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Transport and development of cod eggs and larvae in Placentia Bay (3Ps) Newfoundland, 1997-1998.

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Abstract

Spawning location and timing of Atlantic cod can have a dramatic impact on predominant drift and temperature regimes experienced by developing eggs and larvae. We examined spatial and temporal pattern of cod egg and larval abundance in Placentia Bay with a series of ichthyoplankton and oceanographic surveys throughout the spawning and post-spawning seasons of 1997 and 1998. Mean current patterns suggest a counter clockwise flow around the bay, entering around Cape St. Mary's and exiting at the base of the Burin Peninsula on the western side. CHW egg densities were highest early in 1997 and in the head of the bay. The 1998 peaks, though lower in magnitude, showed a similar spatial pattern. Despite lower egg densities, 1998 larval densities were an order of magnitude higher than in 1997 and were concentrated on the south western side of the bay. A shift in spawning peak to mid summer in 1998 from early spring in 1997 suggests that more eggs were released in warmer waters in 1998, resulting in faster development times and shorter dispersal distances. In terms of larval production, late spawners may be particularly important to successful egg hatching, at least within the Placentia Bay ecosystem.

Résumé

Le lieu et l'époque de frai de la morue de l'Atlantique peuvent avoir des conséquences majeures sur la dérive et le régime de températures que subissent les œufs et les larves en développement. Au cours de 1997 et de 1998, une série de relevés planctoniques et océanographiques ont été effectués dans la baie Placentia, afin d'étudier la distribution spatiale et temporelle des œufs ainsi que l'abondance larvaire pendant et après la saison du frai. Le mouvement moyen du courant indique qu'il longe la baie dans le sens anti-horaire, pénétrant aux environs du cap St. Mary's et ressortant à la base et de la péninsule Burin, du côté ouest. La plus haute densité d'œufs de CHW (morue, aiglefin et plie grise) a été observée tôt en 1997, au fond de la baie. En 1998, ces pics ont été moins importants, mais la distribution spatiale était comparable. Même s'il y a eu moins d'œufs en 1998, le nombre de larves a décuplé par rapport à 1997, et celles-ci étaient concentrées sur le côté sud-ouest de la baie. Le pic du frai, en 1998, s'est produit au milieu de l'été plutôt que tôt au printemps comme c'était le cas en 1997. Il semblerait qu'un plus grand nombre d'œufs auraient été pondus dans des eaux plus chaudes en 1998, réduisant de ce fait les périodes de développement et les distances de dispersion. Ainsi, en ce qui concerne l'écosystème de la baie Placentia, du moins, les géniteurs qui frayent tardivement pourraient avoir une influence déterminante sur le succès de l'éclosion des œufs et, par conséquent, sur la production larvaire.

Introduction

Annual variation in ichthyoplankton densities (by orders of magnitude) have been observed in studies of coastal Newfoundland planktonic communities (Thompson 1943, Laprise and Pepin 1995), and has been attributed to variation in water temperature. Although annual variations in environmental conditions may be significant, the sharp seasonal gradient in water temperatures suggest spawning time may dictate conditions experienced by developing eggs and larvae. Historically, mean spawning date has been shown to vary significantly between years for cod in 3Ps (Hutchings and Myers 1994), and on average tends to occur around mid May. Several theories explaining variation of mean spawning date have been examined with limited success (Cushing 1969, Hutchings and Myers 1994, Saetersdal and Loeng 1987). In areas such as coastal Newfoundland, where seasonal hydrographic conditions vary widely, differences of a month or two can result in dramatically different conditions during spawning and egg development. In addition, development and mortality rates for cod eggs have both been shown to be a function of water temperature (Bonnet 1939, Iversen and Danielssen 1984, Laurence and Rogers 1976, Pepin 1991, Pepin et al 1997). As such, the variability in spawning date that has been documented for 3Ps should impact drift of eggs and larvae and subsequent survival.

Since the collapse of Atlantic cod stocks in the waters surrounding Newfoundland during the 1990's, large inshore aggregations of spawning cod have comprised a major component of the spawner biomass. The contribution of these inshore spawning events to recruitment is currently unknown and the relative success of these spawning events has recently been questioned (Smedbol et al 1997). Within Placentia Bay, on the south coast of the island (see fig. 1), recent documentation of discrete spawning locations and limited data on predominant currents led us to hypothesise that the occurrence of larvae would be related to egg retention and development, and therefore to spawning location, temperature-dependent development, and current patterns. Largely anecdotal data suggest that currents flow into the bay along the eastern side and flow out along the western side. Thus, we predicted that in the absence of outside egg and larval sources, late stage eggs and larvae would be found in the head of Placentia Bay and along the western side, coinciding with greater juvenile habitat availability.

Methods

Coastal Circulation

Coastal circulation was first investigated with a passive drift experiment in which 500 grapefruit were released from each of two sites near Bar Haven and Perch Rock (see fig.1), in June of 1997; both of these sites had been identified from acoustic surveys as major spawning locations in the bay for that year (Lawson and Rose 1999). Further investigations of the coastal circulation were made in the spring of 1998 using a pair of s4 current meters (B. deYoung unpublished data), moored on opposite sides of the bay from

April to May , and a two day ADCP (Acoustic Doppler Current Profiler) survey of the bay conducted during Teleost 65 (June 1998).

Ichthyoplankton Sampling

During the spring and summer of 1997 and 1998, Placentia Bay was surveyed for ichthyoplankton along a set survey grid of six transects (see fig.1). Transects were eight nautical miles apart and stations were four nautical miles apart along each transect. The survey gear consisted of a 2mx2m Tucker trawl with a decreasing mesh sizes from 1000 µm at the mouth to 333µm at the cod end. Two General Oceanic flowmeters were placed at the mouth to allow estimates of flow volumes. Double oblique tows to a maximum depth of 40m and of 15min. duration were collected at a towing speed of 2 knots. Ichthyoplankton samples were preserved in 4% buffered formalin (sampling protocol as per Laprise and Pepin 1995). For sample processing, cod egg and larval abundances exceeding 300 were subsampled using a Motoda splitter (except April and June 1998 which were processed by the Atlantic Reference Center and subsampled using the beaker technique of van Guelpen et al, 1982). All eggs and larvae were identified to the lowest taxonomic level possible and measured to the nearest 0.5mm.

Vertical CTD casts for salinity and temperature were collected concurrently with ichthyoplankton samples at each station using either a Seabird 19 or 25. Mixed layer temperatures were determined by averaging 0-40m from each profile.

