TEMPORAL AND SPATIAL DISTRIBUTION OF LARVAL AND POST-LARVAL BLUE MUSSELS (Mytilus edulis/Mytilus trossulus) AND STARFISH (Asterias vulgaris) WITHIN FOUR NEWFOUNDLAND MUSSEL CULTURE SITES

MIRANDA LEIGH PRYOR

Temporal and Spatial Distribution of Larval and Post-larval Blue Mussels (*Mytilus edulis/Mytilus trossulus*) and Starfish (*Asterias vulgaris*) within Four Newfoundland Mussel Culture Sites

by

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ABSTRACT

As the blue mussel farming industry in Newfoundland continues to grow, farmers anticipate problems regarding spat collection and the presence of predatory starfish on collectors, based on past experience. The objectives of this study were to examine the temporal and spatial patterns of planktonic larval and post-set stages of both mussels and starfish to determine if a consistency in timing of spawning, settlement and abundance exists between these two organisms.

During 1998, four sites were chosen throughout the province, with weekly larval and spat/juvenile samples taken from May to November. Mussel larvae were abundant at three sites, located on the North coast, from mid-June through late August, with starfish larvae appearing from late June through late August. While some trickle spawning events were recorded, most larger pulses of mussel larvae were generally followed by a larger pulse in spat settlement, ~4-6 weeks later. Size data for these sites also indicated the presence of a major influx of larvae early in summer with some smaller events occurring in late summer to early autumn. Mussel spat settlement and starfish juvenile settlement subsequently occurred at varying times for all three sites, with peak starfish settlement occurring about 2-3 weeks after peak mussel settlement.

For the fourth site, located on the southern shore, mussel spawning was sporadic resulting in low settlement on collectors. As well, no starfish were observed on this site. While

larval numbers were highest among sites along the North coast of Newfoundland, geographic location alone does not seem to be the major factor determining larval procurement and spat settlement. The one sample site along the South coast had very low larval numbers throughout 1998 but, without experiencing any loss of spat over the winter months, anticipated spat available for socking in the spring would be comparable to the other three sites.

During 1999, larval size and abundance was examined over a 12-hour tidal cycle, on two of the sites examined in 1998 (one on the North Coast, one on the South Coast) and the results indicated that larval numbers changed often over the tidal cycle, at both sites, with observable changes in the abundance of such fouling organisms as starfish and saxicave clam larvae also recorded. This study demonstrated the importance of a standardized and accurate method for monitoring larval abundances on shellfish culture sites with the timing, occurrence and relationship of abundance between larvae and spat/juveniles of mussels and starfish being site specific throughout Newfoundland.

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1.0 INTRODUCTION

Aquaculture research offers valuable insights into a developing industry, which in turn relies heavily on research for its growth. With the collapse of traditional fisheries in Newfoundland and Labrador, many coastal communities have searched for employment opportunities that would permit residents to remain in rural areas. The global community's appetite for seafood has grown, demanding high quality finfish and shellfish products to satisfy the ever-growing global market. For these reasons, aquaculture has become an industry that holds tremendous promise for the future economic development and commercial production of seafood.

Blue mussel aquaculture, in particular, remains in the forefront of aquaculture production in this province due primarily to large amounts of high quality seed being produced naturally each year. Hatchery-rearing technologies, which are both expensive and labour intensive, have been developed for many species such as oysters, where natural production does not supply enough spat from one year to the next. However, blue mussels along the East coast of Canada do not need to rely on such technologies as there is an ample supply of wild seed available annually.

Wild collection is a fairly inexpensive and potentially reliable source of seed for a shellfish grower (Penney, 1993). For example, in the case of mussel farmers, poly-rope collectors, on average 2 m in length, can be deployed, in areas of abundant larvae, and

collect greater than 60,000 seed per collector (Macneill et al., 2000) . Considering that mussel growers, on average, may deploy several thousand collectors per year then this could ultimately lead to an abundant supply of mussels that will need to be socked in the following season (*Note*: Typically mussels can spend anywhere from 5 to 12 months on a collector, at which time they are stripped and placed inside mesh 'socks'. These socks are again attached to mainlines and provide a surface for the juvenile mussels to crawl through and subsequently attach, using their byssal threads, for final grow-out). Yet, knowing when and where to deploy collectors requires a great deal of consideration and detailed information. To begin with, knowledge of the reproductive cycle of the animal in question is vital.

1.1 Biology of the Blue Mussel, *Mytilus edulis/Mytilus trossulus*

The blue mussel, *Mytilus edulis*, is a member of the family Mytilidae, Class Bivalvia and Phylum Mollusca. It is a filter feeder that is circumglobal in distribution and is found in abundance among naturally occurring mussel beds throughout Newfoundland (McDonald et al., 1991). Also prevalent, in Newfoundland and Labrador, is another common blue mussel species, namely *Mytilus trossulus*, which can be found amongst populations of *Mytilus edulis* (Innes and Bates, 1999). Penney and Hart (1999) noted that while both species are widely distributed throughout Newfoundland, *Mytilus edulis* is the dominant species with *Mytilus trossulus* constituting a low of 0% to a high of 84% depending on sample site. However, hybridization of the two species has been demonstrated (Innes and Bates, 1999; Rawson et al., 1999). In Nova Scotia, *Mytilus trossulus* is very similar in

size, shape and colour to *Mytilus edulis* (Mallet and Carver, 1995) yet due to a perceived lower market value of this mussel, it is often undesirable to both growers and processors alike.

Adults of the blue mussel, *Mytilus edulis/Mytilus trossulus*, tend to spawn during the same period of time, with some evidence indicating that *Mytilus trossulus* may initiate gametogenesis earlier than *Mytilus edulis* (Freeman and MacQuarrie, 1999; Maloy et al., 2003). Gametogenesis of the blue mussel progresses rapidly through spring and early summer, with spawning occurring late in June and July (Lowe et al., 1981; Sutterlin et al., 1981; Thompson, 1984). Timing gametogenesis during or directly following the spring phytoplankton bloom ensures adequate food levels will exist for planktonic larvae (MacDonald and Thompson, 1986; Jaramillo and Navarro, 1995). The pelagic larvae produced may spend 1 to 4 weeks (Bayne, 1965, 1976) actively searching for a suitable substrate on which to settle (Figure 1), with larval settlement and metamorphosis determined by larval competency to respond to cues in the environment (Bonar et al., 1990; Morse, 1990; Pawlik, 1992; Zimmer-Faust and Tamburri, 1994). Thus, if a grower wants to collect mussel spat and does not properly understand the settlement patterns of these animals, the 'wave' of larvae passing through the site could be missed entirely.

Mussels have separate sexes, but while it is not possible to determine sexes by external shell morphology, ripe gonads can be easily differentiated. Spawning occurs in early to mid summer depending on the mussel population or species in question, as well as

environmental conditions (i.e., temperature, salinity, etc.). Repeated spawnings have been identified, particularly during spring and summer for *M. edulis* and is commonly referred to as 'trickle spawning'. However, in a province such as Newfoundland and Labrador where summers are short and only a small window of opportunity exists for spawning to occur, mussel populations will most likely exhibit a single short spawning period lasting only a few weeks (Chipperfield, 1953; Kautsky, 1982; Newell et al., 1982).

Gametes are released into the water column where external fertilization occurs and free swimming trocophore larvae develop (Rodhouse et al., 1984). As larvae grow (~ 50 μm per week) they are now called the 'D' stage or veliger larvae, and under optimum conditions, in approximately 1-2 weeks the larvae have grown to a length of 100-200 μm. The planktonic veliger actively swims by use of the velum and feeds in the water column by utilizing cilia located on this velum (Lutz and Kennish, 1992). This stage can last from 1 to 4 weeks until the foot and eye spots of the larvae develop at ~200-300 μm, at which time larvae are competent to settle and are now referred to as the pediveliger stage (pedi = foot).

There are many physical (i.e., water flow, depth, temperature, substratum type, etc.), biological (i.e., larval behaviour), and chemical cues (i.e., peptides and/or free fatty acids associated with conspecifics or congeners, hexane and ethanol extracts from brown and red algae, polysaccharides and glycoproteins from bacterial films, etc.) involved in the settlement and subsequent metamorphosis of pediveliger stage bivalves (Young, 1985;

Bonar et al., 1990; Parsons et al., 1993; Rodriguez et al., 1993; Harvey et al., 1995; Pearce et al., 1996). Metamorphosis can be delayed for several weeks (up to 40 days @ 10°C) if a suitable substrate is not found (Bayne, 1965, 1976). Yet, once metamorphosis (irreversible morphogenic phase) has occurred, newly settled spat are visible on the spat collector lines as tiny specks or 'pepper' seed. Artificial collectors, especially filamentous ones, are quite effective in monitoring settlement of mussel larvae under natural conditions (Eyster and Pechenik, 1987; King et al., 1989). Thus, the entire process from fertilization to spat ranges from about 2 to 4 weeks, dependent on temperature, salinity, food and other factors (Bayne, 1976; Sprung, 1984).

