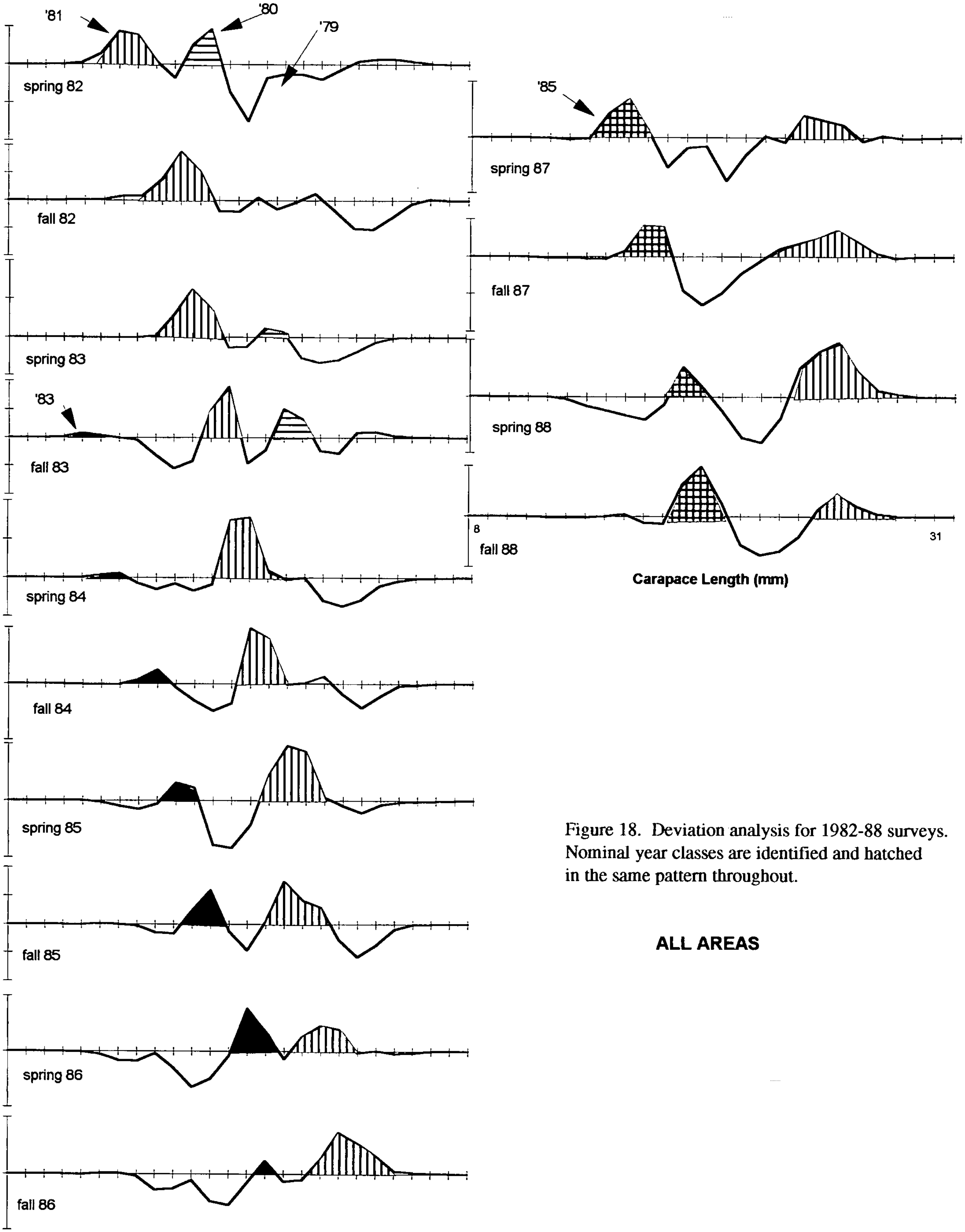



Figure 18. Deviation analysis for 1982-88 surveys. Nominal year classes are identified and hatched in the same pattern throughout.