Results

Coastal Oceanography

Drifters released from the Perch Rock site were recovered in the eastern channel (P - fig 1.) and drifters from both release sites were recovered in the western channel near Bar Haven (BH-fig.1). The drift study, s4 measurements, and ADCP data all support the prediction of southerly flow on the western side and northerly flow on the eastern side of the bay (see figures 1, 2, 3). Average flow speeds were approximately 20cm/s in the outer Bay (from s4 time-series data at 10m). Mixed layer temperature averages (0-40m) for the entire bay showed a 1-2 degree increase for corresponding time periods from 1997 to 1998 (see fig. 4).

Cod eggs and larvae

The difficulty in separating early stage cod eggs from those of witch flounder and haddock necessitated the CHW grouping. Nonetheless, careful identification of many late stage eggs and the larvae has shown only incidental numbers of these other species and it is therefore reasonable to assume the majority of sampled CHW eggs are Atlantic cod.

Densities of stage one eggs were highest in April of both years (particularly April, 1997) suggesting associated spawning peaks (see fig. 5). Highest densities of stage one eggs were observed at stations near Bar Haven, Perch Rock, and Oderin Bank. Distribution of egg stages coincides with spawning location and predicted circulation (see fig. 6), in that late stage eggs usually occurred on the western side of the outer bay where predominant circulation patterns would have allowed the longest development time for eggs spawned within the bay. In addition, the average densities of late stage eggs (stages 3&4) and larvae were higher in 1998 than in 1997 (fig. 5). The temporal peak in late stage eggs observed in May of 1997 occurred in June (stage 3) and August (stage 4) of 1998.

The temperature-dependent development relationships in Pepin et al (1997) allow for prediction of stage duration at various temperatures. These equations were incorporated into a simple model of egg development where percent completion of each stage was accumulated daily and egg numbers were subject to a constant daily mortality rate (set arbitrarily here at 10%). Figure 7 shows the development and mortality of eggs spawned from a normally distributed spawning curve. Each day, eggs are spawned and develop toward hatch while subject to this fixed mortality. As can be seen from the 3 plots, as mixed layer temperature increases, development rates are faster and a shorter time to hatch results in lower total losses to mortality. Shorter development times also suggest decreased passive dispersal distances, suggesting that warmer periods should favour successful development to late stage eggs and hatching within the bay, rather than export out of the bay..

Larval densities were also highest on the south western side of the outer bay (fig. 8) corresponding to the pattern observed in late stage eggs. Although egg densities in April 1997 were highest than at any other time in the two years of the study, larval densities were very low in all of 1997 and highest in August of 1998 (fig. 9). Back calculations of the spawning period expected to result in these peaks in larval density (represented as shaded rectangles in fig. 9) were based on mixed layer water temperatures and the temperature-dependent development relationships in Pepin et al.(1997). The range of larval ages was based on the 95% confidence intervals for the larval lengths of each cruise and a 33mm/day growth rate from Pepin et al 1995. This calculation predicts that the spawning activity that produced the observed hatching likely occurred in mid March and early July in 1997, and in mid July in 1998.

In most of the samples taken, the numbers of cod larvae sampled were too few to make any inferences about size structure. However in August of 1998 a total of over 900 cod larvae were sampled, in contrast to a total of 41 larvae in 1997. Figure 10 shows the changes in maximum larval length and mean larval length measured for each transect. The pattern shows increases in larval size from the inner to the outer bay, a pattern consistent with predicted coastal flow patterns as larvae develop and are transported south along the western side of the bay.

Summary

The measured flow patterns and intensities suggest that currents flow in the eastern side of the bay and flow out the western side. Thus, assuming eggs are spawned largely within the bay, the occurrence of larvae in the bay should be dependent on the temperature-dependent development of the eggs, spawning times, and location. The fact that the peaks in stage one egg density were observed in April of both years, and that these spawning events produced relatively low densities of larvae suggests that eggs spawned early in the season are flushed out of the bay and/or are subject to high mortality as a result of increased exposure to predation and decreased hatch rates at low temperatures.

High egg densities were observed late in the spawning season in 1998 suggesting increased spawning late in the spawning season in 1998 relative to 1999. This delay likely contributed to elevated larval densities within the bay. Adult distributions based on acoustic surveys of the bay show the peak spawning period was delayed by approximately 80 days in 1998 (Lawson and Rose submitted), and juvenile abundances also show a an increase in 1998 (Robichaud and Rose submitted). Our data suggest that this delay in spawning peak, in combination with an increase in mixed layer temperature, are responsible for the increase in larval densities in 1998.

As such, the presence of early stage eggs may be a poor indicator of subsequent larval abundance in coastal Newfoundland. In addition, peaks in inshore spawning may be less important to larval production when they occur in conditions similar to those in April 1997. It may be the late spawners that contribute most to successful hatching of larvae and a subsequent inshore settlement / recruitment signal.