Due to variations in environmental conditions, starvation and predation by fish and invertebrates, mortality of mussel larvae in nature approaches or exceeds 99% (Mileikovsky, 1974; Widdows, 1991). Thus, not only do physical obstacles exist to survival, but biological ones do as well. In fact, many marine species have been identified as potential predators of the blue mussel (Osman et al., 1992; Ray-Culp et al., 1997; Dolmer, 1998; Miron et al., 2002), with the most prevalent of these on mussel culture lines in Newfoundland waters being the predatory starfish species *Asterias vulgaris*. Starfish predators, if present in large enough numbers can completely consume a collector and in the case of the larger organisms, are able to consume mussels through to commercial size (Dare, 1982). Starfish are very effective predators that are capable of adapting to their prey and even changing their attack strategies such that when mussel shells were equipped with electronic indicator devices to measure the force applied by

starfish, three types of attacking behaviour were described: (1) A short pulse (on small and large mussels), (2) A pulse of long duration (on medium sized mussels), and (3) A change in position to the opposite side of the hinge ligament (on large mussels) (Norberg and Tedengren, 1994). However, sea urchins, crabs and lobsters and other invertebrate species will also prey on mussels if the opportunity exists. Therefore, growers should be aware of such predators on their sites, and if present, develop and implement predator avoidance procedures as required.

Hence, with all these factors considered, the primary goal of this research is: ***To maximize spat collection on mussel spat collectors (i.e., determine when they settle and how many settle) through assessment of the influence of biological and environmental factors on four mussel culture sites in Newfoundland.***

1.2 The Blue Mussel Industry

The cultivation of bivalves, and in particular the blue mussel, *Mytilus edulis/Mytilus trossulus*, has been established throughout the world for centuries. Worldwide production of mussels alone exceeded 1.6 million tonnes (t) in 2001 (FAO website, FAOSTAT, 2004). Canadian blue mussel production peaked at 21,666 metric tonnes in 2001, worth an estimated 30.5 million dollars (Figure 2). However, this accounts for less than 2% of global production (McDonald et al., 2002) and still remains a relatively 'new' and growing industry. Newfoundland's current share of this production is still quite low, but is continuing to grow. It has been estimated that this province holds the potential to

produce 2,500 metric tonnes by 2005 (Figure 3). Within the Atlantic Provinces, Newfoundland production is higher than New Brunswick and Nova Scotia, but falls short of Prince Edward Island (Table 1).

As with all aquaculture ventures, the production of a marketable product is highly dependent upon the growth and survival of the cultured animals. Mussels of the *Mytilus* spp. are native to our coastlines, and in most areas there is abundant wild seed supply. However, unpredictability of larval supply from one year to the next has heightened the need for research in this area (Penney, 1993). Growers have experienced excellent collection during one year and in anticipation of a similar set the following year, have deployed extra collectors. Unfortunately, if settlement is delayed or in smaller amounts than previous years, then money has been lost in equipment costs, employee salaries and future sales. Thus, if the mussel industry in Newfoundland is to continue to grow and become competitive on a global scale, knowledge of factors associated with larval supply and spat settlement/retention are needed (Freeman, 1996).

1.3 Commercial Farming Practices in Newfoundland

Throughout the world there are many different methods used to successfully culture blue mussels. The primary method used within the Atlantic Provinces, and in particular Newfoundland, is the longline system. The longline system is an off-bottom cultivation procedure that has only been developed in the last 30-35 years (Hickman, 1992). This system consists of a head rope or 'longline', anchored on either side and suspended by a

variety of different shaped floats and/or barrels. Socks and collectors are suspended from this longline with typically 200-250 collectors being suspended 30-50 cm apart on a 100 m longline, with the number of collectors deployed dependent on the requirement of the owner of the farm (Macneill, 1997). Longlines are generally cheaper, easier to construct and maintain, and provide slightly better growth rates than equivalent raft systems (Hickman, 1992; Fuentes and Molares, 1994). Success of this system relies on the settlement of mussels that exhibit preferential settlement on filamentous substrata (Young, 1983; Eyster and Pechenik, 1987).

The production of blue mussels, from spat settlement to finished product can take anywhere from 2 to 3 years depending on environmental conditions and such influences as site topography, etc. (Bayne and Worrall, 1980; Mallet and Myrand, 1995; Macneill et al., 2001). Current commercial farming practices, particularly in the Atlantic Provinces rely on wild collection of seed in comparison to the more costly hatchery production. Hatcheries for blue mussels in Atlantic Canada are not cost effective at present as there is an abundance of high quality wild-caught seed from most areas of the region. In contrast, it has only been in countries such as China, Chile, Tahiti, and along with the west coast of Canada and the United States that requirements for hatchery production of blue mussel seed exist (Rosenthal et al., 1995). However, selective breeding programs, to improve the quality of the stock may also require hatcheries for the production of triploid animals.

Larval monitoring provides an excellent indication of larval development and possible spat abundance on a site. Past studies have shown a close relationship between the number of larvae and the number of settling spat (Mason and Drinkwater, 1981). As adult mussels in a given area, for the most part, tend to spawn at the same time (all together), growers relying on wild seed collection need to know when to deploy their collectors to 'collect' as many seed as possible. On average, collector deployment ranges from early-July to early-September in Newfoundland, but is entirely dependent upon the grower in question and the site itself.

In 1994 a blue mussel larval monitoring program was instituted for the growers of Newfoundland. It continued though 1999, with a spatfall monitoring component added in 1997. The aim of this program has been to educate mussel growers about mussel biology and, in particular, the spawning and settlement patterns exhibited by these animals each year.

The method of plankton tow sampling was successfully taught to a great majority of the growers. As well, growers were trained in the use of a microscope for plankton analysis (identification and enumeration of mussel larvae), as many other species such as clams and phytoplankton are common organisms in a sample. The spatfall component of this program was aimed at assessing, through autumn and spring collector retrievals, how successful growers actually were at maximizing spatfall on their sites.

There are many steps that mussel growers must follow to acquire a high quality, marketable product. The process begins with collector deployment and continues as these collectors are over-wintered to allow the seed to grow to reach 'socking' size (Figure 4). This usually corresponds to May through August of the following year, depending on the timetable of the grower and the actual amount of growth achieved by the mussels over the first year/winter. Once mussels are socked they are re-suspended with final grow-out taking anywhere from 1 to 1.5 years to complete. Thus, making the timeline of the entire process approximately 2 to 2.5 years.

Therefore, it is easy to understand how this entire production process relies heavily on the availability of high quality, abundant seed to maintain production levels from one year to the next. In essence, wild spat collectors provide a cheap and manageable substrate for larvae to settle on (Mallet and Myrand, 1995) and will be the focus of this study. The timing of wild spat collection is a crucial factor as variations in settlement times occur from one year to the next (Cheong and Lee, 1984; King et al., 1989; Macneill et al., 2001). As larvae frequently pass through sites in 'waves', if not properly monitored, spatfall may be missed entirely. While, on the other hand, if collectors are deployed too early fouling can occur, which may deter spatfall or cause heavy losses as spat grow amongst the algae and fall off when they become too heavy. Predation is also a major problem on spat collectors as predation by sea urchins, other invertebrates and, in particular, predatory starfish can subsequently cause heavy mortality to the supply of seed.

Each year growers throughout Newfoundland contend with the settlement of predatory starfish juveniles, *Asterias vulgaris*, on their collectors, and the inevitable loss of seed incurred by this event. Starfish pose a major threat on sites with large production capabilities due to heavy predation, hindered growth and drop-off, and with no preventative strategies known, there is very little a mussel grower can do to combat this problem. Starfish predation on mussels has also induced phenotypical changes in wild mussels themselves (Reimer and Tedengren 1996, 1997), which may not be commercially desirable. Such documented changes include significantly smaller mussels (shell length, height and width), with significantly larger posterior adductor muscles and thicker shells.

The commonly practiced method of ridding mussel collectors of starfish in many parts of the world is a technique called liming. In this process, the mussel collectors are dipped into a known concentration of hydrated lime (agricultural lime) (MacKinnon et al., 1993). The lime will actually dissolve the tube feet of the starfish forcing them to fall off the collector, while the mussels are unharmed due to their ability to tightly seal their valves. However, as one would expect, there is much hesitation to the introduction of a lime solution into the water systems and the process can be quite labour intensive. Further testing is needed to explore the effects of using this treatment on the surrounding areas of the farm.

1.4 Biology of the Starfish, *Asterias vulgaris*

There are many species of starfish inhabiting the waters of Newfoundland, but only a few of these will actually become problematic for mussel growers. The main species of predatory starfish, which afflicts mussel farms in this Province is *Asterias vulgaris*. It is a member of the phylum Echinodermata, subphylum Asterozoa, class Asteroidea. *Asterias vulgaris* and *Asterias rubens*, which are cited often in the literature have been identified as the same species (Clark and Downey, 1992), therefore, *Asterias vulgaris* will continue to be the referenced species for this study. There is some basic information known concerning the life cycle of the predatory starfish, *Asterias vulgaris*, in comparison to that of the blue mussel, *Mytilus edulis/Mytilus trossulus*.

Starfish have separate sexes, with some hermaphrodites observed (Andrews, 1966). They generally spawn from late summer to early autumn (Barker and Nichols, 1983). *Asterias vulgaris* produces a pelagic larva (Figure 5) that is capable of swimming through the water column as it develops and searches for a suitable substrate on which to settle (Banse, 1985). Four to six weeks, or up to ~64 days (David et al., 1994; De Vooys, 1999) after spawning, the ciliated brachiolaria larvae settle and metamorphose into young starfish (Smith, 1940). Sutterlin et al. (1981) observed settling of starfish larvae on a mussel farm in Garden Cove, NL, occurring in early autumn, i.e., September and October. Levy (1999) also observed starfish settlement on a site along the South coast of Newfoundland during autumn, with late summer spawning being documented in P.E.I. (MacKinnon et al., 1993). When *Asterias* sp. settlement was studied in Nova Scotia in

1992, 1993 and 1994, settlement pulses were observed between July and September each year (Balch and Scheibling, 2000). The magnitude of each pulse varied between years, with the year of maximum settlement differing as well. It further suggested that species-specific processes were regulating settlement in these areas rather than general environmental conditions.