**ALL AREAS**

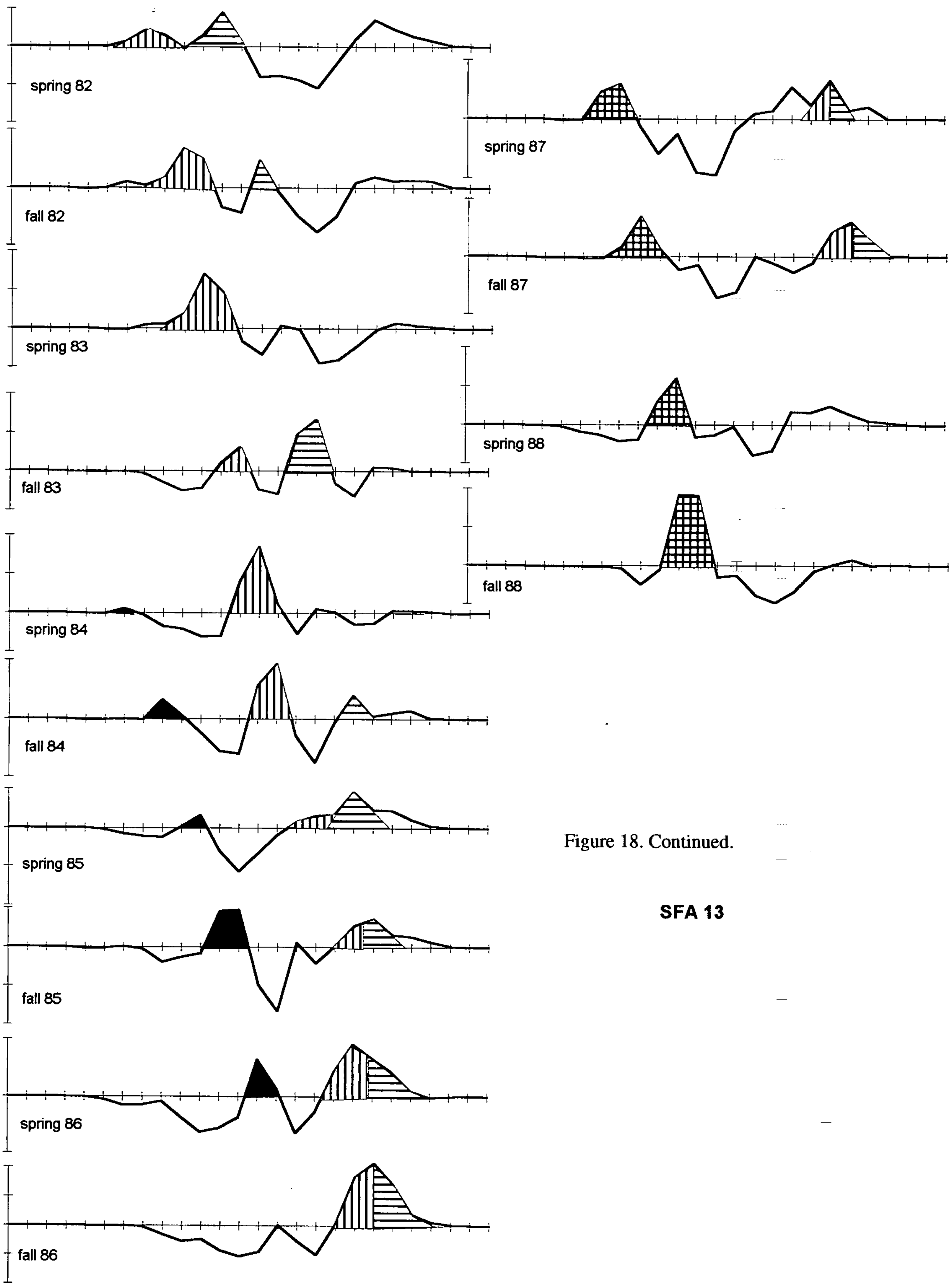



Figure 18. Continued.