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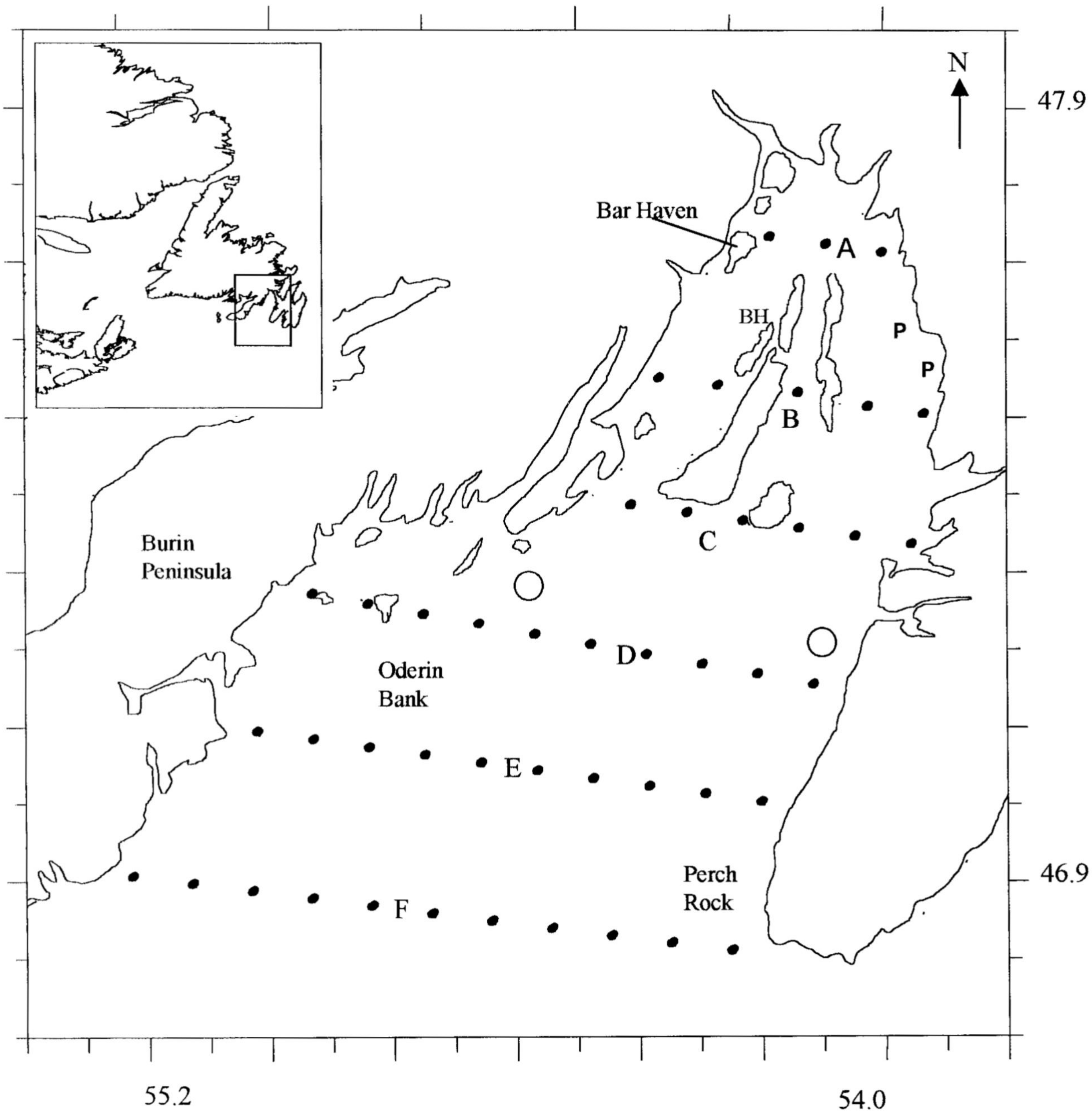


Figure 1. Chart of Placentia Bay survey transects (A -F) and stations; inset shows position of bay in relation to Newfoundland; open circles represent s4 mooring locations; P and BH represent Perch Rock and Bar Haven released drifter recoveries.

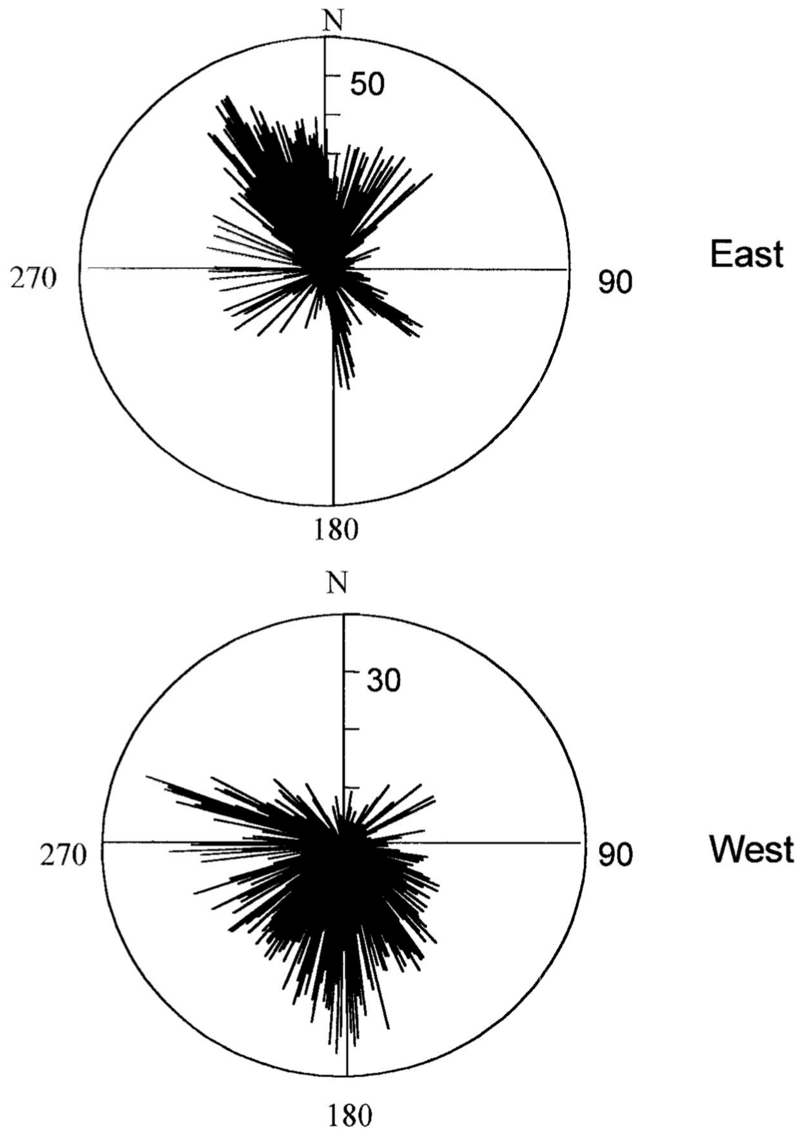


Figure 2. Polar plots of hourly currents at 10m depth from the eastern and western sides of Placentia Bay Newfoundland, April 20 - May 11 1998 measured with S4 current meters.(B. deYoung, upublished data). Scale on North axis indicates speed in cm/s.