As these pelagic larvae are capable of settling on suspended collectors and socks, and have a feeding preference for mussel spat (O'Neill et al. 1983; Penney and Griffiths, 1984; Gaymer et al., 2001), these starfish have become an important predator of mussel seed in this province (Nadeau and Cliche, 1998; Naidu et al., 1999). Thus, since starfish are voracious predators of mussels (Dare, 1982; Chan, 1997) ways to minimize starfish settlement need to be found. This leads to the secondary goal of this study which was: ***To monitor the occurrence and abundance of predatory starfish,* Asterias vulgaris, *larval stages, as well as juvenile settlement on mussel spat collectors on mussel culture sites in Newfoundland.***

1.5 Spatial and Temporal Distributions of Bivalve Larvae and Subsequent Spat Settlement

The development of a larva, through to settlement and metamorphosis involves a precise sequence of events that has been explored and described for many shellfish species (Gaines et al., 1985; Wilson, 1990; Eckman, 1996). Martel et al. (1994) have recently described a strong positive correlation between concentrations of late-stage veligers in

the water column of zebra mussels, *Dreisssena polymorpha*, and settlement rates. Similarly, settlement rate and settlement density of the barnacle *Semibalanus balanoides* have also been found to be strongly correlated with larval availability (Caffey, 1985; Minchinton and Scheibling, 1991).

Regarding the biology of the larval stages of bivalves, spatial and temporal variability within a site are commonplace (Wilson, 1987a; Robinson et al., 1992; Rodriguez et al., 1993; Cranford et al., 1996). The same is true for echinoderm larval patterns (Rumrill, 1989). Studies have described spatio-temporal variability in larval supply directly affecting subsequent settlement (Dadswell et al., 1988; Mallet and Carver, 1989, 1993; Martel, 1993). Reasons for this could be due to reproductive cycles (Davis, 1989), wind and current patterns or changes in rates of larval mortality (e.g., predation) (Hadfield, 1963; Mileikovsky, 1974; Eckman, 1983; Rodriguez et al., 1993). Thus, since each site is different, complete environmental monitoring of individual sites is necessary when performing a multi-site study. Distribution patterns, both temporal and spatial, of larvae from each site would not be comparable otherwise.

Although larval distributions of blue mussels have been found to vary both spatially and temporally in relation to a tidal cycle and the amount of water agitation through a site (Mackas et al., 1984; Newell et al., 1991; Martel et al., 1994; Fegley et al., 1996), it is predicted that with consistent sampling procedures a correlation will exist between the number of mussel larvae on a site and the number of spat that settle (Mason and

Drinkwater, 1981). The same is true for number of starfish larvae observed and number of juveniles that settle. Yet, this may be difficult to quantify as sites with low larval numbers have sometimes been known to display the same or better settlement rates and densities than sites displaying high larval counts (Macneill et al., 2000). Roegner (2000) described the dispersal of invertebrate larvae as a factor of swimming behaviour, length of planktonic development and the hydrodynamic regime within the site itself. Laboratory studies have shown that increased agitation results in an increase in percentage attachment by mussels (Eyster and Pechenik, 1987). Thus, larval flux (number of larvae per liter seawater / time) through a site should be examined, as well as larval concentration (number of larvae per liter seawater) in order to fully assess the number of larvae, which actually pass through a site (Boucher et al., 1987; Wilson-Ormond et al., 1997). Such a relationship would be very beneficial to a mussel grower as larval counts, or flux, could be used as a predictor of expected number of settling animals and allow growers to deploy the correct number of collectors for the estimated number of spat required.

Gametogenesis of the blue mussel progresses rapidly through spring and early summer, with spawning occurring late in June and July, in Newfoundland (Sutterlin et al., 1981; Thompson, 1984). Similar studies in other regions have determined that larvae competent to set may spend 1 to 4 weeks actively searching for a suitable substrate on which to settle depending on temperature, salinity, food and other factors (Bayne, 1965; Sprung, 1984). Larval temporal patterns are expected to proceed in a bell-curve fashion

with decreasing larval concentration corresponding to an expected increase in the number of settled individuals. As well, the delay of metamorphosis phenomenon described for the blue mussel (Bayne, 1965, 1976) may disrupt the occurrence of this type of temporal pattern. Yet, as pelagic larvae of the blue mussel grow and develop, it is inevitable that after a period of time, settlement will begin and pelagic larval abundances will drop as settlement rates increase. Therefore, it is predicted that following spawning, a pre-determined amount of time will elapse before settlement begins.

From an evolutionary point of view it is quite reasonable to assume that spawning of the starfish will either overlap with, directly follow that of their major prey species, the blue mussel, or even precede if there is a growth requirement for the predator, prior to its preys' settlement. Settlement of starfish juveniles before the major settlement of mussels would be futile to the predator as they would then have to actively seek alternate prey instead of conveniently settling amongst a large population of newly settled spat. In fact, in 1981 researchers observed major mussel spawning to occur from late spring to mid summer, while starfish spawning occurred in late summer and early autumn (Sutterlin et al., 1981). Hence, this offers the suggestion that growers may not be able to delay deploying collectors until after the starfish larvae have passed through their site as a possible avoidance strategy.

The coastline of Newfoundland is quite extensive with many sheltered coves and inlets creating different environmental and hydrodynamic conditions from one area to the next.

Yet, it is still essentially all part of the same sub-arctic environment (Thompson, 1984), harbouring similar marine species. Therefore, it is predicted that while some differences may result due to site specificity, similarities will exist throughout Newfoundland with respect to the temporal and spatial patterns of both blue mussel (larvae and spat) and starfish (larvae and juveniles). Future site selection processes would benefit from such knowledge, as well as offer predictability of time frames related to spawning and subsequent settlement throughout Newfoundland.

Shellfish grown in suspension culture are exposed to less extreme environmental conditions than their wild counterparts that typically live on shore, in the intertidal zone. It is widely believed that the annual cycle of a shellfish is influenced by not one, but rather a series of interactions between many different environmental variables such as the presence or absence of thermoclines, pycnoclines, phytoplankton blooms, etc. Furthermore, it has been suggested that mussels are capable of responding to the direct effects of environmental change by modulating their biochemistry, physiology and/or morphology in order to compensate (Bohle, 1972; Meadows and Campbell, 1972; Cooper, 1982; Hawkins and Bayne, 1992).

Blue mussels are most often in peak condition for harvesting in Newfoundland immediately following the winter months, in early spring. This is believed to be due to the phytoplankton bloom that occurs in late winter or early spring with environmental conditions such that spawning will most often not be triggered until early summer. Both

temperature and food supply seem to be particularly important as controls of gametogenesis and spawning in mussels (Wilson, 1987b; Seed and Suchanek, 1992) with a series of factors working together to determine such events. Also, as these bivalve larvae feed on seston then it also seems reasonable to assume that spawning would be correlated with a phytoplankton bloom, thus representing an increase in chlorophyll-a levels. This has been described in a similar species, the Chilean ribbed mussel *Aulacomya ater*, such that fluctuations of phytoplankton levels (microflagellates and diatoms) had a marked affect on gametic production in adults (Jaramillo and Navarro, 1995). It was further suggested that while temperature has been reported as the main factor influencing reproduction in bivalves, food availability may in fact play a larger role in successful gametogenesis and spawning. For this reason, it is most likely that blue mussels (*Mytilus* sp.) do not exhibit a single reproductive strategy, but rather exhibit a variety of patterns depending on the particular environmental regime (Newell et al., 1982).

1.6 Tidal Effects on Temporal and Spatial Distributions of Bivalve Larvae

Geographically every shellfish site is unique, with many factors affecting the amount of larvae that will pass through it on a given day. It has been demonstrated that larval abundances vary from spring to neap tides, with large numbers of mussel larvae being present during spring tide (Newell et al., 1991). However, tidal level alone does not determine bivalve larval retention in a site, as water velocity or hydrographic conditions also play a major role (Andrews, 1979; Newell et al., 1991; Tremblay and Sinclair,

1992). Therefore, when determining how to successfully monitor and assess a site it is important to consider the environmental and hydrographic conditions to ensure accurate predictions are made.

1.7 Objectives

The rationale of this study is to address the lack of knowledge concerning the temporal and spatial distribution patterns of blue mussel, *Mytilus edulis/Mytilus trossulus* larvae and spat, as well as predatory starfish, *Asterias vulgaris* larvae and juvenile settlement on mussel aquaculture sites in Newfoundland and Labrador.

The objectives of this study were:

1. To determine the temporal distribution patterns of blue mussel and predatory starfish larvae, as well as subsequent blue mussel spat settlement and predatory starfish juvenile settlement on collectors, from four Newfoundland commercial mussel farms.
2. To determine the spatial distribution patterns of blue mussel and predatory starfish larvae, as well as subsequent blue mussel spat and predatory starfish juvenile settlement on collectors, among three different farming regions of Newfoundland.
3. To examine the temporal and spatial distribution patterns of blue mussel and predatory starfish larvae within a commercial mussel farm over a 12-hour tidal cycle period, during a spring and neap tide event.

