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Relative Importance of Environmental and Ecological Factors to the Management of the Northern Shrimp (*Pandalus Borealis*) Fishery on the Scotian Shelf

by

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ABSTRACT

The biology of *P. borealis* on the Scotian Shelf is discussed in relation to the Gulf of Maine and Newfoundland Shelf stocks. The Scotian Shelf as a whole is an area of transition for *P. borealis* with a change in oceanographic characteristics in the mid shelf area that has resulted in populations with characteristics of both more southern and more northern stocks. The relatively large, commercially important population on the eastern Scotian Shelf is restricted to small areas of suitable habitat despite favorable temperatures over a wide area. On the southern and western Scotian Shelf a small population inhabits relatively small areas of marginally suitable temperatures, despite large areas of suitable habitat. Commercially important concentrations in this area appear only rarely after temperatures decrease to more favorable levels. Growth rates and age at first maturity on the Scotian Shelf are intermediate between the Gulf of Maine and the Newfoundland shelf, and migrations include inshore movements of ovigerous females in winter as in the Gulf of Maine, as well as localized ontogenetic migrations. While shrimp populations on the Scotian Shelf are influenced by water temperatures and habitat availability, predation pressure is also a significant determinant of abundance. The implications for the management of shrimp fisheries in the area are discussed.

INTRODUCTION

Pandalus borealis is a circumpolar species which is most abundant north of 46^{o}N in the western North Atlantic. 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/or ecological limits. Its preferred temperature range is 1-6^{o}C (Shumway et al 1985). In the Gulf of Maine landings (Dow, 1977) and recruitment (Richards et al 1996) have been inversely related to sea water temperatures, with mechanisms proposed by Appolonia et all (1984) and Tande et al (1993). The literature shows both direct and inverse temperature-abundance relationships for more northern stocks (Nilssen and Hopkins 1991) but population fluctuations are also linked to predator abundance (e.g, Stefánsson et al 1994, Stefánsson and Pálsson 1998).

On the Scotian Shelf, *P. borealis* is the object of a relatively small (1998 catches 4000 mt), recently established, offshore trawl fishery and a developing inshore trap fishery (Koeller et al 1995, Koeller et al 1997). The purpose of this paper is to contrast the available biological and environmental information on the Scotian shelf with information on shrimp stocks to the north and south, and to discuss the broad management implications of the results. The working hypothesis is that temperatures are more important than predators in regulating southern shrimp stocks, and vice versa in northern stocks. The Scotian Shelf should exhibit characteristics intermediate to the southern and northern populations which bracket it geographically.

METHODS

Bathymetric information was obtained as digitized depth contours from the Canadian Hydrographic Service. The distribution of shrimp habitat can be inferred from surficial geology maps published by the Atlantic Geosciences Centre, Bedford Institute of Oceanography, Dartmouth, Nova Scotia. Historical bottom temperature data in areas of shrimp distribution were obtained from the Marine Environmental Data Service (MEDS), Ottawa. Bottom temperatures were also recorded continuously at a fixed location (depth 100m) off Canso, Nova Scotia, using Vemco temperature recorders.

Information on shrimp distribution was obtained during DFO stratified random groundfish surveys (Halliday and Koeller 1981) conducted on the entire Scotian Shelf from 1970 to 1983, DFO shrimp surveys conducted on the eastern Scotian Shelf twice per year (spring and fall) on R.V. *E.E. Prince* from 1982 to 1988 (Etter and Mohn 1988), and cooperative DFO-industry shrimp surveys conducted on the eastern Scotian Shelf in 1995-97 (Koeller et al 1997). Groundfish surveys which recorded shrimp catches covered the entire Scotian shelf once per year (summer) from 1971-78 and 3 times per year (spring, summer, fall) from 1979-83. The stratification scheme of these surveys ensured that the 2168 randomly chosen stations completed between 1970 and 1983 were relatively evenly distributed on the entire Scotian Shelf covering all areas, depths (<400m) and habitat types. Information on shrimp distributions on the Scotian Shelf and Bay of Fundy are also available from exploratory surveys conducted by the Nova Scotia and New Brunswick Departments of Fisheries from 1965-1970 (MacPhail and MacDonald 1965, Johnson 1966, Scullion 1969, Cadegan 1970, Pettigrew 1970) and by the Department of Fisheries and Oceans (Ang 1993). Information on the inshore distribution and migrations of shrimp was obtained from trapping surveys conducted in 1994-97 using Maine-style shrimp traps (Koeller et al 1995) and from the DFO-industry shrimp surveys in 1995-97 (Koeller et al 1997).

Sex and reproductive condition of individual shrimp was determined using the methods of Allen (1959) and McCrary (1971). Growth was determined using modal analysis according to the methods of Parsons et. al (1989) using the ELEFAN computer program to separate modes. Samples for detailed analysis including carapace length, individual weights and reproductive condition were collected from all survey sets and representative commercial catches. Where possible, each sample consisted of a minimum of 500 animals to ensure adequate representation of the catch and separation of life history stages.

Predator abundances were calculated from available groundfish survey data in the Gulf of Maine, on the Scotian Shelf, and on the Newfoundland-Labrador Shelf. Most groundfish feed on crustaceans at some point in their life history, and shrimp are often identified as an important component of their diet. In addition, the important commercial groundfish species which comprise most of the biomass in the three areas considered have all been identified as predators of shrimp (Atlantic cod, silver hake, Greenland halibut, Sebastes sp., and various flatfish species). Consequently, total groundfish abundance in each area, as measured by the mean stratified catch per tow of all groundfish species in strata (Doubleday 1981) coinciding with known areas of shrimp distribution was considered to be directly proportional to predation pressure in each area. In cases where actual shrimp abundance indices from surveys were not available, commercial catch per unit effort from the relevant stock assessment document was used as a proxy. Multiple regression analysis was used to determine if water temperatures and predator abundance could explain a significant amount of the variation in shrimp abundance in the three areas according to the working hypothesis i.e. temperatures would explain more of the variation in shrimp abundance in the Gulf of Maine, predator abundance would be more important on the Newfoundland Shelf, and both factors would come into play on the Scotian Shelf. Correlations of shrimp and predators were conducted without lags because natural (predation) mortality should effect a shrimp population immediately. Since temperatures appear to influence survival of shrimp eggs or larvae (Appolonio et al 1984, Shumway et al 1986, Richards et al 1996) its affect on shrimp populations would not be detected until shrimp become available to the fishing/survey gear, consequently lags of 4 years were used for temperature data.

In this paper the "eastern Scotian Shelf" includes Louisbourg, Canso, and Misaine Holes, The Gully, Chedebucto Bay, and the inshore area known as The Noodles; the "central Scotian Shelf" includes LaHave and Emerald basins; the "western Scotian shelf" includes the Bay of Fundy and Roseway Basin; and the Gulf of Maine includes Jordan and Crowell Basins and areas to the west (Figure 1). The term "shrimp" refers exclusively to *P. borealis.*

RESULTS

The distribution of shrimp on the Scotian Shelf as a whole indicates that major concentrations of shrimp are restricted to the eastern Scotian Shelf (Figure 1). Within the eastern shelf shrimp are largely restricted to shrimp holes (Louisbourg, Canso and Misaine) at depths >200m where the present fishery concentrates. Two minor concentrations are evident on the western shelf in areas where fisheries occurred in the late 1960's. These western shelf fisheries began in the Bay of Fundy in the mid 1960s and moved to the Roseway Basin area in the late 1960s when Bay of Fundy catch rates declined sharply. The fishery had largely disappeared by 1970 after catch rates in Roseway basin also declined (Pettigrew 1970, Scullion 1969, Cadegan 1970). Shrimp have not been found in commercial quantities on the western shelf since then, despite extensive exploratory surveys in 1992-93 (Ang 1993) and the presence of a fleet of vessels licensed to fish shrimp only in this area. The trawl fishery on the eastern Scotian Shelf began in the late 1970s. In the 1990s inshore trap fisheries appeared in Chedebucto and Mahone Bays (Figure 1).