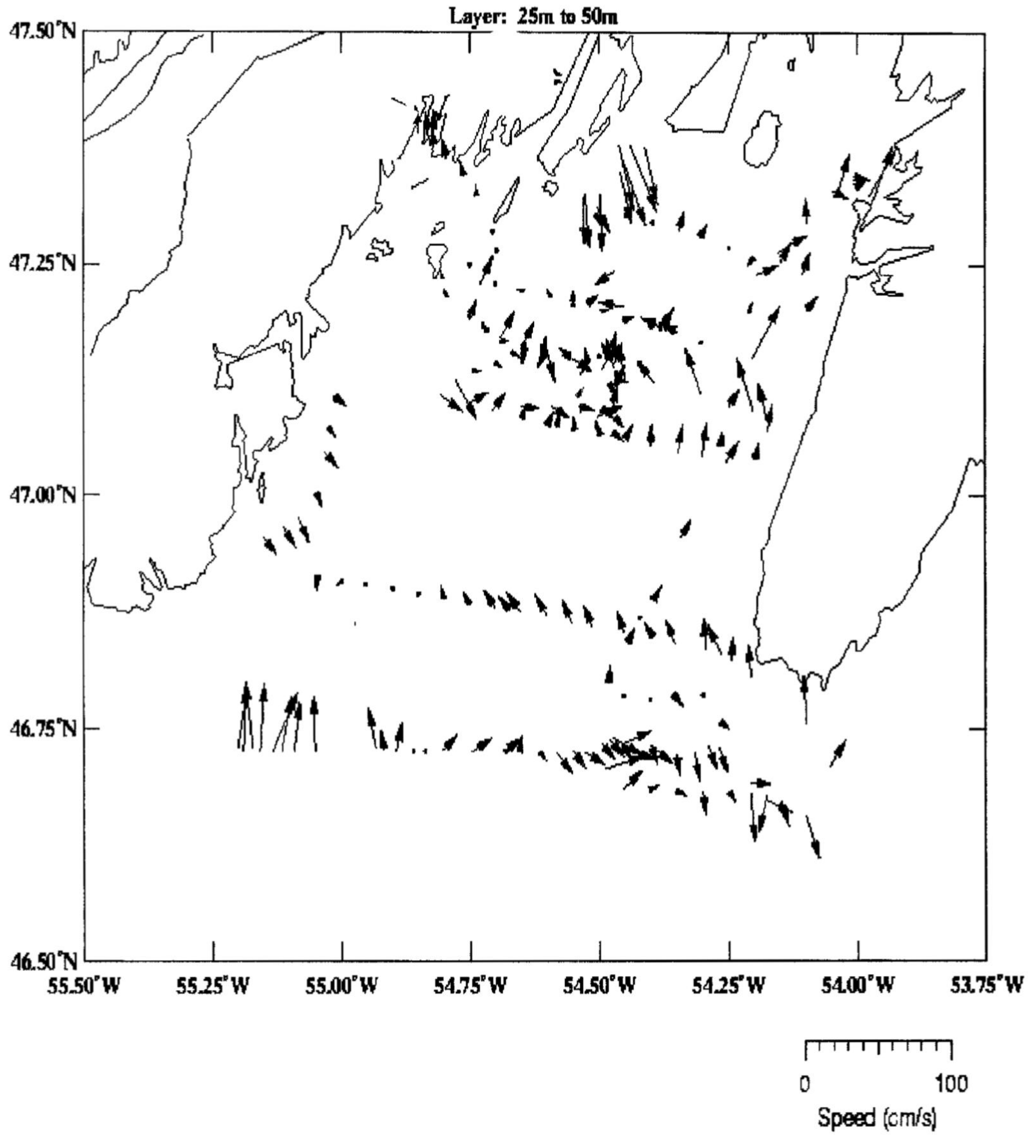


Figure 3. Current vectors (average 25-50m) measured using ADCP, data from June 21-22 1998. Tidal component has not been removed from data.

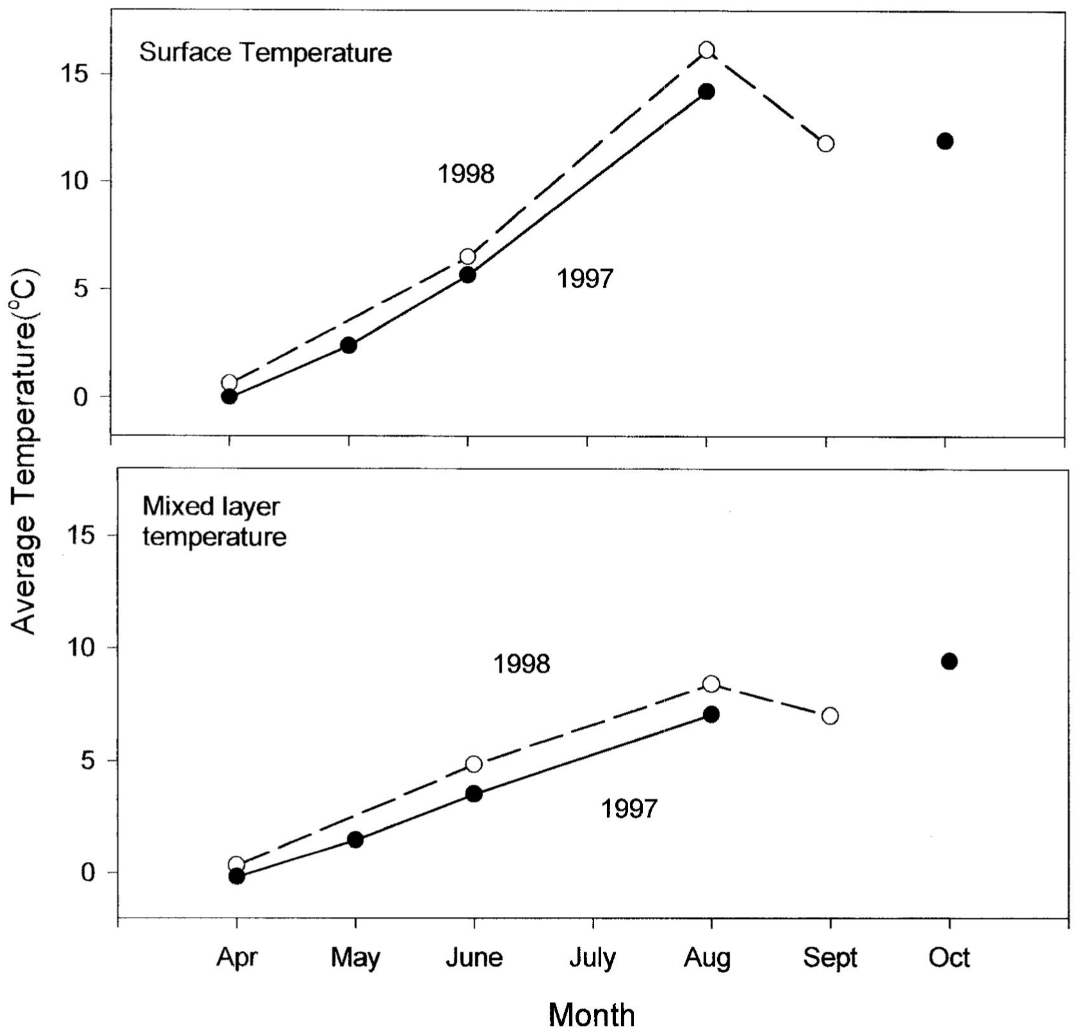


Figure 4. Seasonal changes in average surface (5m) and mixed layer (0-40m) temperature for Placentia Bay from survey CTD profiles conducted in 1997 and 1998. Data averaged from all stations in sampling grid, except for April and October(single point), which only include stations from transects D and C northward respectively.