4. To assess the influence of environmental conditions on temporal and spatial distribution patterns both within commercial mussel farms, as well as among different farming regions of Newfoundland.

2.0 MATERIALS & METHODS

2.1 1998 Multi-Site Study: Temporal and Spatial Distributions of Blue Mussels (*Mytilus edulis/Mytilus trossulus*) and Predatory Starfish (*Asterias vulgaris*) among Four Newfoundland Mussel Culture Sites

2.1.1 Study Sites

Four sites were chosen in three geographically distinct areas in Newfoundland (Figure 6). Site 1 (Reach Run) is a large flow through site measuring >300 hectares in size (Latitude = 49.4150°, Longitude = 54.6866°, to middle of site). This site is owned by Alvin and Jane Hodder of Farewell Mussel Farms and is located in Notre Dame Bay, along the North coast of Newfoundland.

Site 2 and 3 (Little Shellbird Bight and Shellbird Bight, both located within Little Bay Arm) were owned by Ed and Denyse Sheppard, of Blue Treasures Limited. These two sites are located in Green Bay (Latitude = 49.5852°, Longitude = 55.9421°, to middle of site), also along the North coast of the province but are smaller flow-through sites with small islands on their perimeters.

Site 4 (Jersey Hr.) is a dead-end or harboured site, measuring approximately 100 hectares from shoreline to the entrance of the harbour. This farm was owned by ConAqua Limited, and was managed by Travis and Juanette Mahoney, in Harbour Breton. It was

the only site located on the South coast, in Fortune Bay (Latitude = 47.5462°, Longitude = 55.7326°, to middle of site).

2.1.2 Period of Study

To ensure the sampling period encompassed the spawning periods for both mussels (*Mytilus edulis/Mytilus trossulus*) and starfish, sampling for larvae and spat occurred between May 27, 1998 and November 13, 1998. Site 1 (Reach Run) was sampled a total of 19 times, Site 4 (Jersey Harbour) was sampled a total of 18 times, and Sites 2 (Little Shellbird Bight) and 3 (Shellbird Bight) were sampled a total of 17 times.

2.1.3 Larval Analysis

To determine the occurrence and abundance of mussel and starfish larvae, each site was visited weekly with vertical plankton tows performed at three stations within each site. Larval samples were collected as close to mid-tide as possible for each site. Mid-tide was selected arbitrarily as the degree of tidal change would differ from one site to the next, and as molluscan larvae show differential abundances based on tide situation (i.e., flood vs ebb, low vs high) (Newell et al., 1991), consistency of timing was key. The sampling stations were identified as the outside, middle and inside of each site. (Figures 7.1, 7.2 and 7.3) This sampling regime was designed to examine temporal and spatial distributions within each site, as well as to assess any differences among the regions of the Province.

Samples were collected using standard plankton tow procedures. A weighted 100-µm-mesh plankton net (radius = 0.15 m) was lowered, vertically to a depth of 10 m at each sampling station (Figure 8) and each tow was timed for "ascent time", from 10 m to boat (surface), at ~0.25 m/s. Each sample was screened through an 80-µm-mesh screen and placed in a labeled 500 mL sample jar. Over this depth range, reduced filtration efficiency was not considered a concern based on previous Larval Monitoring program results for Newfoundland and Labrador.Samples were preserved in 95% ethanol or 70% isopropyl alcohol for future microscopic analysis.

2.1.3.1 Microscopic Examination

In the laboratory, larval samples were examined using a compound microscope at 100x and 400x magnification. Each larval sample was well mixed, and three 1 mL subsamples were examined. Within each 1 mL subsample, larvae were identified, counted and sized (µm) using an ocular micrometer. For mussel larvae, larval lengths were measured (Figure 9). For starfish larvae, in addition to being counted and sized ((Note: as starfish larvae grow lengthwise, total length, µm, was measured along the longest axis), starfish larvae were also identified according to developmental stage observed (Table 2).

Observations were also made of the occurrence of all other bivalve larvae such as clams and scallops, as well as any other significant plankton species, for example common phytoplankton bloom species.

2.1.4 Settlement Analysis

Presently, the most common method of seed collection in Newfoundland is the use of rope collectors. Thus to determine the timing of settlement of both mussels and starfish, rope collectors made of 13 mm diameter green poly rope and measuring 2 m in length were used. Each collector was attached to the mainline using polypropylene twine and was weighted by a rock placed in a small amount of socking material and then tied to the bottom of each collector (Figure 10).

In an area representing the front of each site (Figures 7.1, 7.2 and 7.3), five collectors were deployed weekly, approximately 60 cm apart (Figure 10), and retrieved after two weeks. Thus, sampling was staggered so that an accurate indication of settlement patterns could be obtained (Figure 11). Site 1, Reach Run, was sampled a total of 16 times (June 30 - November 4). While Site 2, Little Shellbird Bight, and Site 3, Shellbird Bight, were sampled a total of 13 times (July 13 - November 13). Site 4, Jersey Hr. was sampled a total of 14 times (July 8 - October 26).

In the laboratory, each collector was stripped (washed with a mild solution of javex, with all settled organisms removed from the rope) and screened onto an 80-μm-mesh screen. These samples were then washed into a 500 mL jar and preserved using 95% ethanol or 70% isopropyl alcohol. All settled starfish juveniles were also counted and the length (i.e., length, mm, was measured as the diameter of the five-armed starfish juvenile) measured at this time.

It should also be noted that during the sampling of 1998, five additional collectors were deployed at each site monthly, in a location adjacent to where the bi-weekly sampling was occurring. These collectors were to remain on each site over the winter and would be collected during the spring of 1999 to examine mussel set and starfish predation, if any, at each site. Unfortunately ice damage over the winter months destroyed the lines at two of the sites completely and partially at the two remaining sites. Thus, collector retrieval in the spring did not produce sufficient results for analysis.

2.1.4.1 Microscopic Examination

For samples with less than 200 mussel spat per collector, all mussel spat were counted and sized (μm) using an ocular micrometer. However, samples that contained greater than 200 spat were split into equal portions of the original sample using a Folsom Plankton splitter. These portions ranged from 1/8 to 1/32 of the original sample and within each subsample all spat and/or starfish juveniles were sized using the ocular micrometer and the numbers recorded. These numbers were then calculated back to number of original settled organisms per collector.

2.1.5 Environmental Monitoring

2.1.5.1 Conductivity-Temperature-Depth Casts

A Seabird SBE 25 (Conductivity-Temperature-Depth or CTD probe, Seabird Electronics Inc., Washington, USA, with an attached fluorometer for chlorophyll-a determination), was used to monitor the environmental conditions on a farm. CTD casts were performed throughout 1998 with the assistance of the ACERA (Aquaculture Component of the Canada/Newfoundland Economic Renewal Agreement) Mussel Production Capacity Program staff (Marine Institute, Memorial University of Newfoundland). Sites were visited every two weeks with three CTD casts performed per site at the inside, middle and outside of each site. The probes were lowered to a depth approximately 2 meters from the bottom with a depth profile created for each cast to examine temperature (^{o}C), salinity (ppt) and chlorophyll-a (µg/L). Calibration of the CTD probe was performed periodically by the Mussel Production Capacity Program staff (Marine Institute, Memorial University of Newfoundland). Data for all sampling stations within a site were pooled to calculate an average value for 2 m, 5 m and 10 m depths for the site. Due to sampling logistics within sites 2 and 3, Mussel Production Capacity Program staff pooled the data within these two sites.

2.1.5.2 Temperature Data Loggers (Thermographs)

Also within each site, a thermograph or continuous temperature data logger (Vemco Ltd., Shad Bay, Nova Scotia) was deployed. The ACERA (Aquaculture Component of the Canada/Newfoundland Economic Renewal Agreement) Mussel Production Capacity Program staff again provided assistance with sampling. Thermographs are capable of

recording temperatures (°C) at programmable intervals (every 45 minutes). They were attached to the mainlines near the outside of each site, at approximately 2-3 meters depth.

2.1.5.3 Wind Data

An hourly wind speed (km/h) was obtained for 3 sampling locations throughout the Province for April through November for 1998. Data were obtained from the Environment Canada Weather Office in Gander, Newfoundland, and the 3 sampling stations closest to the sample sites were La Scie, near Green Bay, Twillingate, near Notre Dame Bay and Sagona Island, on the South Coast. The hourly data for wind speed (km/h) were averaged to give an average daily wind speed (km/h) for each station.

2.1.6 Data Analysis

Within each site, triplicate plankton tow samples were collected (i.e., inside, middle, outside), with three subsamples of each tow examined to give an average value of larval abundance per sampling station.

The calculation for number of larvae/L original seawater sampled was:

Volume filtered = $\pi r^2 \times D$

Note: r = radius of plankton net (0.15 m), and D = depth of tow (10 m)

Therefore = $\pi (0.15 \text{ m})^2 (10 \text{ m}) = 0.70685 \text{ m}^3 \times 1{,}000 = 706.85$

Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater

Note: This calculation assumes 100% net efficiency.

Average values of mussel and/or starfish settlement per collector were calculated for each sampling date as number per metre of collector.

The larval and settlement data were analyzed using Microsoft Excel (Version 2000) with statistical analysis performed using SPSS (Base 9.0). A single factor analysis (ANOVA) was performed for 1) the number of larvae in relation to sample site, over the entire sampling period, and 2) the number of settled spat and/or juveniles per collector on each site, over the entire sampling period. A two-way ANOVA was performed for the larval size in relation to sampling location within each site, and sample date. The level of significance was set at $\alpha = 0.05$.