**SFA 13**

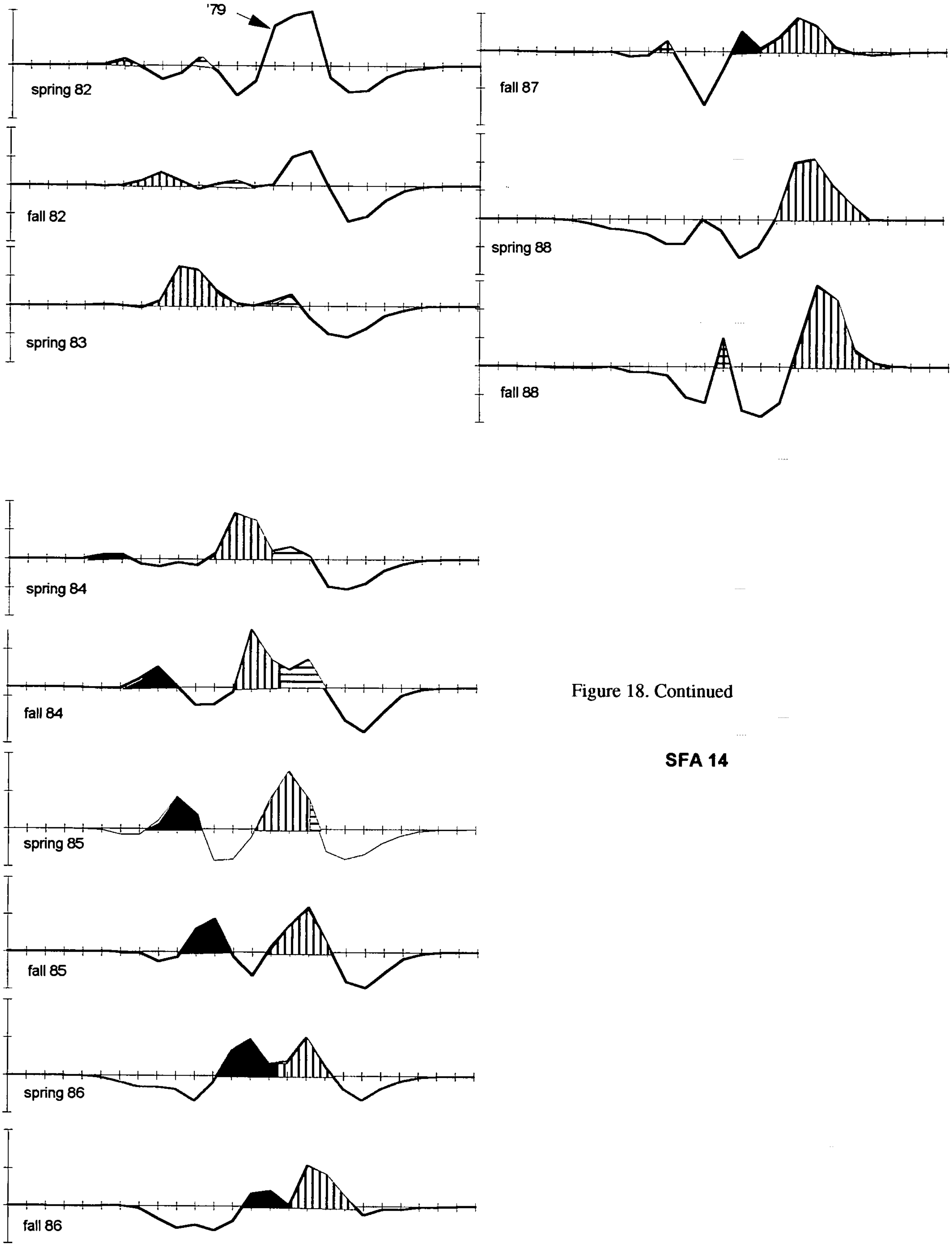



Figure 18. Continued