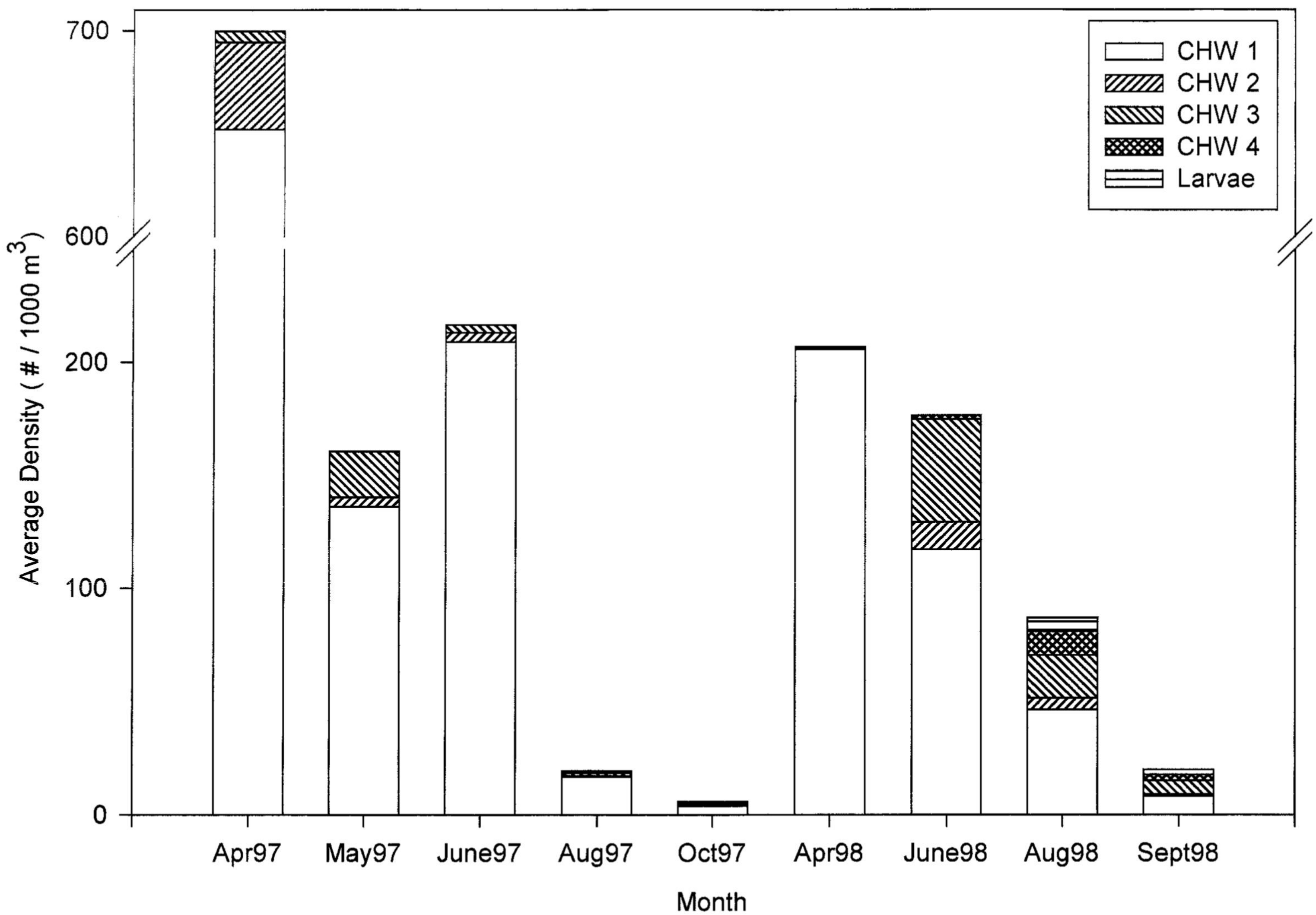


Figure 5. Temporal changes in mean egg stage and larval density in Placentia Bay during the Spring and Summer of 1997 and 1998, based on Tucker trawl survey data.