2.2 1999 Tidal Study: Larval Distributions of Blue Mussel (*Mytilus edulis/Mytilus trossulus*) and Predatory Starfish (*Asterias vulgaris*) during a 12-hour Tidal Cycle within Two Newfoundland Mussel Culture Sites

2.2.1 Study Sites

Two commercial mussel farms that were involved in the 1998 study previously outlined were chosen (Figure 6). They represented two geographically distinct areas of the Province; site 1, Reach Run, is a large flow through site measuring >300 hectares in size and located on the northeast coast of Newfoundland. Site 2, Jersey Harbour, (formerly referred to as site 4) is a dead-end or harboured site located on the south coast of Newfoundland, measuring approximately 100 hectares from shoreline to the entrance of the harbour. (*Note:* Due to the typically high larval counts on sites 2 and 3, it was felt

that these sites should be included for this portion of the study. However, these sites could not be sampled during 1999 due to on-site logistics problems.)

2.2.2 Period of Study

Sampling dates were chosen around the spring and neap tidal cycles for Newfoundland during 1999. For site 1, Reach Run, two 12-hour samples were performed (July 2, 1999 = Spring Tide and October 5, 1999 = Neap Tide). While site 2, Jersey Harbour was sampled only once (July 5, 1999 = Spring Tide). Weather conditions in the autumn made it impossible for a second visit to this site during its neap tidal cycle.

Sampling spanned a complete 12-hour tidal cycle (when daylight permitted) with samples taken every 90 minutes, at each station. For site 1, Reach Run, on July 2, 1999, sampling began at 9:00 am and ended at 8:55 pm for a total sampling period of 11 hours 55 minutes. On October 5, 1999, the sampling period for this site was shorter due to the limited daylight at this time of year. Sampling began at 7:50 am and ended at 6:50 pm for a total sampling period of 11 hours. In comparison, for site 2, Jersey Harbour, on July 5, 1999, sampling began at 9:00 am and ended at 8:50 pm for a total sampling period of 11 hours 50 minutes.

2.2.3 Larval Analysis

To determine the occurrence of mussel and starfish larvae during a 12-hour spring and neap tidal cycle, each site was divided into two sampling stations; one at the outside and

one at the inside (Figure 12). At 90 minutes intervals, one vertical plankton tow was performed, to a depth of 10 m, at each station.

Samples were collected using standard plankton tow procedures. A weighted 100-µm-mesh plankton net was lowered, vertically to a depth of 10 m at each sampling station (Figure 8) and each tow was timed for "ascent time", from 10 m to boat (surface). Each sample was screened onto an 80-µm-mesh screen and placed in a labeled 500 mL sample jar. Samples were preserved in 95% ethanol or 70% isopropyl alcohol.

2.2.3.1 Microscopic Examination

In the laboratory, larval samples were examined using a compound microscope as outlined previously in Section 2.1.3.1.

2.2.4 Environmental Monitoring

2.2.4.1 Conductivity-Temperature-Depth Casts

To monitor environmental conditions throughout the 12-hour cycle, a Seabird SBE 25 (Conductivity-Temperature-Depth or CTD probe, Seabird Electronics Inc., Washington, USA, with an attached fluorometer for chlorophyll-a determination) cast was performed, at each station, coinciding with the plankton tow sample previously described. The probes were lowered to a depth approximately 2 meters from the bottom with a depth profile obtained for each cast to examine temperature (°C), salinity (ppt) and chlorophyll-

a (μg/L). Problems were experienced with the CTD probe sampling for site 2, Jersey Harbour, on July 5, 1999, such that when data were analyzed only data at the 2 and 5 m depths could be plotted.

2.2.4.2 S4 Current Meters

To continuously record water velocity, two Interocean Systems Inc., Model S4 current meters were deployed, one per sampling station, at 2 m depth to record current velocity for the entire 12-hour period. These current meters are designed to measure the true magnitude and direction of horizontal current motion in any water environment, as well as the current speed over complete tidal cycles.

2.2.4.3 Wind Data

An hourly wind speed (km/h) was obtained for 2 sampling locations closest to the sample sites during July 2, July 5 and October 5, 1999. Data were obtained from the Environment Canada Weather Office in Gander, Newfoundland, and the 2 sampling stations closest to the sample sites were Twillingate, Notre Dame Bay and Sagona Island, South Coast.

2.2.4.4 Tidal Height

Tides for each site were calculated using the Canadian Tide and Current Tables, Atlantic Coast and Bay of Fundy, published by the Department of Fisheries and Oceans.

2.2.5 Data Analysis

The larval data were analyzed using Microsoft Excel (Version 2000) with statistical analysis performed using SPSS (Base 9.0). Independent t-test analysis was used to determine equality of means for the number of larvae at station 1 and station 2, over the 12-hour sampling period, as well as for the average larval size in relation to sampling location within each site, and sample hour. The level of significance was set at $\alpha = 0.05$. If no significant difference was observed, a one-way ANOVA was then conducted over time with the inside and outside of the site being replicates. If a significant difference was observed, no further statistical analysis was performed.

3.0 RESULTS

3.1 1998 Multi-Site Study: Temporal and Spatial Distributions of Blue Mussels (*Mytilus edulis/Mytilus trossulus*) and Predatory Starfish (*Asterias vulgaris*) Among Four Newfoundland Mussel Culture Sites

Plankton tow results varied among the four sites with mussel larvae collected at all sites. Starfish larvae, however, were recorded at 3 sites (sites 1, 2 and 3), with only one starfish larva recorded for the entire sampling period at site 4 (Jersey Harbour). Overall, mussel spat settlement was recorded on all four sampling sites, yet starfish juvenile settlement was only recorded on the two sites within Green Bay (sites 2 and 3). A detailed analysis of these results follows.

3.1.1 Larval Distributions

3.1.1.1 Site 1 - Reach Run

For site 1, mussel larvae were observed throughout the entire sampling period, at varying densities (Figure 13). Identical patterns were observed for the starfish larvae at this site (Figure 13), but at lower concentrations. The overall maximum mean peak larval mussel abundance (of the 3 stations sampled) of 18 larvae/L (SE = 2.32) occurred on July 16, followed by a smaller peak of 6 larvae/L (SE = 0.85) on September 8 (Figure 13; Appendix 1.0 - 1.1a). Starfish larvae coincided with the first wave of mussel larvae, and were present from June 24 through August 5, 1998. Two peaks in starfish larval

abundances of 2.5 larvae/L occurred on both July 16 (SE = 0.16) and August 1 (SE = 0.96) (Appendix 1.0 - 1.1b).

Mussel larvae of all sizes were collected during 1998 within Site 1 (Reach Run) (Appendix 2.0 - 2.1a). When the average size of mussel larvae in relation to sampling location and date were analyzed using a two-way ANOVA, the results were found to be significantly different in relation to size and date ($F_{(18,54)} = 39.495$, $p < 0.001$). However, size and location alone were not found to be significant ($F_{(2,54)} = 1.283$, $p = 0.278$).

To examine the mussel larval size data over time for site 1, larval length (μm) data were grouped into percent distributions within four size categories according to larval lengths (Figure 14). Larvae of each of the four categories were present throughout the majority of the sampling period, which may indicate that more than one spawning event supplied larvae to this site during 1998, assuming standard larval growth patterns were observed, and no growth differences occurred with each spawning class.

When the average size of starfish larvae in relation to sampling location and date were analyzed using a two-way ANOVA significant differences were only observed between size and date ($F_{(18,55)} = 16.790$, $p < 0.001$). However, size and location were not found to be significant ($F_{(2,55)} = 0.091$, $p = 0.913$). To examine the six developmental stages, ranging from early bipinnaria to advanced brachiolaria, for site 1, the percent distribution within five size categories are represented in Figure 15. The fast progression from one

developmental stage to the next indicated that only one wave of starfish larvae passed through site 1 during 1998 (Appendix 2.0 - 2.1b).

3.1.1.2 Sites 2 and 3 - Little Shellbird Bight and Shellbird Bight

For sites 2 and 3, the results were very similar with only one major wave of both mussel larvae and starfish larvae being observed. For both sites, mussel larvae were present from late June to early September, with site 2 having an overall mean peak abundance of 225 larvae/L (SE = 13.91) observed on July 13 (Figure 13; Appendix 1.0 - 1.2a) and site 3 having a mean peak abundance of 240 larvae/L (SE = 17.86) on July 6 (Figure 13; Appendix 1.0 - 1.3a). Similarly, starfish larvae were recorded on both sites from mid-July through early September, with a mean peak starfish larval abundance for site 2 of 9 larvae/L (SE = 1.16) recorded on August 14 (Appendix 1.0 - 1.2b), 4 weeks later than peak mussel abundance. While, for site 3, mean peak starfish abundance of 9 larvae/L (SE = 0.16) occurred on August 21 (Appendix 1.0 - 1.3b), 6 weeks later than peak mussel larval abundance at this site.

For site 2, a two-way ANOVA of mussel larval size in relation to sampling location and date indicated significant differences between mussel larval size and date ($F_{(16,49)} = 1252.472$, $p < 0.001$). While, no significant differences were observed between size and location ($F_{(2,49)} = 1.099$, $p = 0.333$). Interestingly, for site 3, significant differences were observed for both mussel larval size and date ($F_{(16,49)} = 2213.140$, $p < 0.001$), as well as mussel larval size and location ($F_{(2,49)} = 21.804$, $p < 0.001$).