**SFA 14**

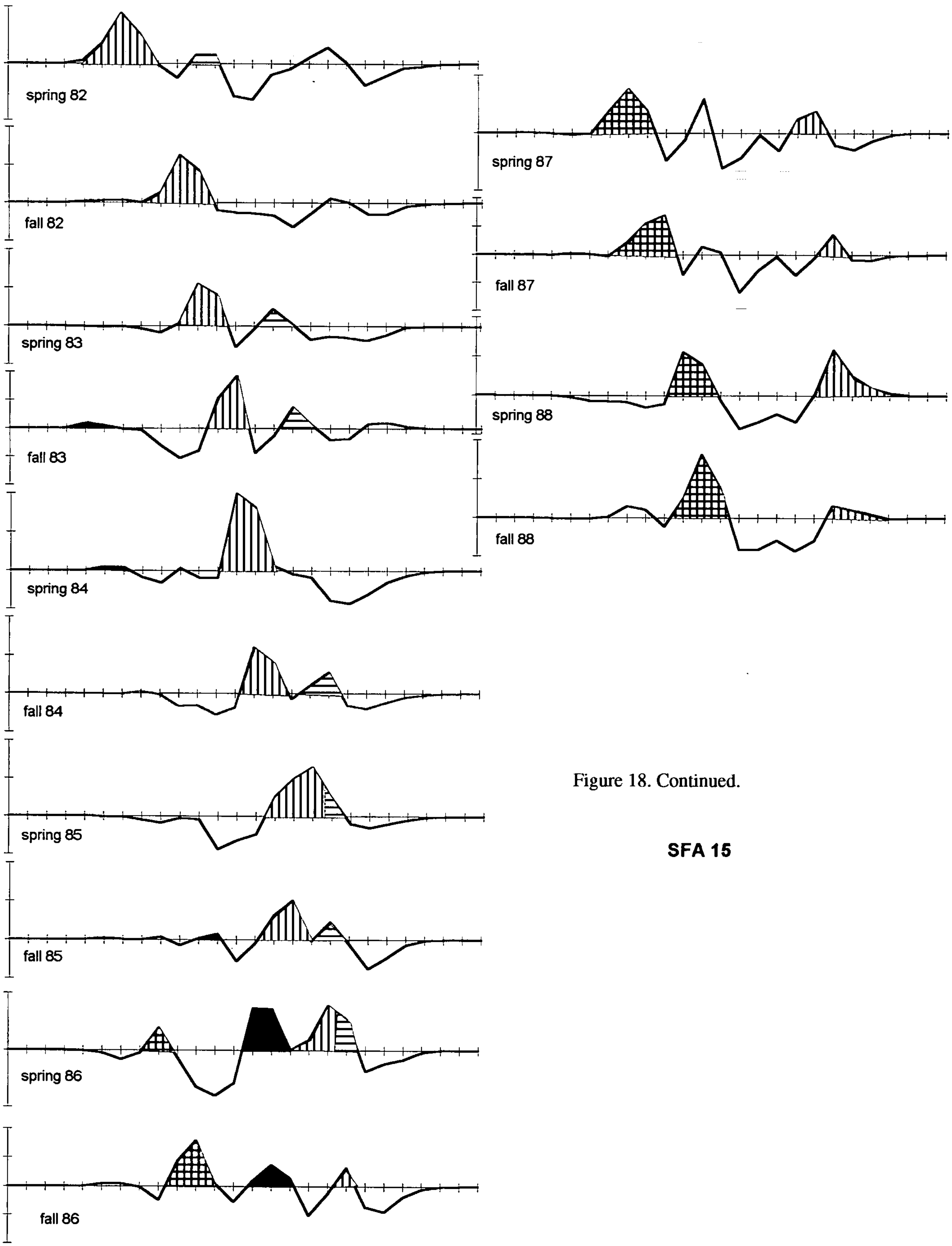



Figure 18. Continued.