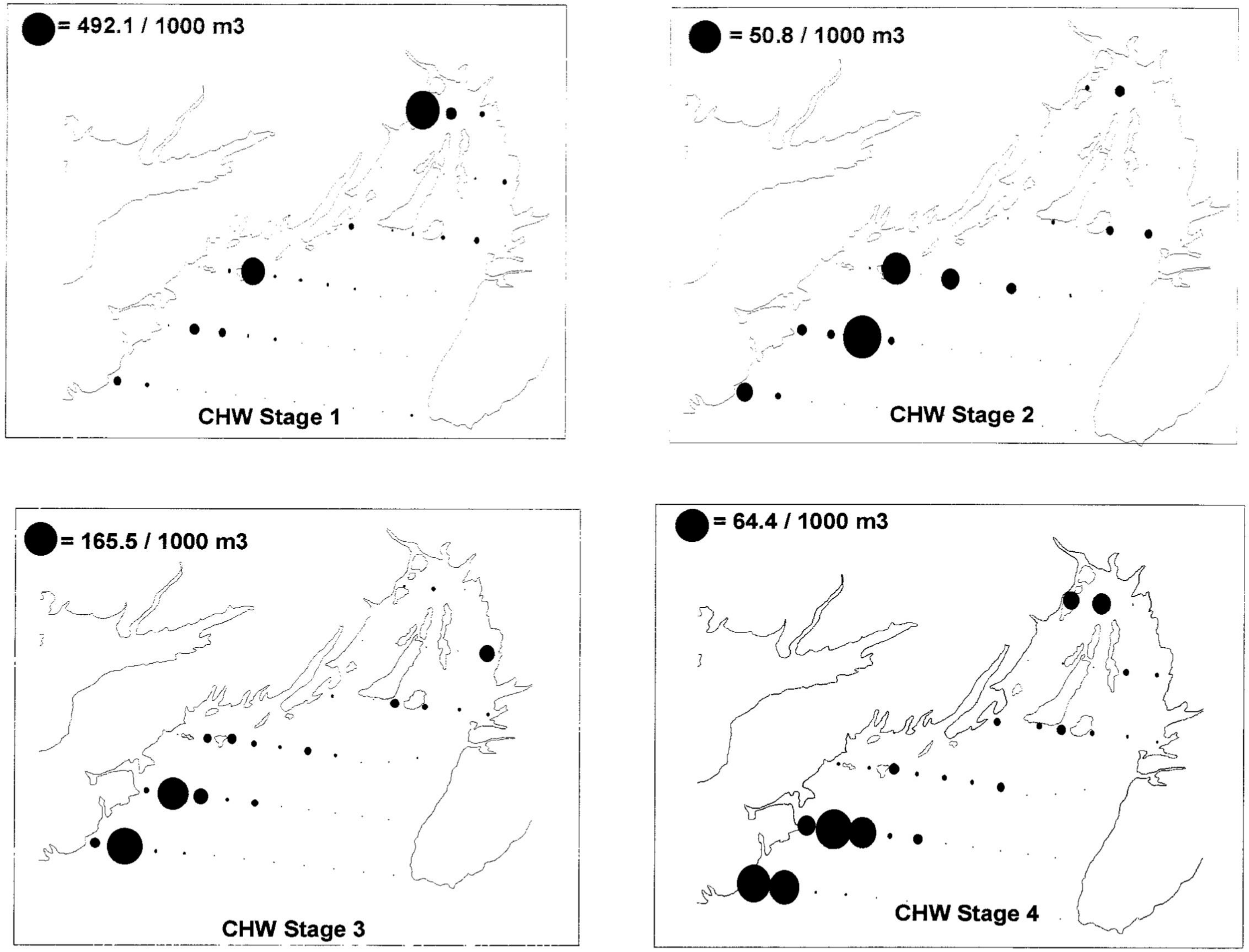


Figure 6. Density of CHW eggs from the August 1998 Tucker trawl survey of Placentia Bay. Note. Scales change from panel to panel.

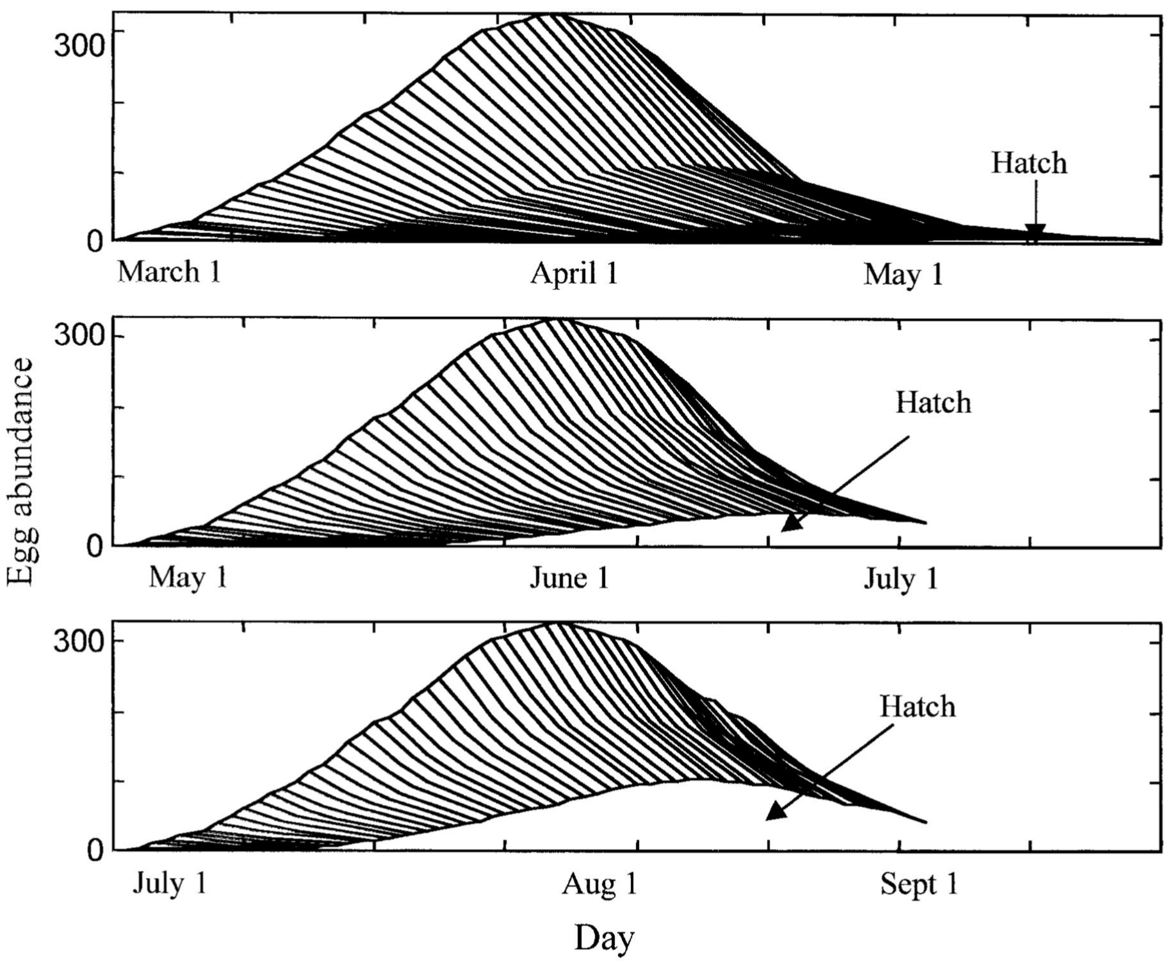


Figure 7. Model predictions of egg development and mortality from three normally distributed spawning events centered on April 1, June 1, and August 1. Eggs spawned from the spawning curve develop toward hatching (end of the line) while subject to fixed mortality (set at 10% daily loss). The area beneath the lines represents the number of individuals that hatch. Intersection with the x-axis indicates 100% mortality. Temperature dependent stage durations from Pepin et al (1997).