For sites 2 and 3, mussel larval size data were grouped into four categories according to larval lengths (Figure 16 and Figure 17, respectively). One major wave of larvae passed through each of these sites during 1998 as one uniform wave for each size class in sequence (Appendix 2.0 - 2.2a and 2.3a). This pattern was similar to that of the starfish larvae, for both Sites 2 and 3, in which there was a fast progression through the six developmental stages of the starfish with only one major wave of larvae evident, on both sites, during 1998 (Figure 18 and Figure 19, respectively; Appendix 2.0 - 2.2b and 2.3b).

Similarly, when starfish larval lengths for site 2 were examined in relation to sampling location and date using a two-way ANOVA, the results were found to be significantly different in relation to size and date ($F_{(16,49)} = 338.539$, $p < 0.001$), as well as between starfish larval size and location ($F_{(2,49)} = 51.290$, $p < 0.001$). While for site 3, significant differences were again observed between starfish larval size and date ($F_{(16,49)} = 264.216$, $p < 0.001$), as well as between starfish larval size and location ($F_{(2,49)} = 13.042$, $p < 0.001$).

3.1.1.3 Site 4 – Jersey Harbour

The occurrence of mussel larvae for site 4 was sporadic for the entire sampling period, with only one starfish larvae being recorded for this site during the entire sampling period on July 22 (Appendix 1.0 - 1.4a). A mean peak in mussel larval abundance of 6 larvae/L (SE = 3.01) was observed on August 4 (Figure 13).

When the size of mussel larvae was examined in relation to sampling location and date using a two-way ANOVA, the results were found to only be significant between mussel larval size and date ($F_{(17,52)} = 21.820$, $p < 0.001$) as expected. While, size and location were not found to be significant ($F_{(2,52)} = 2.483$, $p = 0.085$).

For site 4, the mussel larval size data were grouped into four categories according to larval lengths (Figure 20). Several small waves of larvae passed through this site with larvae of each of the four categories being present throughout the majority of the sampling period during 1998. Small peaks were observed near the end of June and the end of July, but no single major wave of larvae was identified (Appendix 2.0 - 2.4a).

3.1.2 Spat/Juvenile Distributions

3.1.2.1 Site 1 – Reach Run

For site 1, there was a significant difference in the number of settled spat over time (one-way ANOVA, $F_{(15,64)} = 99.329$, $p < 0.001$). As with the larval patterns observed on this site, two peaks of spat settlement were recorded. Peak spat settlement of 12,000 spat/collector (SE = 131.1) was recorded on August 1, 2 weeks after peak larval abundance (Figure 21; Appendix 3.0 - 3.1). A second, larger peak of 16,000 spat/collector (SE = 426.6) on September 30 occurred 3 weeks after the second peak of mussel larvae. No starfish juveniles settled on the collectors used during this study, on this site.

The average size of the newly settled spat varied little during the sampling period (Figure 22; Appendix 3.0 - 3.1). The minimum average size of settled spat was 390 μm, recorded on July 9, August 13, and November 4, 1998. While a maximum average size of 500 μm was recorded on September 8, 1998.

3.1.2.2 Sites 2 and 3 - Little Shellbird Bight and Shellbird Bight

Over time, the number of settled spat per collector varied significantly for both site 2 (one-way ANOVA, $F_{(12,48)} = 26.308$, $p < 0.001$) and site 3 (one-way ANOVA, $F_{(12, 48)} = 8.112$, $p < 0.001$).

For both sites 2 and 3, the pattern of settlement was similar in that one major wave of mussel larvae preceded one major wave of spat settlement. For site 2, peak mussel larval abundance was followed 4 weeks later by peak spat settlement of 11,000 spat/collector (SE = 123.8) on August 14 (Figure 21; Appendix 3.0 - 3.2a). Similarly, for site 3 the peak of mussel larvae was followed by peak spat settlement of 16,000 spat/collector (SE = 132.9) 4 weeks later on August 7 (Figure 21; Appendix 3.0 - 3.3a).

The average size of settled spat also varied very little during the sampling period (Figure 22; Appendix 3.0 - 3.2a, 3.3a). For site 2, the minimum average size of settled spat was 385 μm, recorded on July 31, and the maximum average size of settled spat was 630 μm, recorded on October 7, 1998. In comparison, for site 3, the minimum average size of

settled spat was 340 μm, recorded on July 20, and the maximum average size of settled spat was 700 μm, recorded on October 7, 1998.

Starfish juvenile settlement was observed for both sites 2 and 3, with similar patterns to mussel spat settlement. Over time, the number of settled juveniles per collector varied significantly for both site 2 (one-way ANOVA, $F_{(12,52)} = 16.142$, $p < 0.001$) and site 3 (one-way ANOVA, $F_{(12,52)} = 42.088$, $p < 0.001$).

For site 2, peak starfish juvenile settlement of 3.5 juveniles/collector (SE = 0.40) on August 21 was recorded 1 week later than peak starfish larval abundance (Figure 23; Appendix 3.0 - 3.2b) and about 1-3 weeks later than peak mussel settlement (Figure 24). While, for site 3, peak starfish juvenile settlement of 9 juveniles/collector (SE = 0.68) on September 4 was recorded 2 weeks later than peak starfish larval abundance (Figure 23; Appendix 3.0 - 3.3b) and about 3-5 weeks later than peak mussel settlement on this site (Figure 24).

For both sites 2 and 3, the average size of settled starfish juveniles per collector also varied very little during the sampling period (Appendix 3.0 - 3.2b, 3.3b). For site 2, the minimum average size of settled juveniles was 1,200 μm, recorded on August 7, and the maximum average size of settled juveniles was 1,500 μm, recorded on August 28, 1998. In comparison, for site 3, the minimum average size of settled juveniles was 1,000 μm,

recorded on August 28, and the maximum average size of settled juveniles was 1,500 µm, recorded on October 7, 1998.

3.1.2.3 Site 4 - Jersey Harbour

The number of settled spat was significant over time (one-way ANOVA, $F_{(13, 56)} = 101.153$, $p < 0.001$). Sporadic patterns were observed in spat settlement as was apparent in larval abundances. Spat counts remained very low for most of the sampling period, 1,500 - 3,000 per collector, until October 4 when a peak of 7,000 spat per collector (SE = 107.9) was observed (Figure 21; Appendix 3.0 - 3.4). This peak coincided with the peak mussel larval abundance on August 15. While only one starfish larva was recorded on this site during 1998, no juveniles were observed on site 4.

The average size of settled spat also varied little during the sampling period (Figure 22; Appendix 3.0 - 3.4). The minimum average size of settled spat was 450 µm, recorded on July 8, while the maximum average size of settled spat was 765 µm, recorded on August 20, 1998.

3.1.3 Environmental Monitoring

3.1.3.1 Seabird CTD Casts

CTD sampling was performed on all four sites; site 1 (Figure 25), sites 2 and 3 (Figure 26) and site 4 (Figure 27). Temperatures on sites 1, 2 and 3 were cold through winter and

early spring (-1-0 °C), with warming occurring quickly during April and May 1998 (3-6 °C). (*Note:* Due to sampling logistics, CTD sampling could not begin at site 4 until June.) Temperatures continued to rise steadily for all four sites for June through August, with site 4, along the South coast displaying the most stratification in the water column (i.e., 2-6 °C), throughout the year, for 2-10 m depths. Water temperatures peaked at nearly 18-20 °C on site 1 during August, and at 17-18 °C during August on site 4. Temperatures were cooler at sites 2 and 3 with temperatures peaking at only 13-14 °C in early September.

Salinity values were markedly different for the three sample regions of this study. Site 1 (Reach Run) experienced lower salinity values during the spring months, while values throughout the remainder of the year remained constant at approximately 28 ppt (Figure 25). However, salinity values dropped considerably in June at sites 2 and 3 (Little Bay Arm) with the values in the first 5 meters of the water column consistently lower than the 10 m depth values (Figure 26). This indicated an influx of freshwater into these sites. Yet, all recorded values remained above 28 ppt, which are considered good for mussel survival and growth. Site 4 (Jersey Hr.) also showed an influx of freshwater into the site during late August (Figure 27); however salinity changed only slightly (1.0-1.5 ppt), with values never recorded lower than 29 ppt for this site.

Using the chosen sampling interval, no spring phytoplankton blooms were detected at either site 1 (Figure 25) or site 4 (Figure 27), yet both showed the presence of a late

summer to early autumn bloom. Sites 2 and 3 (Figure 26) recorded high concentrations of chlorophyll-a (μg/L) at both 5 and 10 m depths (9.94 μg/L and 9.58 μg/L respectively) during April, and at 2 m depth (9.79 μg/L) during July. The recording during April could be the end of the late spring bloom in this area, with the July readings indicating the start of a mid - late summer bloom. Interestingly, chlorophyll-a concentrations (μg/L) remained low for the remainder of the sampling on sites 2 and 3 following this single peak in July 1998.

3.1.3.2 Temperature Data Loggers

Temperature was recorded at site 1 (Reach Run) from January to November 1998 (Figure 28a). Temperatures were cold throughout the winter months (-1.5-0 °C) and slowly began to warm, in late April-early May (3-8 °C). Warming through this site was gradual during the spring and summer months with no major events in temperature change recorded, with highest recorded temperatures occurring in July and August (18-20 °C).