In addition to the preferred temperature range of 1-6ºC, *P. borealis* prefers soft mud substrates containing a large amount of organic material (Schick, 1991), termed LaHave clay on the Scotian Shelf (Fader 1991). Shrimp habitat i.e. LaHave clay, is found mainly in the deep basins of the Scotian Shelf. The 200m depth contour roughly outlines most patches of this substrate, with the notable exception of shallower water in the Bay of Fundy, The Noodles, around Roseway Basin, and in the area immediately east of Emerald Basin (Figure 2). Temperatures for July 1996 (Figure 2) show persistent features evident every year in plots of bottom temperatures from nearly 30 years of summer groundfish surveys, including relatively cold temperatures (1-3ºC) on the eastern shelf, warm temperatures (>10ºC) on the central shelf and moderate temperatures (3-10ºC) to the west. Note that the coldest temperatures on the eastern shelf cover an area that is much wider than the area of shrimp distribution, while the coldest temperatures on the western Scotian Shelf are restricted to smaller patches in the Bay of Fundy and in the Roseway Basin area. Further, the areas with the largest amount of shrimp habitat (central Scotian Shelf, and eastern Gulf of Maine) have temperatures above the preferred range, and no sustained shrimp concentrations. On the western Scotian Shelf, shrimp concentrate in two relatively small patches of habitat i.e. Bay of Fundy and Roseway Basin, where temperatures are cooler, despite a large amount of available habitat elsewhere. Since temperatures are favourable over wide areas on the eastern shelf, they are not restricting shrimp to the well defined concentrations in the deep water of Canso, Misaine, and Louisbourg Holes. Since shrimp also concentrate inshore in the Noodles and Chedebucto Bay at depths as shallow as 40m (Koeller et al 1995) it is apparent that depth is also not the restricting factor. It is particularly noteworthy that the area with the least amount of preferred habitat i.e. the eastern Scotian Shelf, is the one with the largest shrimp concentrations. The percentages of the total areas of bottom within and above the preferred temperature range on the western and eastern Scotian Shelf in July since 1970 confirm the persistence of the very different temperature regimes in these areas (Figure 3).

Long term changes in the abundance of shrimp on the Scotian Shelf and in the Gulf of Maine are shown in Figure 4. Since commercial catches in the Gulf of Maine closely track shrimp abundance estimates from groundfish surveys (Armstrong et al 1997) total catch is used as a proxy for abundance in the Gulf of Maine and western Scotian Shelf, while catch per unit effort from commercial shrimp trawlers is used as an abundance index for the eastern Scotian Shelf (Figure 4A). Catches in the short-lived western Scotian Shelf fishery peaked in the same year as in the Gulf of Maine, although they were an order of magnitude smaller. Abundance on the eastern Scotian shelf was high in the late 1970s when the Gulf of Maine fishery had collapsed, and it was at its lowest in the mid 1980s, when the Gulf of Maine fishery had recovered. Eastern Scotian Shelf abundance increased greatly in the 1990s when Gulf of Maine catches were falling. The increase in Gulf of Maine catches during the most recent years is thought to be due to increases in effort rather than abundance (Armstrong et al 1997). Relative changes in shrimp abundance from groundfish survey indices (Figure 4B) reflect the similarity of catch data in the Gulf of Maine and the western Scotian Shelf, and the different pattern on the eastern Scotian Shelf, i.e. relative abundance was high in the Gulf of Maine and western Scotian Shelf during the early 1970s when it was low on the eastern

Scotian Shelf. However, as with historical commercial catches, survey catches and densities on the western Scotian Shelf are about an order of magnitude lower than the Gulf of Maine or the eastern Scotian Shelf.

Average bottom temperatures (>99m) in the Gulf of Maine, on the eastern Scotian Shelf and on the Newfoundland-Labrador Shelf since the late 1970s were near the top, middle and bottom of *P. borealis'* temperature range, respectively (Figure 5 upper). The long term bottom temperature anomaly in the Gulf of Maine generally decreased until the late 1960s, reaching historical lows a few years before the record high catches and abundances in the early 70s (Figure 5 lower). Conversely, bottom temperatures in the Gulf of Maine increased from the late 1960s to the late 1970s and reached historical highs a few years before the record low catches abundances of the early 1980s. Except for recent years, temperatures in the Gulf of Maine appear to have decreasing since the late 1970s. Eastern Scotian Shelf temperatures showed a decreasing trend throughout the 80s and 90s when the shrimp population cycled through periods of low and high abundances. Bottom temperatures on the Newfoundland-Labrador Shelf also decreased during the 80s and 90s, but they increased in recent years. Shrimp abundance tends to mirror predator abundance in all three areas (Figure 6). A multiple regression analyses showed that, while the model explained a relatively small amount of the variance in the data, predation was the only a significant determinant of shrimp abundance in all areas. Bottom temperatures lagged by 4 years were insignificant in all cases (Table 1).

Shrimp migrations on the eastern Scotian Shelf can be inferred from the seasonal survey results given in Table 2. Considering real abundance changes between surveys and the variability of the estimates (CVs ~20%) the densities of females in the offshore holes (Canso, Misaine and Louisbourg, Figure 1) are quite similar during spring and fall between 1982-88 i.e. there is no evidence of large scale female emigration as occurs in the Gulf of Maine. Moreover, effort in the trawl fishery concentrates in the offshore holes throughout the year (Koeller et al 1997) and does not follow large shrimp inshore in winter as in the Gulf of Maine. Summer surveys between 1995 and 1997 show significant concentrations of females both inshore (i.e. the Noodles, Figure 1) and offshore (Table 1). Large numbers of juveniles are found in both areas, indicating that breeding occurs both inshore and offshore. While there is little evidence of long distance seasonal movements of larger animals, there is a significant correlation between mean carapace length and depth in the offshore holes during both spring and fall, indicating local offshore ontogenetic migrations of older animals into deeper water throughout the year (Figure 7).

Additional information on shrimp migrations on the Scotian Shelf is available from the nearshore (<3 miles from shore) trap fisheries conducted in Mahone and Chedebucto Bays (Figure 1, Table 3). The Mahone Bay winter trap fishery catches mainly females (> 80% by number), most of are ovigerous which (> 90% by number). This composition is similar to the winter trap fishery in the Gulf of Maine and suggests that these animals immigrated into the bay. Despite the selectivity of fixed gear for larger animals, traps in Chedebucto Bay catch more juveniles and males, and the percentage of ovigerous females is much lower than in Mahone Bay. The Chedebucto Bay fishery is conducted throughout most of the year from summer to spring, but catches decrease to negligible levels in spring-early summer when temperatures in the Bay drop below 1ºC (Figure 8). Trawl surveys at this time (June) show very low numbers of females in Chedebucto Bay itself, but high concentrations immediately outside the Bay (Koeller 1996, Koeller et al 1997). During the Chedebucto Bay trap fishery, catch rates cycle several times during the season in phase with changes in the percentage of ovigerous females (Figure 9), indicating that the fishery is sustained mainly by ovigerous females immigrating into the Bay in “waves” from the surrounding inshore areas.

Differences in the seasonal changes in shallow (0m) and deeper (>99m) water temperatures in the Gulf of Maine, Scotian Shelf and Newfoundland-Labrador shelf (Figure 10) can be related to differences in shrimp migration patterns observed in these areas. On the Newfoundland Shelf average temperatures at depths >99m are near the midpoint of the species temperature range and there is no need to migrate into shallower water (Figure 10A) to find more favorable temperatures. There are no reports of such migrations in this area. In the Gulf of Maine temperatures at depths >99 m are near the upper limit of *P. borealis* temperature range throughout the year but tend to exceed this limit in the fall and winter. At this time ovigerous females appear in large numbers in the shallow inshore areas where water temperatures remain well within the preferred range until early spring. Shrimp are rare in the central Scotian Shelf (Emerald Basin) where mean water temperatures >99m exceed the upper temperature limit throughout the year. Temperatures in the deep water of the western Scotian Shelf (Roseway Basin) are within the temperature range throughout the year, but are near the upper limit during fall and winter when large numbers of ovigerous females appear nearshore in Mahone Bay. On the eastern Scotian Shelf water temperatures are near the lower limit of the species temperature range throughout most of the year. Shrimp are found both inshore and offshore in high densities, but during late winter and early spring when nearshore temperatures in Chedebucto Bay approach lethal limits shrimp move into deeper, warmer water immediately outside the Bay. From this perspective it is not clear why ovigerous females move into Chedebucto Bay from the surrounding inshore area from late summer to spring. The catch patterns of Figure 9 may simply reflect depletion of accumulated stock in a small area by fishing, and subsequent movement of shrimp into suitable unoccupied habitat from surrounding areas of high density.