**SFA 15**

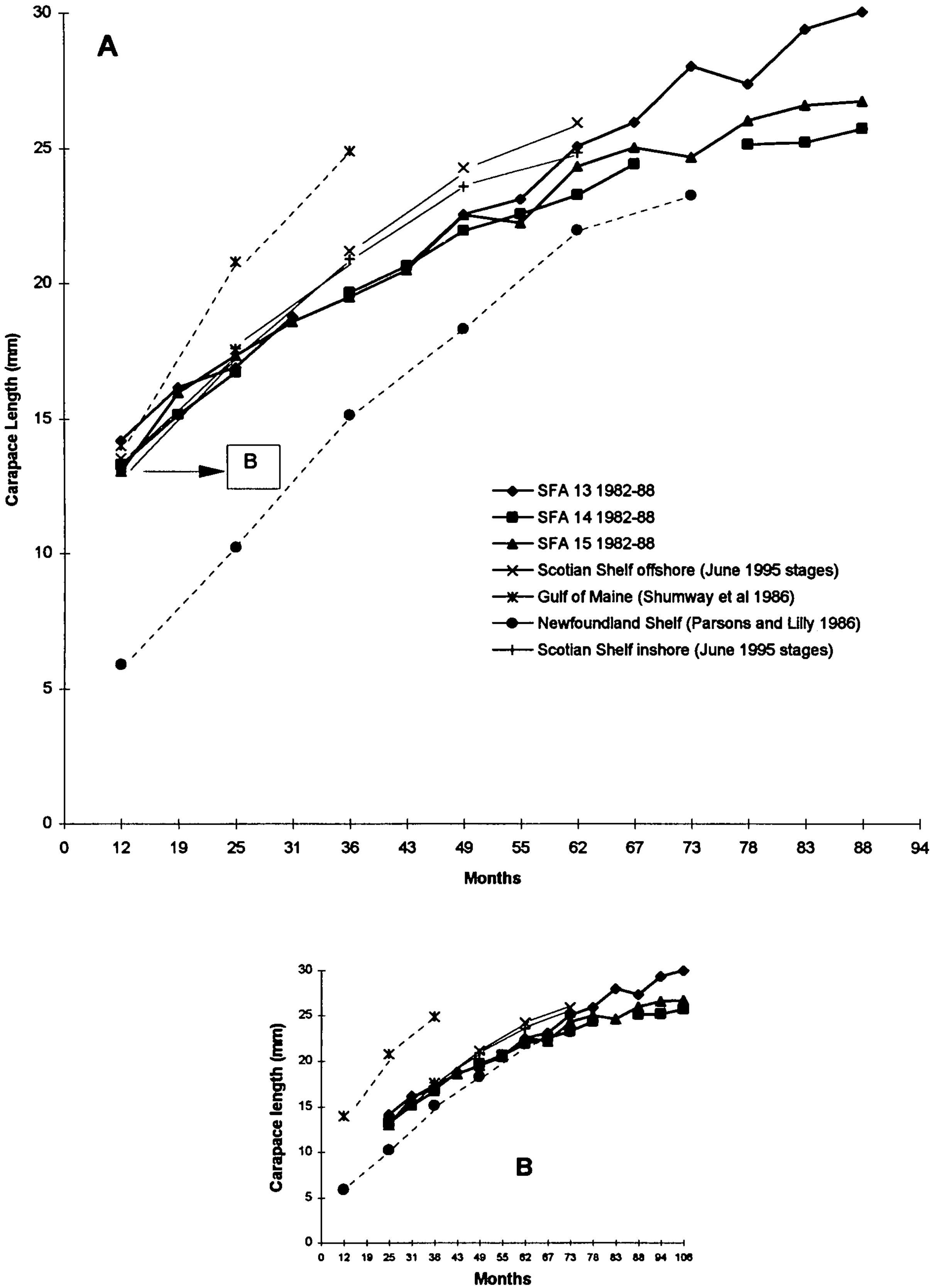



Figure 19. Growth of Pandalus borealis on the Scotian Shelf and adjacent areas. Arrow and inset in A. shows offset of one year for Scotian Shelf curves used in B.