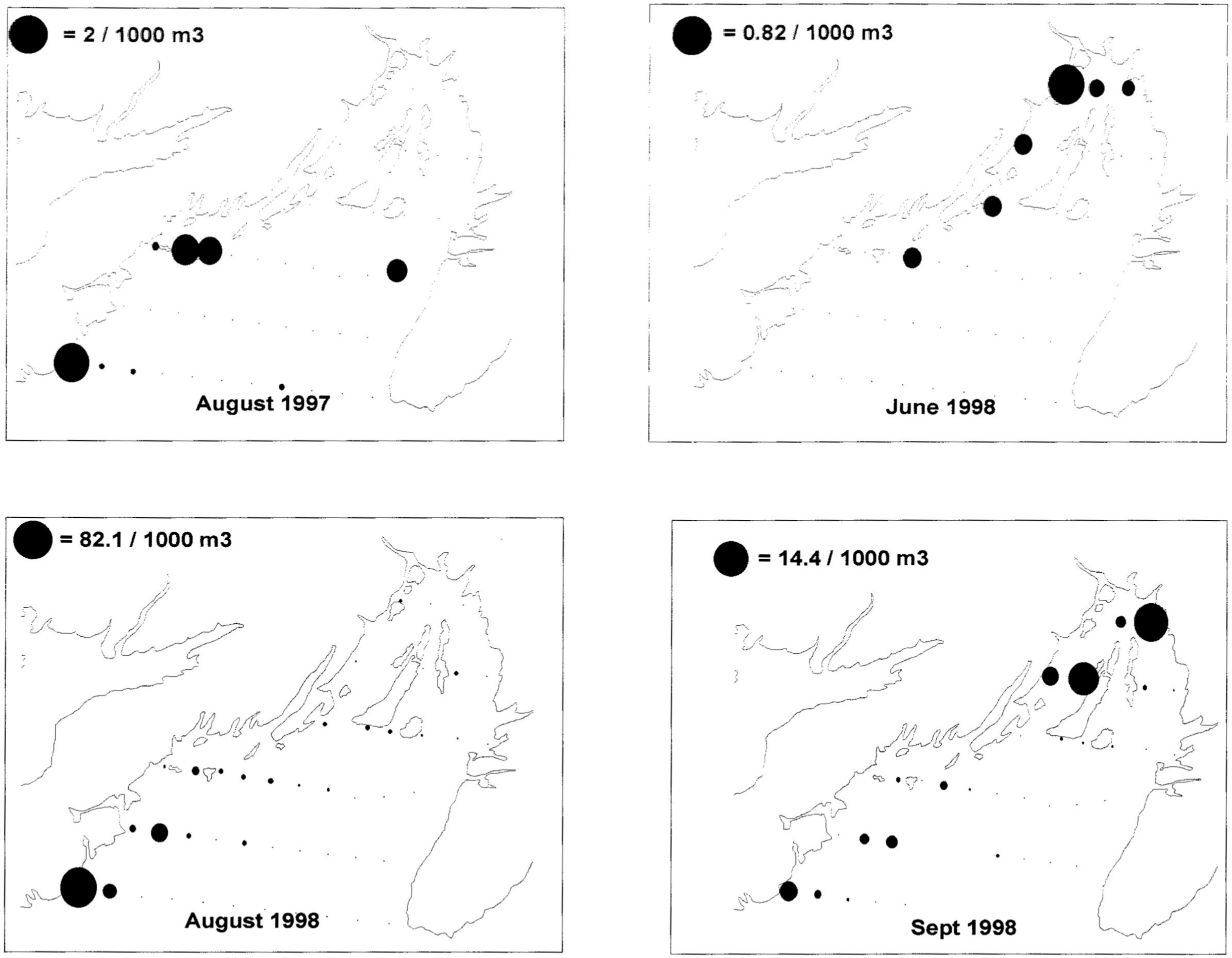
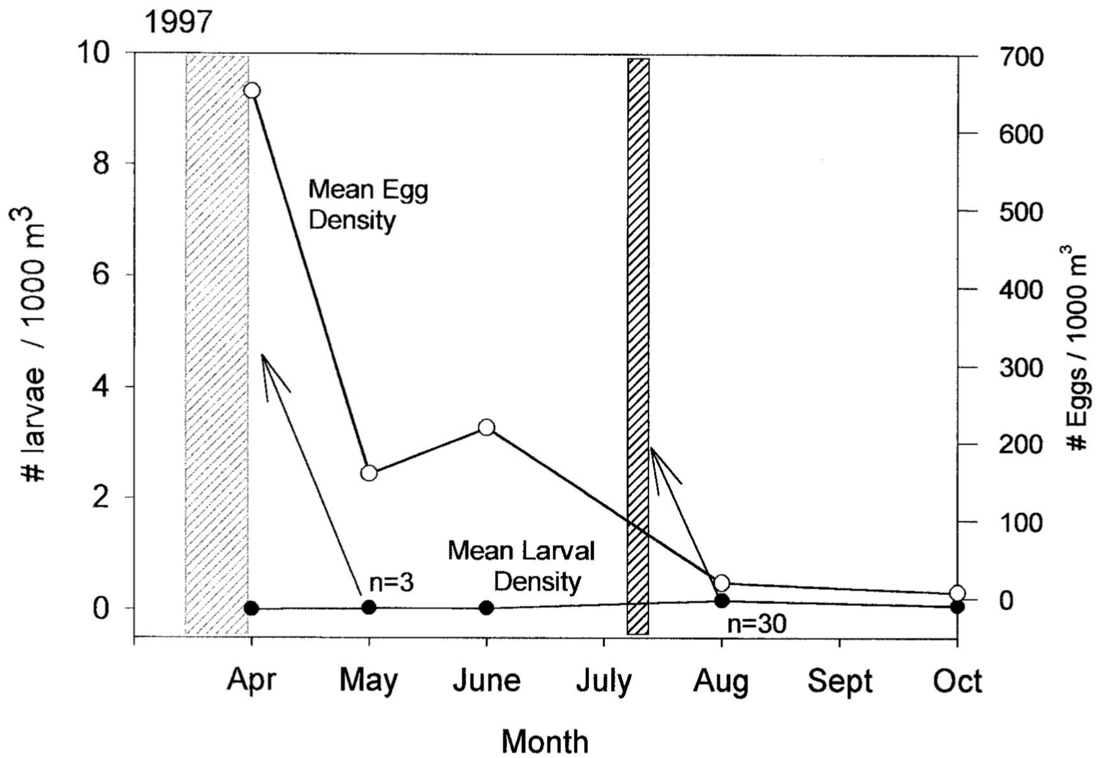


Figure 8. Distribution of cod larvae from the 1997 and 1998 Tucker trawl survey of Placentia Bay. densities recorded in May and June of 1997 were extremely low- see figure 5.