Growth rates of *P. borealis* on the eastern Scotian Shelf are intermediate to those in the Gulf of Maine and on the Newfoundland Shelf (Figure 11), as expected for an area with intermediate temperatures (Figure 5 upper). Scotian Shelf shrimp grow to an age of about 6 years (Koeller et al 1997), about the same as in the Gulf of Maine (Armstrong et al 1997), but considerably less than on the Newfoundland Shelf (8yr, Parsons et al 1989). The year of first spawning on the eastern Scotian Shelf occurs at age 4, also intermediate between The Gulf of Maine (3) and the Newfoundland Shelf (5-6). The size at first spawning on the central Scotian Shelf (Mahone Bay) is significantly smaller than both the Gulf of Maine and the eastern shelf but it is not possible to determine growth and age at first spawning because the shrimp sampled in Mahone Bay constitute only one mode. In view of the warmer water in this area, and resulting faster growth rates, it is probable that these females were younger than the females on the eastern Scotian Shelf.

DISCUSSION

Data from groundfish surveys, exploratory shrimp surveys and the historical shrimp fisheries on the Scotian Shelf and Bay of Fundy show that *P. borealis* concentrates on the eastern Scotian Shelf. While shrimp are also present in the central and western shelf region their abundance here is much lower, and the population has reached commercially viable densities only once in the historical record. The central and western shelf regions have bottom temperatures which are above the preferred temperature range except in the areas where these fisheries occurred i.e in Roseway Basin and in the mouth of the Bay of Fundy. Since temperatures in these areas are only marginally within the preferred range they can be expected to cycle into and out of it over the long term, allowing the population to increase if conditions remain favorable for a suitable period of time. The coincident development of the shrimp fishery in the western Scotian Shelf and the record catches in the Gulf of Maine in the late 1960s was preceded by a lengthy period of below average temperatures. The subsequent collapse of the Gulf of Maine fishery and disappearance of the western Scotian shelf fishery was preceded by a period of above average temperatures. This apparent connection between temperature and shrimp abundance in these areas does not preclude the concurrent influence of other environmental factors or fishing effects. The longstanding controversy on what regulates the shrimp stock in the Gulf of Maine i.e. “is it temperature (Dow 1977, Richards et al 1993, Appolonia et al 1985, Tande et al 1993) or is it fishing (Anthony and Clark 1980)?” in itself suggests that both factors are involved, the answer being dependant on the particular data set and time period under review. This paper shows that in more recent years predation was also an important factor regulating shrimp abundance in all areas examined, including the Gulf of Maine. The overriding question that must be answered if this type of information is to be useful in stock management is, what is the relative importance of these factors at any given time?

While the Gulf of Maine and western Scotian Shelf have similarities with regard to shrimp population dynamics, they are different in one important respect - long term average abundance in the Gulf of Maine is much higher and, with the exception of the stock collapse in the late 1970s, has managed to sustain a fishery for an extended period. A comparison of the Gulf of Maine, Scotian Shelf, and Newfoundland Labrador shelf provides some insight into the relative importance of the known environmental\ecological factors (i.e. habitat, temperature, depth and predators) to *P. borealis* population dynamics. If the marginal temperature conditions in the Gulf of Maine have resulted in a relatively unstable stock, i.e. large and rapid environmentally induced population fluctuations which can lead to stock collapse in combination with fishing, the more extreme conditions in the western Scotian Shelf have resulted in a small population which increases to commercially viable densities only rarely and for short periods of time. On the other hand, the eastern Scotian Shelf shrimp stock is similar in size, density, and sustainability to the Gulf of Maine. On the eastern Scotian Shelf shrimp concentrate in small areas of suitable habitat within a large area of favorable temperatures. On the western and central Scotian Shelf they are restricted to small areas of marginal temperatures despite the availability of large amount of suitable habitat. Depth does not appear to be as important as habitat in restricting *P. borealis* to the deep offshore holes on the eastern Scotian Shelf, since it is also found in large numbers on suitable habitat in the shallow inshore areas off Cape Breton. Apparently, a combination of suitable temperatures and habitat is a precondition for a high density population of *P. borealis* with the relative importance of factors in this context being temperature>habitat>depth. Superimposed on these factors is predation, which apparently becomes important when temperature and habitat conditions result in a suitable relative abundance of *P. borealis* to other forage species.

On the Scotian Shelf *P. borealis* exhibits migratory behavior with similarities to both the Gulf of Maine and more northern stocks. On the western Scotian Shelf, ovigerous females migrate inshore during winter as in the Gulf of Maine, to find cooler water and/or escape warm water. However, unlike the Gulf of Maine where the fishery follows the shrimp stock inshore in winter and offshore in spring/summer, on the western Scotian Shelf shrimp are usually not present offshore in densities suitable for commercial trawling. Recently, the area has only been able to support a small trap fishery, and only after shrimp have concentrated nearshore in small embayments during winter. On the eastern Scotian Shelf shrimp are present offshore throughout the year in commercial quantities, as occurs in Newfoundland-Labrador and other northern stocks. They are also present inshore throughout the year, however some migration occurs within this area, including nearshore movements in areas with suitable habitat from late summer to early spring which cease and may be reversed in spring-summer when nearshore temperatures become too cold.

Growth rates and age at sex transition on the eastern Scotian Shelf are intermediate to those of Newfoundland-Labrador and the Gulf of Maine populations, as expected for an area with intermediate temperatures. The smaller size at sex transition of shrimp on the western Scotian Shelf is consistent with faster growth in warmer temperatures.

In the absence of empirical, stock specific exploitation parameters Pandalid shrimp managers have tended to use a blanket “rule of thumb” approach, despite well documented differences in biological and population characteristics between stocks that could result in different reactions to similar exploitation rates (Savard and Parsons 1990). For example, target exploitation rates of 35% were widely used in eastern Canada until this was exceeded in some areas with no apparent harm to the stock (Mohn et al 1992). Nilssen and Hopkins (1991) point out that differences in life cycles should be taken into account when developing ecologically acceptable management strategies. The above description of Scotian shelf shrimp biology in relation to more northern and southern populations could have important implications for management in the area.

It is apparent that the western Scotian Shelf cannot sustain a shrimp fishery, yet harvesting opportunities do arise for short periods from time to time. A successful fishery would launch exploratory surveys when temperature conditions are favorable and mobilize/demobilize rapidly as catch rates increase above and decrease below commercially viable levels. Harvest controls would be introduced only if environmental monitoring suggested a prolonged period of favorable temperatures and overfishing could precipitate a “premature” stock collapse.