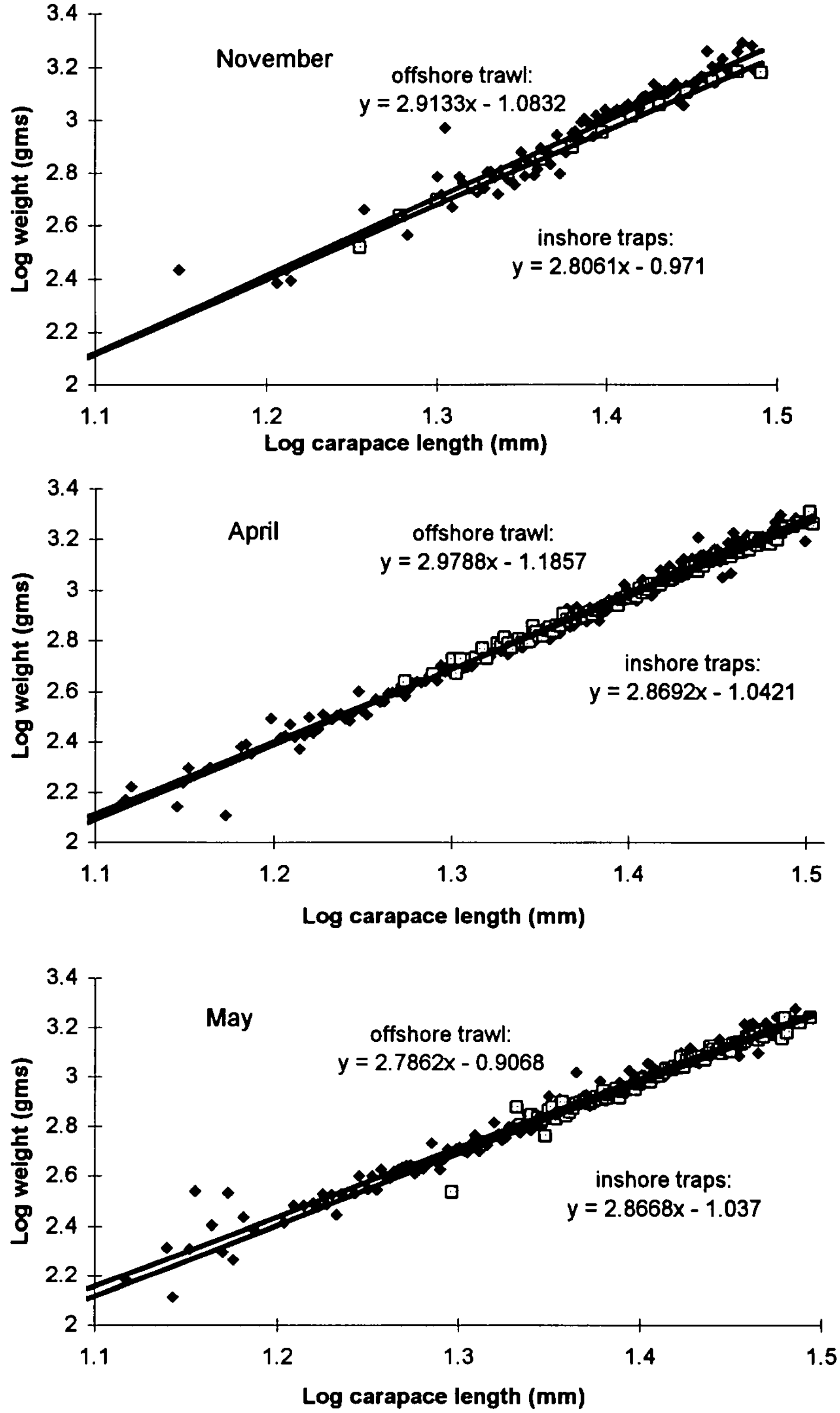
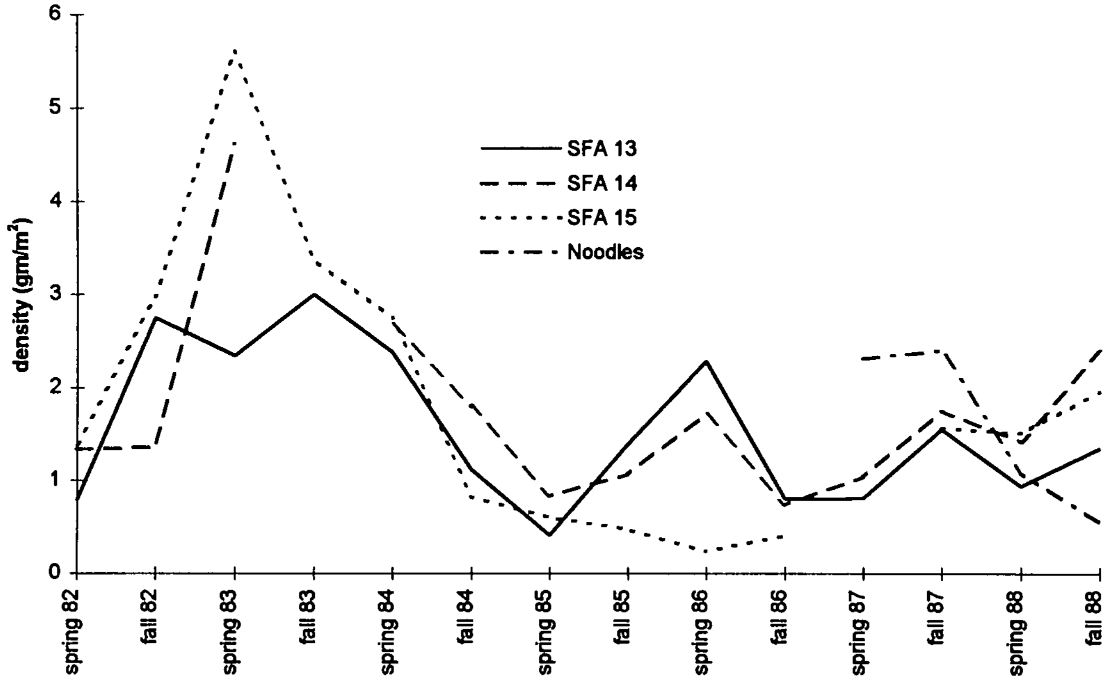