For sites 2 and 3 (Little Bay Arm), temperatures displayed a similar pattern to site 1, with cold temperatures during the winter months (-1-0 °C) changing to warmer temperatures in early May (0-5 °C) (Figure 28b). Temperatures remained steady during the summer months (13-15 °C), with two events during July resulting in recorded temperatures decreasing by 5 °C in a single day. Temperatures were also cooler on this site as they did not peak above 15 °C.

Temperature data for site 4 (Jersey Hr.) could only be recorded for July - November 1998 (Figure 28c). While temperatures were steadily increasing during July and early August (15-19 °C), large changes in temperature of greater than 5 °C appeared to be occurring almost daily. Temperatures were warm on this site during August and peaked at approximately 18-20 °C. Temperature remained variable during September with two identifiable extreme temperature changes observed during this month.

3.1.3.3 Environment Canada Wind Data

Average daily (24 hour period) wind speeds (km/h), for 1998, for three stations closest to the sample sites for this study are outlined in Figure 29. Wind speeds were high (10-50 km/hr) for site 1, Reach Run, (Figure 29a) with highest recorded events occurring in September (>75 km/hr). Wind speeds for sites 2 and 3, Little Shellbird Bight and Shellbird Bight, were low (5-24 km/hr) through most of 1998 (Figure 29b), with winds never peaking above 40 km/h. Yet, along the South coast on site 4, Jersey Hr., (Figure 29c) winds were often variable (10-50+ km/hr) with high wind events occurring frequently throughout most of 1998. Highest wind speeds were recorded in the autumn months, from early September to late November (50-80 km/hr).

3.2 1999 Tidal Study: Larval Distributions of Blue Mussel (*Mytilus edulis/Mytilus trossulus*) and Predatory Starfish (*Asterias vulgaris*) during a 12-hour Tidal Cycle within Two Newfoundland Mussel Culture Sites

3.2.1 Larval Distributions

3.2.1.1 Site 1, Reach Run, July 2, 1999

Mussel larval abundance varied during the 12-hour sampling period at station 2, while station 1 displayed little change (Figure 30; Appendix 4.0 - 4.1a). The number of mussel larvae/L was greater at station 2 than at station 1 for 8 of the 12 hours sampled, however, the results were not significantly different (t-test, $t = -1.326$, d.f. = 10, $p = 0.107$).

For both station 1 and 2 (Figure 12A), a general tendency of increasing mean mussel larval size, over the 12-hour sampling period was observed (Figure 31; Appendix 4.0 - 4.1a). Also, interestingly, the greatest size range of mussel larvae found at both stations 1 and 2 occurred in the late afternoon (~4:30 pm), when the tide was the lowest. When the size of mussel larvae in relation to sampling hour and station were analyzed, the results were not found to be significant (t-test, $t = 0.666$, d.f. = 369, $p = 0.252$; one-way ANOVA, $F_{(1,434)} = 0.432$, $p = 0.520$).

Starfish larvae (*Asterias vulgaris*) were present at both stations, with station 2 having the greatest variation in abundance over time (Figure 30; Appendix 4.0 - 4.1b). In fact, the number of starfish larvae at station 1 and station 2 was found to be statistically different (t-test, $t = -3.212$, d.f. = 10, $p = 0.005$). Station 2 displayed the greatest variability in starfish larval numbers, over the 12-hour period, with numbers at station 1 decreasing slightly throughout the day.

When the average size of starfish larvae, in relation to tidal height is compared, no obvious patterns were observed (Figure 32; Appendix 4.0 - 4.1b). However, the greatest size range of larvae sampled was consistently recorded at station 2, with station 1 displaying a much narrower range of starfish larval sizes throughout the entire 12-hour sampling period. Starfish ranging from 300 μm to 1,200 μm were observed at the outside of the site, while sizes ranged from 700 μm to 1,200 μm at the inside of the site. Most larvae recorded were in the brachiolaria stage of development (Table 2). Late stage brachiolaria, or settling juveniles, with developed tube feet were observed in the tows from both stations.

When the size of starfish larvae in relation to sampling hour and station were analyzed, starfish larval size and hour were found to be significant (t-test, $t = 3.907$, d.f. = 102, $p < 0.001$).

No observable changes were recorded in the temperature (^{o}C) or salinity (ppt) profiles at 2 m, 5 m or 10 m depths for this sampling day (Figure 33). On average, peak temperatures of 17 ^{o}C were recorded throughout the day at 2 m, which is approximately 1 ^{o}C warmer than 5 m depth, and 2 ^{o}C warmer than 10 m depths. Salinities remained constant at 28.0 ppt at all depths indicating a well mixed site. Chlorophyll-a concentrations were also fairly consistent throughout the water column for the majority of the day, except for a single spike at 10:30 am, at 2 m depth only. Each bar in Figure 33 represents the average of two CTD casts (one at the inside and one at the outside of the

site) per sample time. Thus, when the individual tows were analyzed, it appears that only the inside of the site displayed the single peak in Chlorophyll-a concentrations (18.5 μg/L), while the outside remained consistent at 2.28 μg/L. This spike was not observed again and could have been the result of the sensor not being sufficiently calibrated or reading a concentration of marine snow.

The average current speed (cm/s), at 2 m depth, for the 12 hours of this study was 4.56 cm/s at station 1 (inside), in comparison to 1.23 cm/s for the same time period at station 2 (outside) (Figure 34). Temperatures were also recorded with the S4 current meter, with both stations displaying warmer temperatures as the day progressed. Readings were lower and more variable at station 1, with station 2 showing a steady increase to a peak of ~16.5 °C late in the evening.

Wind speed increased throughout the day, peaking at ~28 km/h at 2 pm, and then decreasing into the evening hours. The tide was high when sampling began at 9 am, and reached its lowest point of ~0.35 m at 3:05 pm. Tide was then high again when sampling ended at 8:35 pm. It was also noted that the current speed at station 1 seemed to correspond with tide; however, these patterns were not apparent for station 2.

3.2.1.2 Site 2, Jersey Harbour, July 5, 1999

Most mussel larvae sampled for site 2, Jersey Harbour, were present at station 1 in comparison to station 2 (Figure 12B) for the entire 12-hour period, with a considerable

change over time in the number of mussel larvae present at station 1 being observed (Figure 35; Appendix 4.0 - 4.2a). The number of mussel larvae at station 1 and station 2 was found to be statistically different (t-test, $t = 2.209$, d.f. = 8, $p = 0.029$). Also, at station 1 there appeared to be a correspondence between mussel larval abundance and tidal cycle such that the peak in larval abundance occurred prior to low tide.

For both station 1 and 2, a general tendency of increasing mean mussel larval size, over the 12-hour sampling period was observed (Figure 36; Appendix 4.0 - 4.2a). Also, the greatest size range of mussel larvae found at station 1 occurs as the tide is falling (i.e., mid-tide) at 3:00 pm. While, at station 2, this occurs just prior to this at 1:35 pm. The largest range of sizes was observed consistently at station 1 (outside), with much narrower size ranges observed throughout at station 2 (inside). When the size of mussel larvae in relation to sampling hour and station were analyzed, mussel larval size and sampling hour were found to be significant (t-test, $t = 2.375$, d.f. = 34, $p = 0.012$).

While there were no starfish larvae observed at the site, there was a large number of another bivalve species, the saxicave clam larvae (*Hiatella* sp.) recorded (Figure 35; Appendix 4.0 - 4.2b). The pattern of clam larval abundance was similar to that of the mussels, for this site, such that a greater number of clam larvae were found at station 1 than station 2, with considerable variation in clam larval abundance over the 12-hour sampling period observed at station 1 (Figure 35). In fact, the number of clam larvae found at station 1 and station 2 was found to be significantly different (t-test, $t = 2.550$,

d.f. = 8, p = 0.017). Similar to the mussel larval patterns previously described for this site, clam larval abundance appeared to correspond to tidal height such that the peak in larval abundance occurred prior to low tide.

As previously observed for mussel larvae on this site, there was a general tendency for increasing mean clam larval sizes, over the 12-hour sampling period (Figure 37; Appendix 4.0 - 4.2b). The greatest size range of clam larvae was again observed at station 1 (outside), with the greatest range of sizes recorded during low tide. Size ranges were much narrower at station 2 (inside); however, the greatest range of size was also recorded during low tide (~6:25 pm). When the size of clam larvae in relation to sampling hour and station were analyzed, clam larval size and hour were not significant (t-test, t = 0.531, d.f. = 615, p = 0.298; one-way ANOVA, $F_{(1,3856)} = 0.295$, p = 0.587).

Due to the shallow depth of this site, only 2 m and 5 m depths could be analyzed using the CTD depth probe (Figure 38). Temperature remained fairly constant throughout the day and was approximately 1.0-1.5 degrees warmer at 2 m (~11 ^{o}C) than at 5 m depth (9.5-10.0 ^{o}C). Salinity varied very little, with 5 m depths displaying a slightly higher number than the 2 m depths. Interestingly, concentrations of chlorophyll-a were highest at 2 m during the first portion of the day, when the tide was the highest, with results during low-tide being very similar at both 2 m and 5 m depths.

The average current speeds for both stations at site 2, for this 12-hour period were slightly lower than had been recorded for site 1 (Figure 39). The average current speed (cm/s) at 2 m depth was 1.36 cm/s at station 1 (outside), in comparison to 0.65 cm/s for the same time period at station 2 (inside). Current speeds were more variable at station 1 than station 2, for the entire sampling period, with peak current speed events recorded during the morning hours.