The eastern Scotian Shelf shrimp fishery appears to be sustainable, yet large changes in abundance in the absence of significant fishing pressure appear to occur due to trophic effects. This suggests a vulnerability to overfishing, including the possibility of collapse when concurrent negative environmental/ecological and fishing effects produce rapid populations declines as apparently happened in the Gulf of Maine in the 1970s. The absence of long range inshore-offshore migrations on the eastern Scotian Shelf suggests that temperatures are less extreme relative to the species’ tolerances and preferences, and that a rapid environmentally induced population decline may be a rarer event than in the Gulf of Maine. However, the lack of significant correlation between bottom temperature and shrimp abundance on the eastern Scotian Shelf in the present analysis does not preclude such an effect since its absence may be due to the time window when temperatures and shrimp abundance indices are available for analysis or the overriding effect of predation in recent years. The area of favorable temperatures surrounding this stock varies significantly over the long term and has resulted in incursions and exclusions of some cold water species such as capelin (Frank et al 1996). It is particularly noteworthy that the two incursions of capelin since 1970 attributed to anomalous cold temperatures occurred during the late 1970s and the 1990s, coincident with periods of high shrimp abundance. Stock assessments should flag any concurrent increases in predation, temperatures and fishing effort since they could lead to rapid population decrease and stock collapse.

The strong affinity of eastern Scotian Shelf shrimp for mud substrates and their resulting concentration in small areas is another potential problem which should be taken into account when considered exploitation levels for this stock. In the Newfoundland-Labrador Shelf, local overfishing will likely result in replenishment from the extensive surrounding shrimp grounds. The Scotian Shelf stock is relatively isolated – it is unlikely that the nearest “upstream” stock in the northern Gulf of St. Lawrence provides significant numbers of viable larvae, consequently recruitment overfishing is likely to be less forgiving. The small patches of habitat suitable for adults result in equally small suitable settling sites for juveniles after the prerequisite planktonic phase. In a dynamic hydrographic regime where horizontal tidal ranges and larval retention gyres are probably larger than the area of suitable habitat, a higher percentage of larvae will settle on unsuitable substrate. Moreover, the northeasterly Nova Scotia current will carry larvae produced in the eastern Scotian Shelf shrimp holes into unsuitable areas only a few miles to the west. The resulting higher larval mortality for this stock will require a higher spawning stock to maintain any particular target yield. Conversely, the intermediate growth rates and ages at maturity of Scotian Shelf shrimp relative to those in the Gulf of Maine and the Newfoundland-Labrador Shelf, suggest a lower vulnerability to recruitment overfishing than the Newfoundland-Labrador Shelf and a higher vulnerability than the Gulf of Maine population for any given gear selectivity.

The above analyses suggest that the management approach to the eastern Scotian Shelf shrimp stock should be more precautionary than for the Newfoundland-Labrador populations, and similar to that of the Gulf of Maine population. The current challenge is to set such “more” or “less” precautionary harvest rules in the general absence of such rules elsewhere.

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		Coefficient	Std. Error	t value	Pr (t)	R Sq.	F	Df	Pr (F)
	Groundfish	-0.0596	0.0161	-0.3705	0.0030	0.5637	7.7550	2(12)	0.0069
Gulf of Maine	**Temperature**	0.0620	0.1554	0.3990	0.6969				
	Intercept	2.2334	0.9395	2.3772	0.0349				
	Groundfish	-13.4293	3.3482	-4.0109	0.0011	0.5230	8.2230	2(15)	0.0039
Eastern Scotian Shelf	**Temperature**	2.2265	10.3870	0.2144	0.8332				
	Intercept	217.8580	39.1024	5.5715	0.0001				
	Groundfish	-0.6622	0.3328	-1.9896	0.0681	0.2504	2.1720	2(13)	0.1535
Newfoundland-Labrador	**Temperature**	-17.7862	31.6720	-0.5616	0.5840				
	Intercept	659.9467	83.7724	7.8779	0.0000				
	Groundfish	-0.6253	0.2242	-2.7896	0.0131	0.3272	7.7820	1(16)	0.0131
	Intercept	647.4811	48.9658	13.2231	0.0000				

Female density (numbers/m^2)

	Spring	Summer		Fall
	Offshore	Inshore	Offshore	Offshore
1982	0.14			0.14
1983	0.40			0.26
1984	0.22			0.10
1985	0.07			0.08
1986	0.15			0.05
1987	0.08			0.12
1988	0.10			0.14
1995		0.29	0.38	
1996		0.12	0.26	
1997		0.25	0.26	
1998		0.36	0.26	
Juvenile density (numbers/m^2)				
1995		0.19	0.31	
1996		0.07	0.08	
1997		0.20	0.17	
1998		0.29	0.29	

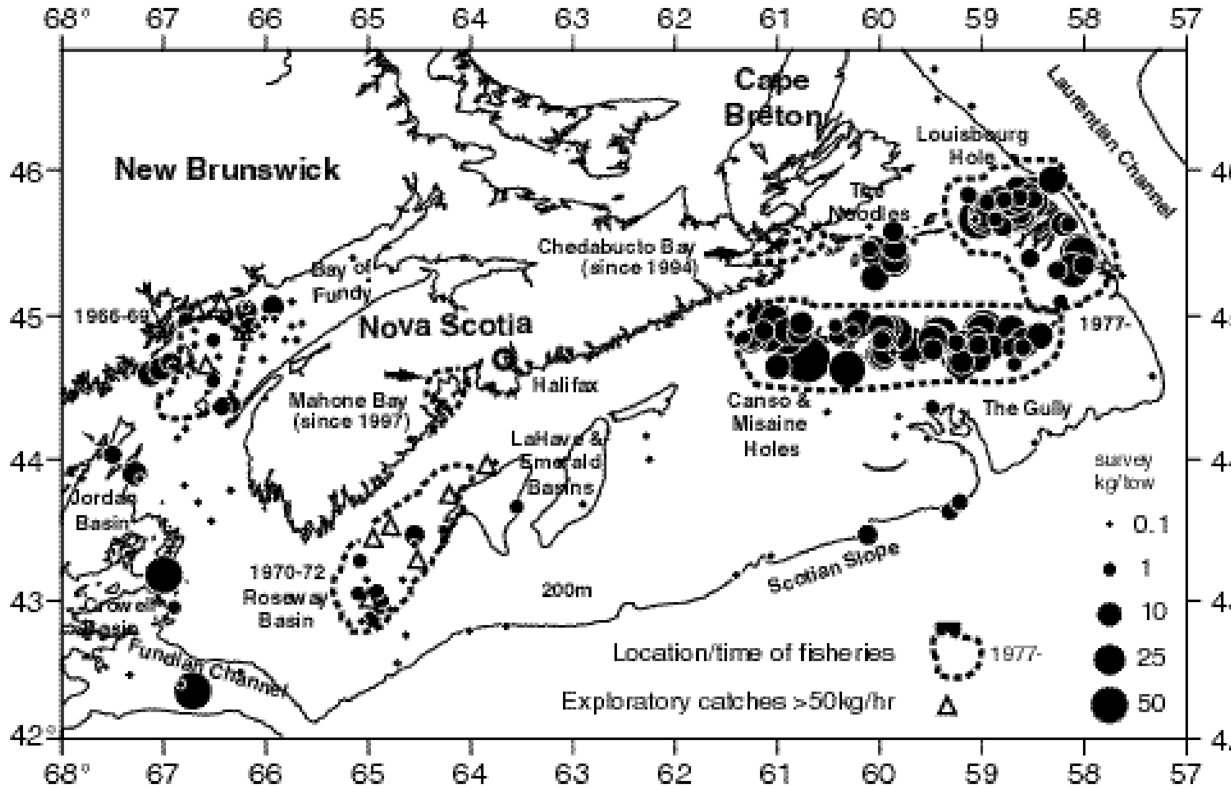

Fig. 1. Scotian Shelf and Bay of Fundy showing the distribution of catches from DFO groundfish surveys (1970-84), location of significant exploratory survey catches (1965-70, 1992-93), and the location of historical fisheries. The place names used in the text are also given.