Figure 20. Length-weight relationships for inshore trapped (open square) and offshore trawled shrimp in November 1994, and April and May, 1995. The November and April slopes are significantly different at <0.05.



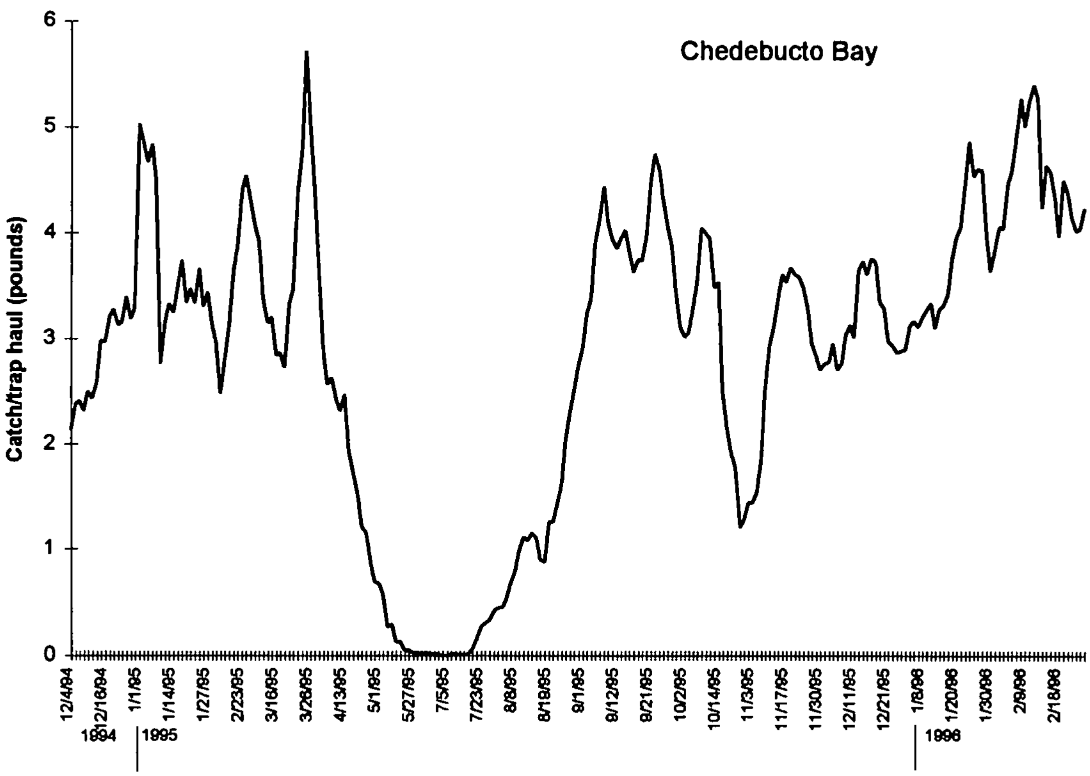




Figure 21. Density of shrimp in the offshore holes during spring and fall 1982-88 (top) and adjusted 5-d mean catch per trap haul in Chedebucto Bay during 1995 and early 1996 (bottom).