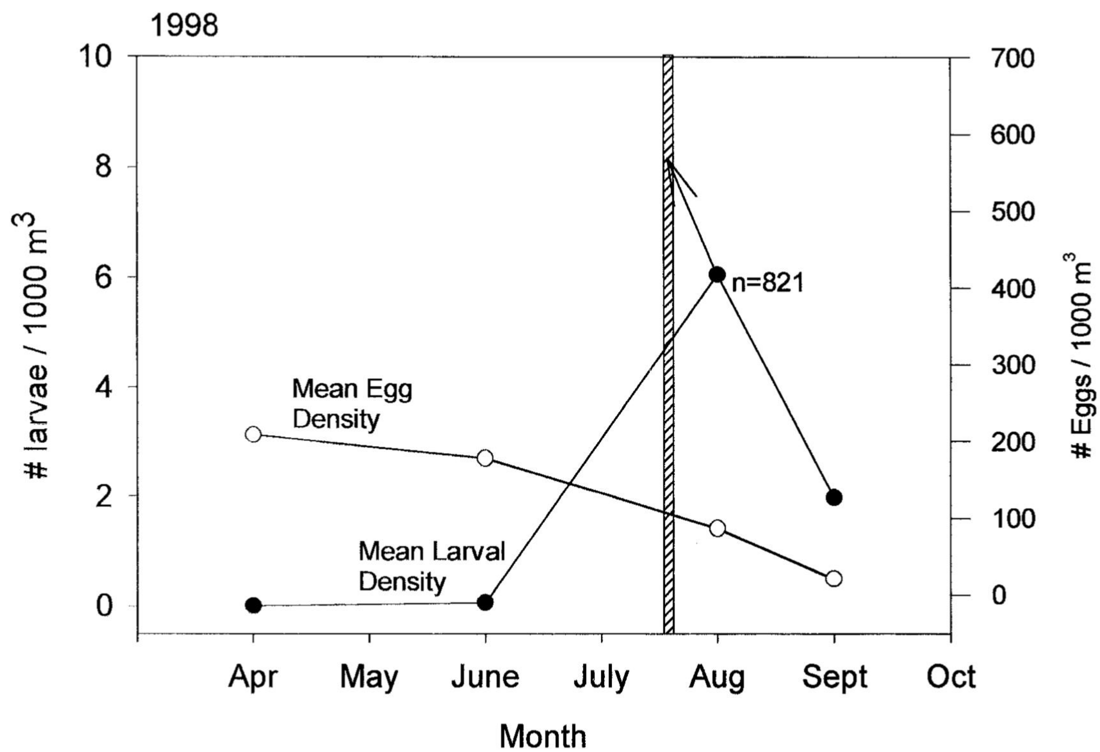


Figure 9. Seasonal changes in mean larval density for Placentia Bay. Solid points indicate survey dates and each bar represents the predicted period during which spawning would have to occur to produce the larvae sampled at each indicated peak in larval density. Back calculation of spawning period based on relationships in Pepin et al. (1997) and a maximun larval life based on 95% CI of larval lengths and a 0.33mm/day growth rate(Pepin et al 1995).

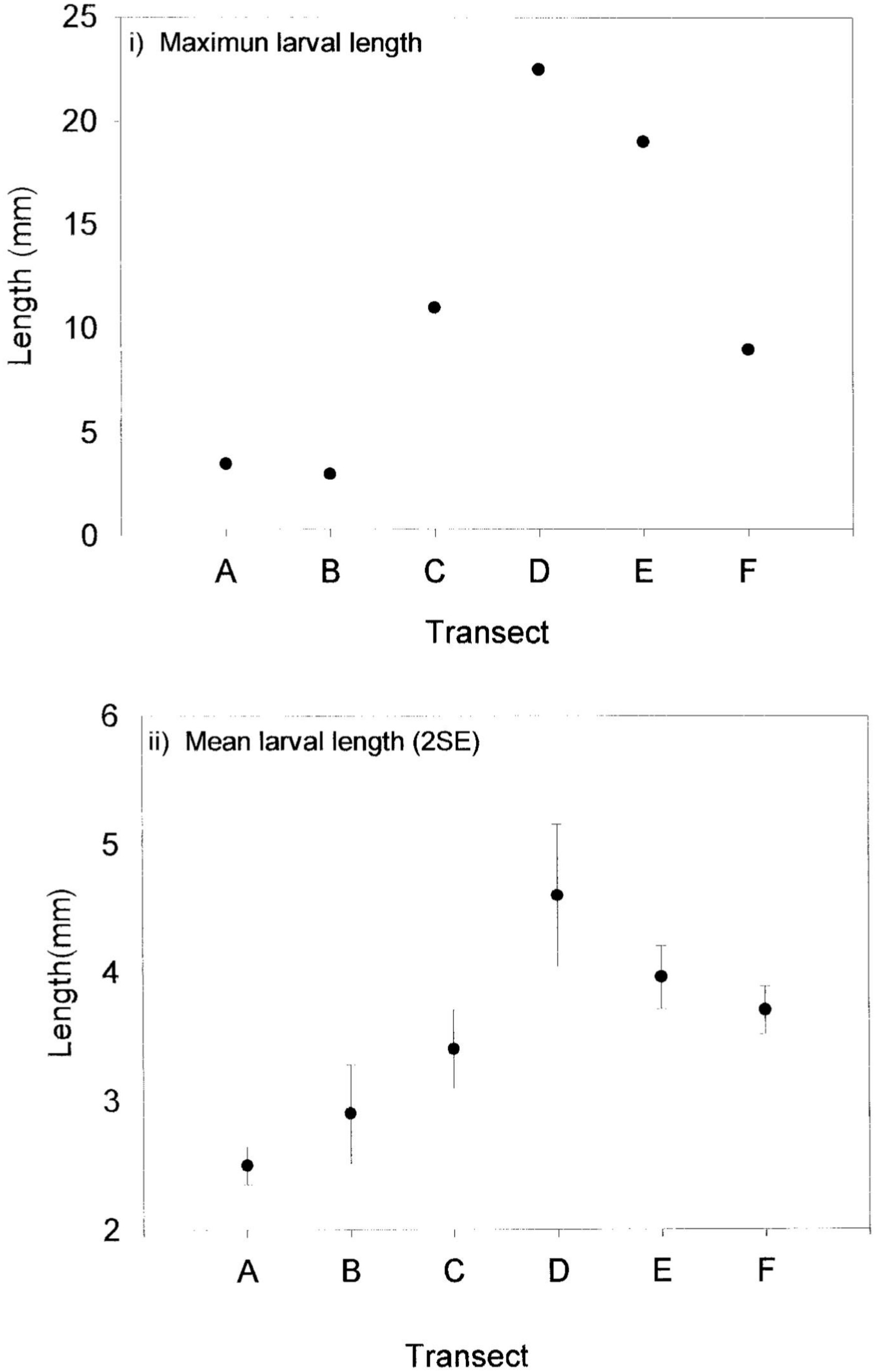


Figure 10. Changes in maximun and mean larval size with transect based on data collected during a Tucker trawl survey in August 1998. Lengths are averaged across each transect.