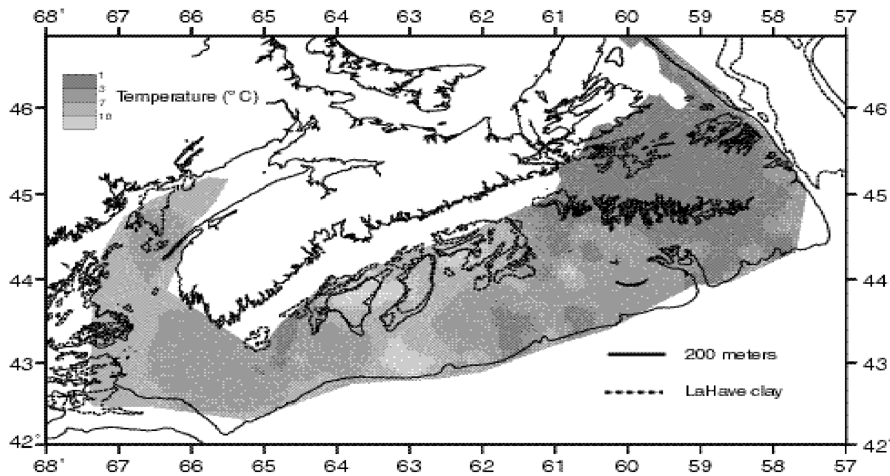

Fig. 2. Scotian Shelf and Bay of Fundy showing the distribution of bottom temperatures during the July 1996 groundfish survey, the distribution of shrimp habitat (LaHave clay), and the 200m depth contour.

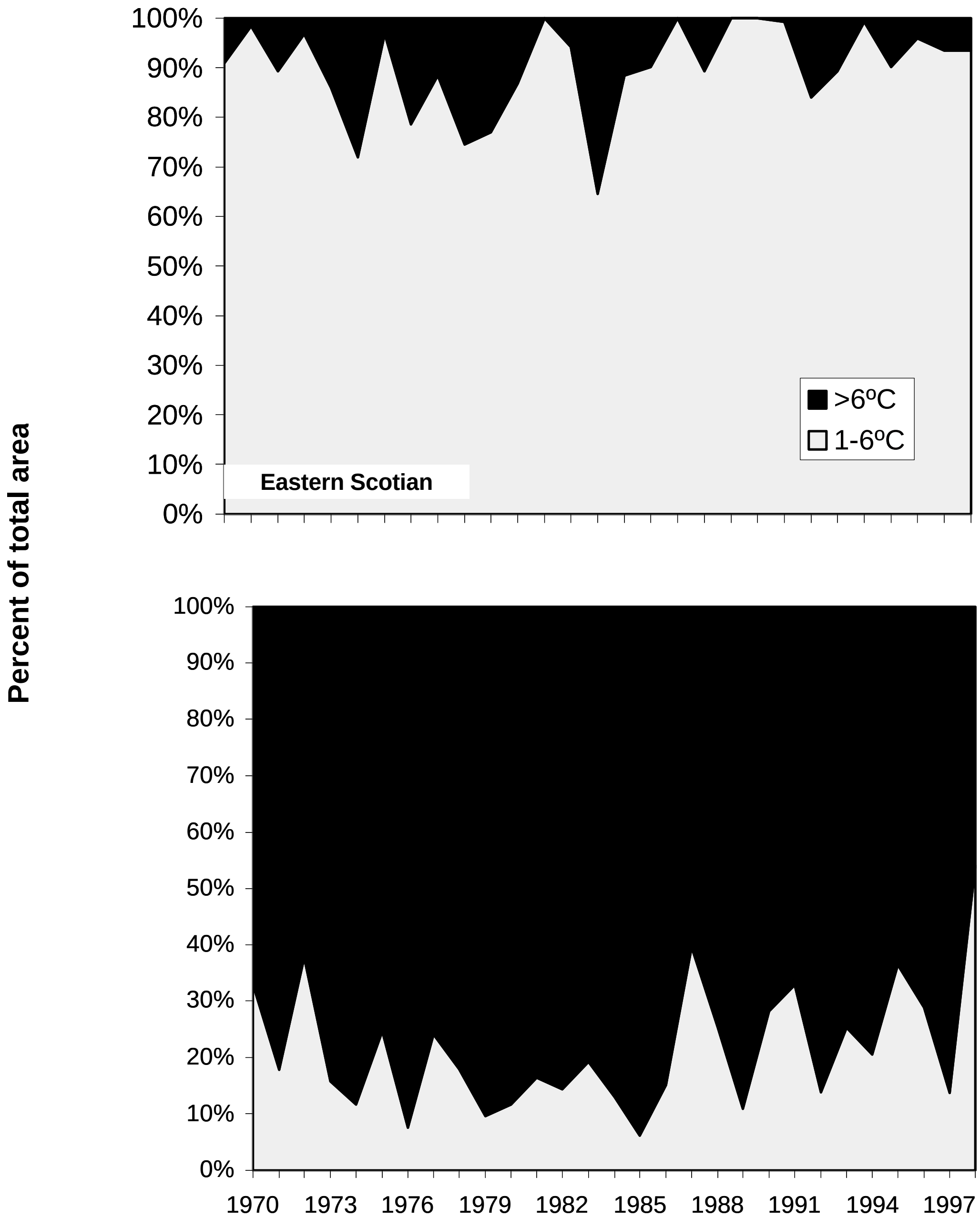

Fig. 3. Percent of the area of bottom on the eastern and western Scotian Shelf having July bottom temperatures within (1-6°C) and above (>6°C) the preferred temperature range of *P. borealis.*