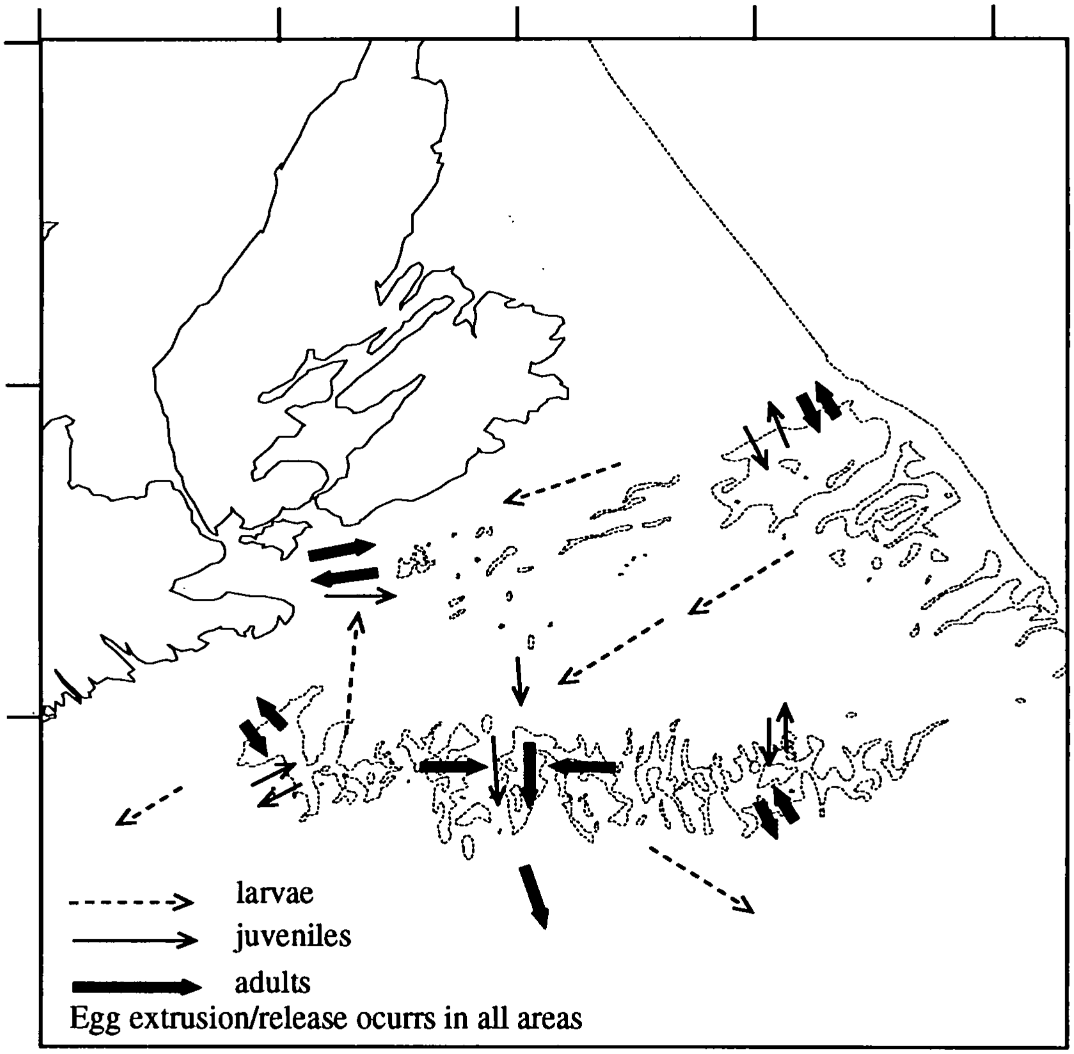



Figure 22. Hypothetical movements of Pandalus borealis larvae, juveniles and adults (see text).