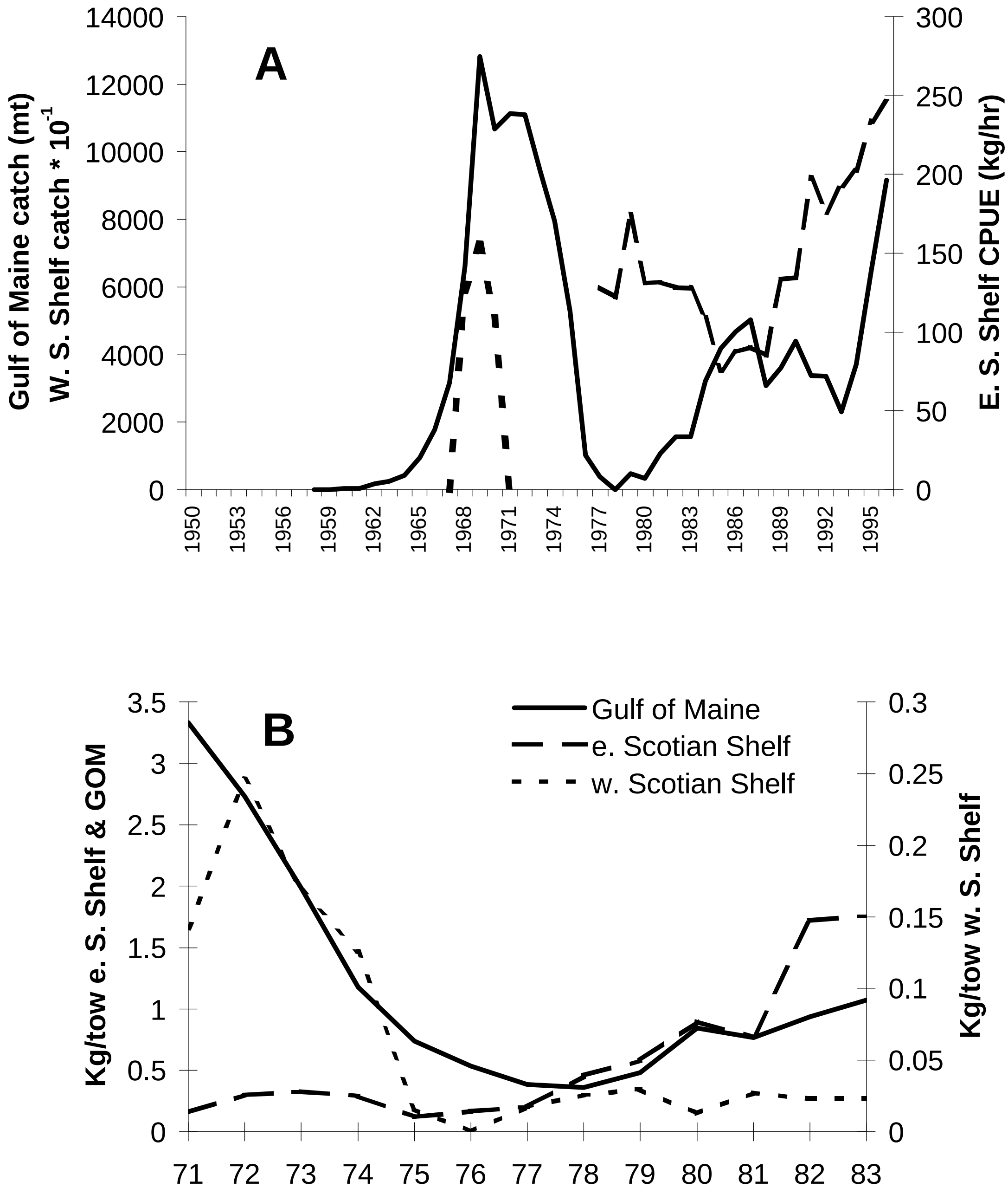

Fig. 4. Changes in shrimp abundance in the Gulf of Maine, western Scotian Shelf and eastern Scotian Shelf as implied from A. landings and commercial catch per unit effort since 1950, and B. stratified mean catch/tow from groundfish surveys since 1971.

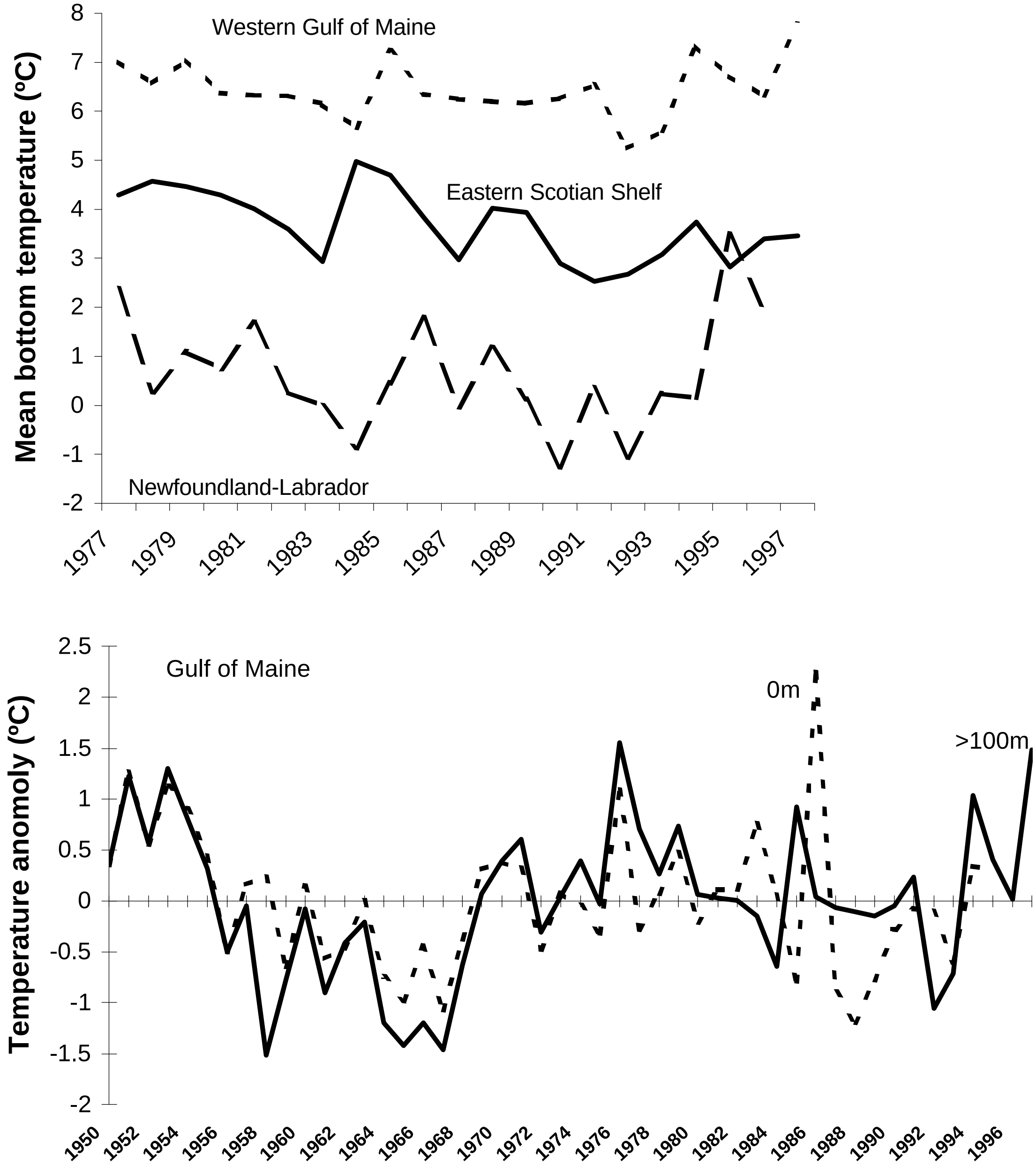

Fig. 5. Mean bottom temperatures (>100m) from groundfish surveys in the western Gulf of Maine, eastern Scotian Shelf and Newfoundland-Labrador shelf since 1977 (upper) and long-term temperature anomalies (surface and >100m) from the Gulf of Maine (lower).

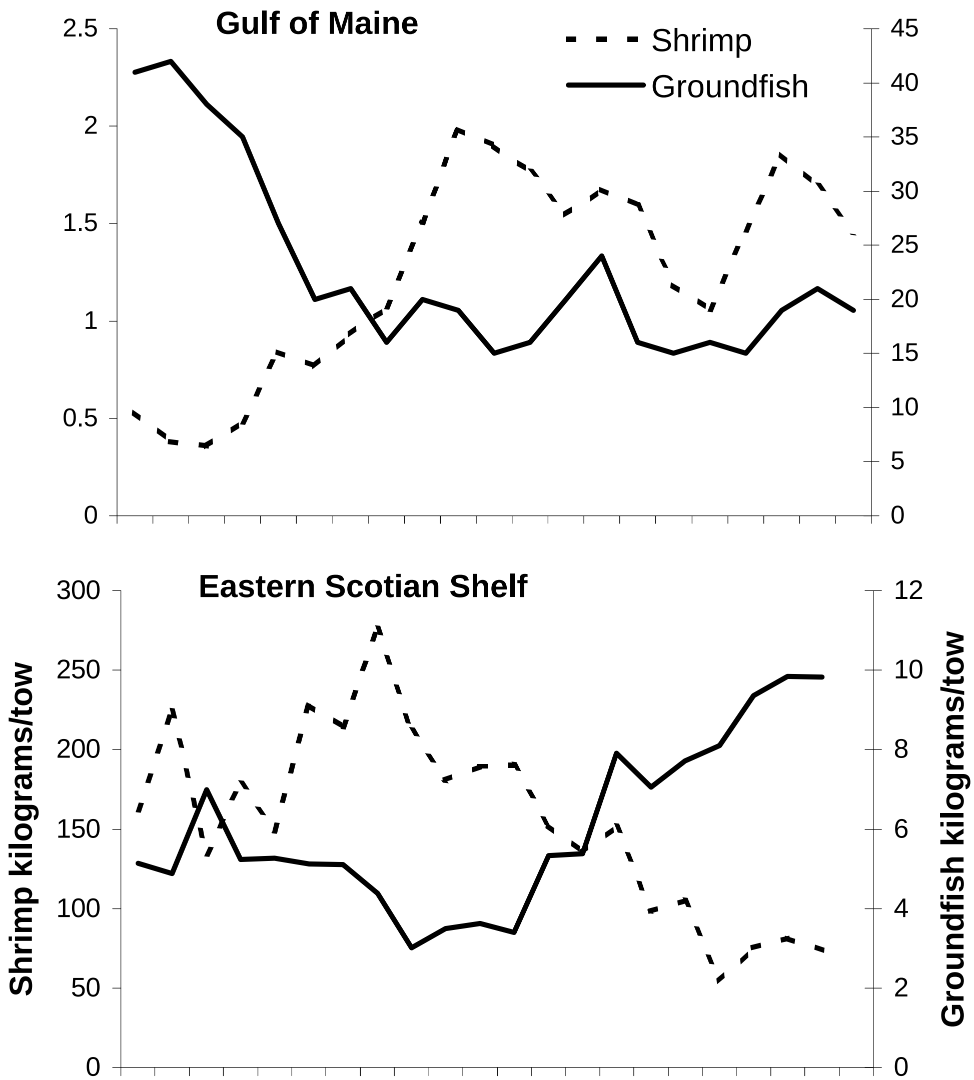

Fig. 6. Shrimp and groundfish catch/tow in the Gulf of Maine, eastern Scotian Shelf and Newfoundland-Labrador Shelf since 1977. All data are from stratified random groundfish surveys except eastern Scotian Shelf and Newfoundland-Labrador Shelf shrimp data, which are commercial CPUE series taken from stock assessment documents.

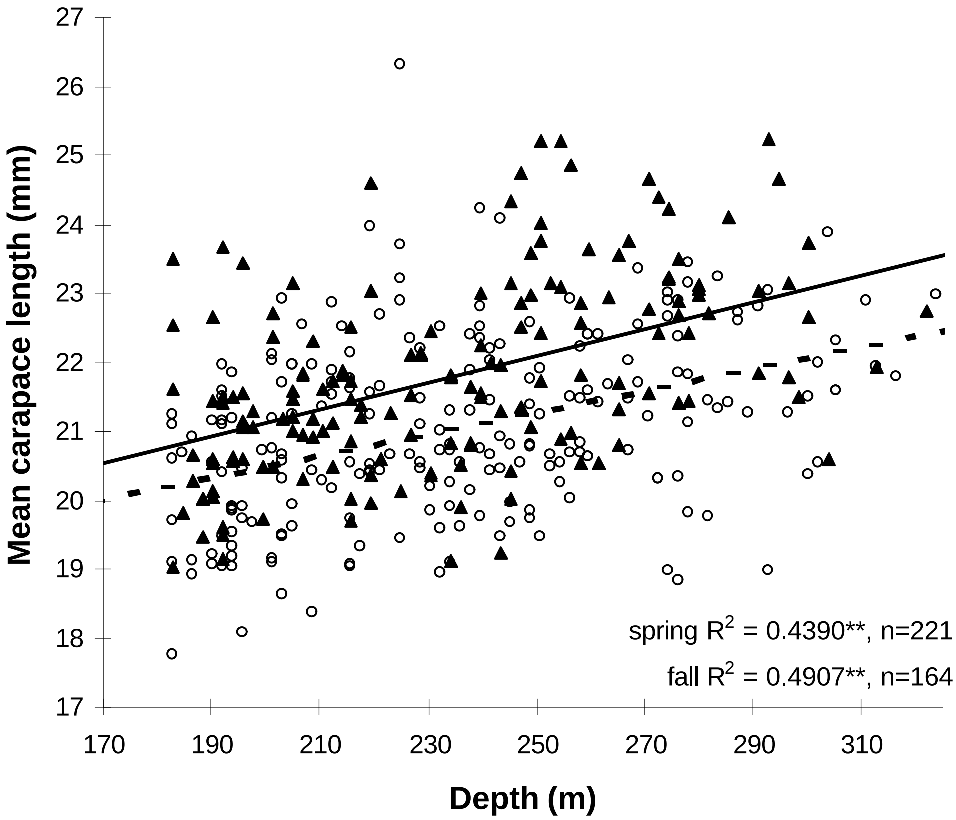

Fig. 7. Mean carapace length versus depth from all shrimp catches taken during spring and fall shrimp surveys conducted from 1982-1988 on the eastern Scotian Shelf.

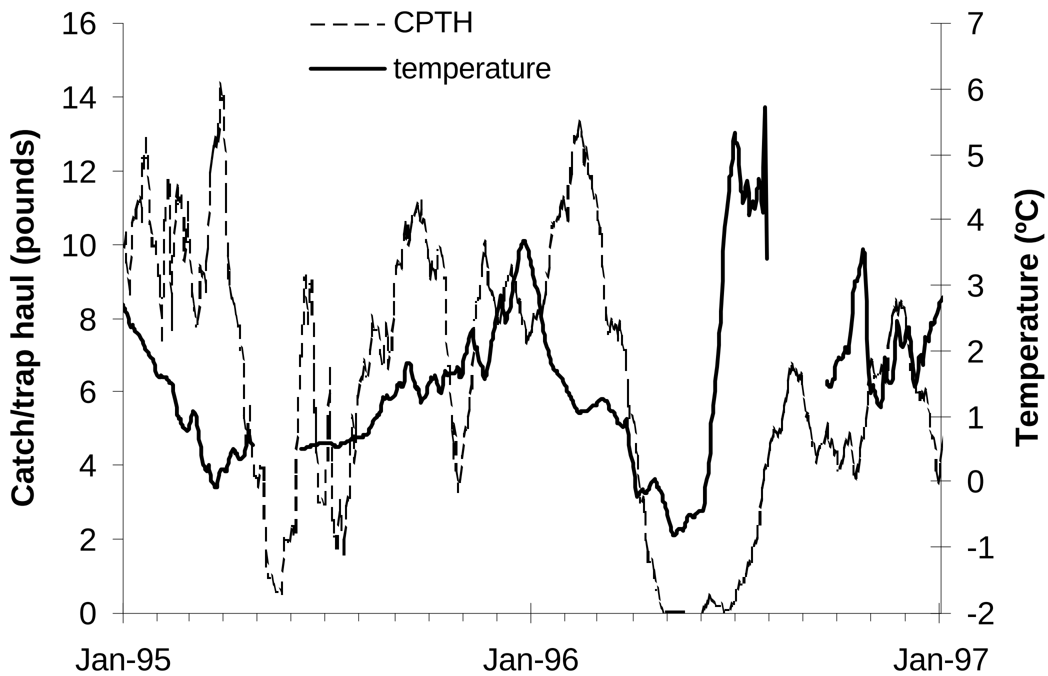

Fig. 8. Average daily commercial catch per trap haul and bottom temperatures in Chedebucto Bay, Nova Scotia during 1995-96.

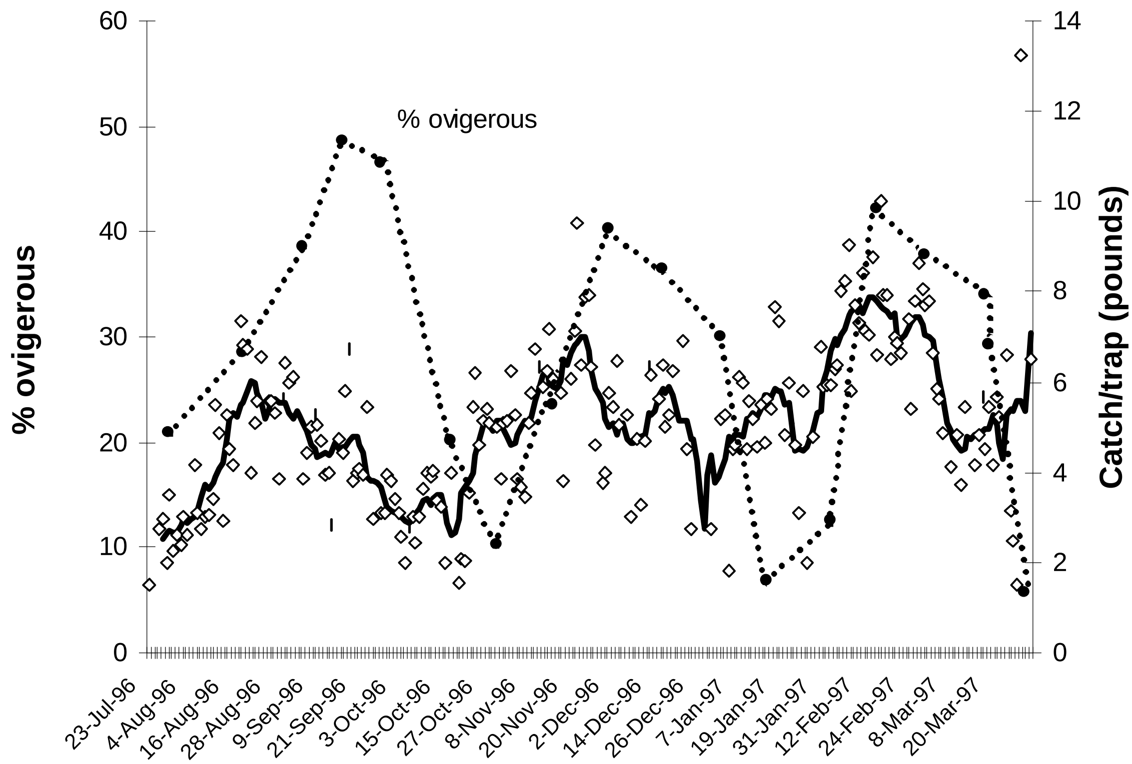

Fig. 9. Average daily commercial catch per trap haul and the percent of females that were ovigerous in commercial trap catch samples during the 1996-97 trap fishing season in Chedebucto Bay, Nova Scotia. Solid line - three-day average of catches; dotted line – percentage of females that were ovigerous.

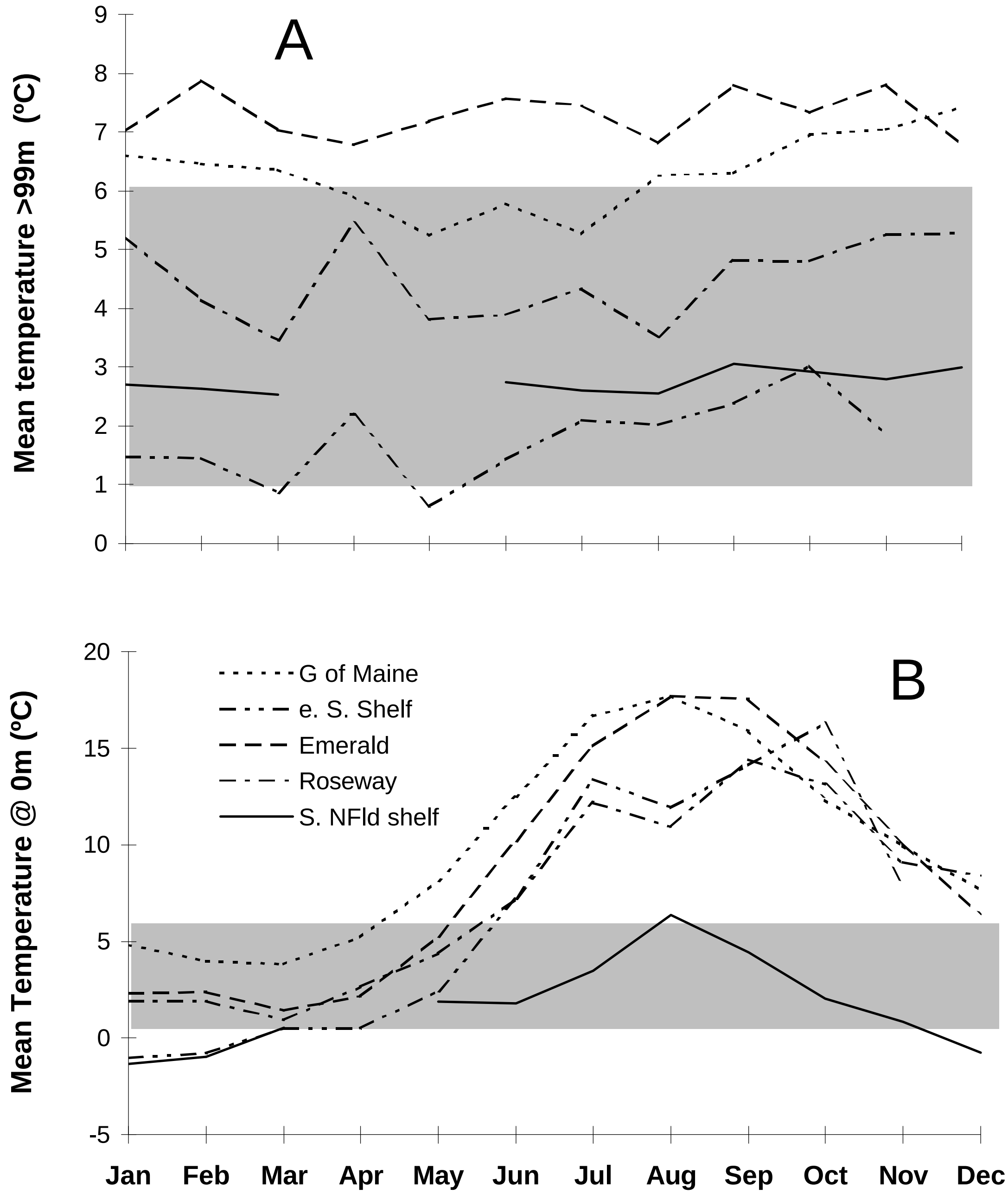

Fig. 10. Monthly mean temperatures for selected areas in the northwestern Atlantic at A. >99 m and B. 0 m.

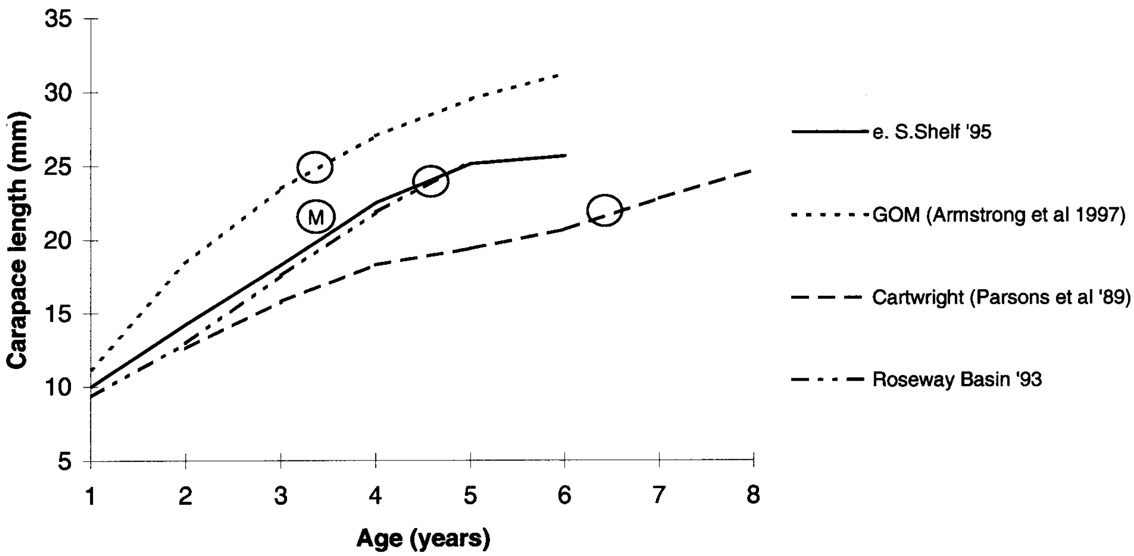

Fig. 11. Growth rates in the Gulf of Maine, the Scotian Shelf (eastern Shelf and Roseway Basin) and the Newfoundland Labrador Shelf (Cartwright Channel) as inferred from modal analysis. The open circles represent the size and age at first spawning in each area except the circle labeled "M" (Mahone Bay) where aging was not possible and size at first spawning only is shown.