Wind speed displayed an interesting pattern, with highest wind speeds recorded at the beginning and the end of this 12-hour period, with very little wind occurring during the day. The tide was rising as sampling began and peaked at 1.25 m at noon. The tide then continued to drop to a low of 0.75 m at 6:25 pm, before beginning to rise back to the same height (at 8:40 pm) as when sampling began at 9:00 am (i.e., 1 m).

Temperatures recorded using the S4 current meters averaged 4 °C cooler at site 2 than at site 1, for the entire sampling period. Slight differences were observed between sampling stations, with respect to temperatures, with the outside temperatures ranging from 11.5 °C to 12.5 °C, and the inside of the site ranging from 11 °C to 12.5 °C.

3.2.1.3 Site 1, Reach Run, October 5, 1999

Mussel larval abundance varied during the 12-hour sampling period at both station 1 and station 2 (Figure 40; Appendix 4.0 - 4.3), with the number of mussel larvae/L being greater at station 1 than at station 2 for 9 of the 12 hours sampled. However, the number

of mussel larvae recorded at station 1 and station 2 were not found to be statistically different on this date (t-test, $t = 1.009$, d.f. = 8, $p = 0.171$).

Similar to the results obtained in July on this site, the mean mussel larval size increased slightly for station 1 (inside) during the 12-hour sampling period (Figure 41; Appendix 4.0 - 4.3). However, while the mean size did not increase initially during mid-tide for station 2 (outside), it decreased as the day continued, and the tide rises. Size ranges for both the inside and the outside also appeared to be mixed better than during July, as large size ranges were recorded during both low and high tide during October. The influence of tide appears to be having less of an effect on larval size distribution throughout the site during the neap tide event in the autumn. When the size of mussel larvae in relation to sampling hour and station were analyzed, the results were found to be significant (t-test, $t = -3.669$, d.f. = 206, $p < 0.001$). There were no starfish larvae observed for site 1, Reach Run, on this date.

The environmental results for this site during October, as recorded using a CTD depth probe, were slightly more variable than during July (Figure 42). Both temperature and salinity displayed minimal changes throughout the water column, with slightly warmer temperatures and higher salinities recorded at 2 m and 5 m depths. Temperatures averaged 4 °C colder on this sampling day than they were in July, with salinity levels remaining unchanged between the July and October samples. Chlorophyll-a concentrations varied throughout the water column, and were consistently higher during

October than they had been in July. An increase in chlorophyll-a concentrations (particularly at the deeper depths) in the late afternoon appeared to coincide with the rising tide.

The average current speed (cm/s) at 2 m depth, for the 12 hours of this study was 4.39 cm/s at station 1 (inside). Problems were experienced with the S4 current meters on this day such that the data could not be retrieved from the meter placed at station 2 (outside), as well temperatures could not be displayed. This recorded current speed is slightly less than the 4.56 cm/s recorded at this station on July 5, 1999. Also, the speeds seem to be higher earlier in the day, with slight decreases observed towards the end of the day.

Wind speed displayed a similar pattern to that experienced during July on this site. Wind speed increased throughout the day, peaking at ~ 20 km/h at 1 pm, and then decreasing into the evening hours. On the other hand, the tide experienced in October was far less than in July. The tide was almost low when sampling began and was at its lowest (~ 0.6 m) at 11:00 am. Following this the tide continued to rise slowly and peaked at 1.2 m at 5:00 pm.

4.0 DISCUSSION

4.1 Blue Mussels (*Mytilus edulis/Mytilus trossulus*)

4.1.1 Blue Mussel Larval Patterns

In 1994, a blue mussel larval monitoring program was started in Newfoundland, with a spatfall component added in later years. This program continued through 1999, with the four farm sites included in this study participants in some, if not all, of these years. As blue mussels are found throughout Newfoundland (McDonald et al., 1991), it was expected that mussel larvae would be found on all four sites, to varying degrees. As larval counts obtained using net tows samples may depend on spatial distributions of the larval within each site (i.e., larger vs smaller sites), consistency in sampling location among sampling sites provided reliable larval numbers at all sampling sites.

Historically, site 1, Reach Run, consistently has low larval numbers (i.e., <10 larvae/L), with two peaks in larval abundances occurring during July and September (Macneill et al., 1998). My results were very similar, with two peaks observed; one on July 16 (18 larvae/L) and a smaller one on September 18 (6 larvae/L).

Similarly, temporal patterns within Little Bay Arm (Sites 2, Little Shellbird Bight and 3, Shellbird Bight) were on par with previous years' data, with a single wave of larvae passing through each site from July through September (Macneill et al., 1998). Larval

counts were however much higher during this sampling season than in previous years, with larvae/L counts in 1997 peaking on September 3 at only 78 larvae/L and 77 larvae/L for sites 2 and 3, respectively. In comparison, during this study, temporal patterns were earlier, with a peak of 224 larvae/L being recorded on July 13, for Little Shellbird Bight, and 239 larvae/L being recorded on July 6, for Shellbird Bight.

When data from previous years is analyzed for site 4, Jersey Harbour, the only year to display multiple spawnings was during this study, with single spawning events in late June - early July recorded in 1997 and 1999, respectively (Macneill et al., 2000). Larval counts were also very low during 1998 in comparison to previous year's data, with data from 1997 recording 44.7 larvae/L on August 8 (Macneill et al., 1998), while larval counts peaked at only 6 larvae/L on August 4 in 1998.

When compared to other studies that have been performed in Newfoundland, Crocker (1998) noted that bivalves had spawned on or before August 12, 1995, with another spawning in early September in Charles Arm, Notre Dame Bay. The number of bivalve larvae recorded was highest in early August, up to 23 larvae/L with two cohorts identified. Penney (1993) also reported for this same site that while the first plankton tows were conducted in mid-June, veligers were not observed until August, with a peak of 200 veligers/L recorded on August 12. Thus, inter-annual variability in larval numbers appears to occur frequently among sites, with variations of one to four times as many larvae observed from one year to the next (Macneill et al., 2000).

It is important to assess the spatial and temporal variability that exist within a site, when studying the biology of the larval stages of bivalves (Wilson, 1987a; Robinson et al., 1992; Rodriguez et al., 1993; Cranford et al., 1996). Previous studies within Newfoundland have found significant differences among larval distributions within sampling sites (Penney, 1993; Crocker, 1998; Levy, 1999). A significant objective of this work was to address the issue of spatial and temporal patterns, in addition to temporal, throughout the Province, as well as within each site. However, within site analysis would have required multiple samplings at each station (3 stations in total per site) which was beyond the scope of this study. In the future, this may be important for within site studies as significant differences have been observed among sampling stations on all sampling dates in Charles Arm during 1995 (Crocker, 1998). Spatially, from a regional point of view, multiple-spawning events do not appear to be that common and thereby remain difficult to predict. The two sites which did exhibit more than one obvious spawning period were neither consistent in their timing or numbers. Thus, these events are determined to be site-specific, not lending to broad-scale interpretation.

Mussel larval sizes increased over time as expected, as later in the summer and autumn, void of any trickle spawning events, the majority of larvae sampled would be expected to be near settling size. A second peak of larvae within site 1 did display smaller larvae; however, the progression of small sizes to larger sizes was observed to take ~ 4 weeks, in comparison to the 6 weeks required earlier in the season. Possible explanations for this could be that better growing conditions (i.e., warmer water temperatures) later in the

season, and the presence of a possible late summer bloom could allow for faster larval growth (Scheltema, 1986).

We know from previous studies, both *Mytilus edulis* and *Mytilus trossulus* occur together throughout the province (Innes and Bates, 1999), with the likely event of hybridization occurring as well (Rawson et al., 1999). When three mussel culture sites in Notre Dame Bay, NL, were studied, it was found that seed populations varied significantly among sites in relative proportions of each species and hybrids (Penney et al., 2002). There is currently no sure way of distinguishing the species by external morphology. The morphological differences expressed are small and not as reliable as genetic markers (Bates and Innes, 1995). Yet, there is some evidence that *Mytilus trossulus* may initiate gametogenesis earlier than *Mytilus edulis* (Freeman and MacQuarrie, 1999; Maloy et al., 2003). Hence, for sites that experience small, multiple spawnings, perhaps it is in fact different species of mussels within these areas spawning at different times. However, from a larval point of view, without genetic analysis it is not possible to determine species, so larvae of this study were identified as *Mytilus* spp. only, for all sites.

In an attempt to standardize the larval data collected during 1998, it was felt that a study to examine the effects of tides, through two of the study sites would be appropriate. It has been demonstrated that larval abundances vary from spring to neap tides, with large numbers of mussel larvae being present during spring tides in New England estuaries (Newell et al., 1991). However, tidal level alone does not determine bivalve larval

retention at a site, as water velocity or hydrographic conditions also play a major role (Andrews, 1979; Mackas et al., 1984; Newell et al., 1991; Tremblay and Sinclair, 1992; Martel et al., 1994; Fegley et al., 1996). Continuous plankton recording, with biomass estimates, over a complete tidal cycle is necessary (George, 1995). Water transport and its velocity also need to be investigated because of possible lateral transport.

Tidal influences play an important role in interpreting zooplankton data from a time series of samples made at regular intervals over a day or longer (Omori and Ikeda, 1984; Levin, 1986; Newell et al., 1991). Roegner (2000) described the dispersal of invertebrate larvae as a factor of swimming behaviour, length of planktonic development and the hydrodynamic regime within the site itself.

Therefore, when the larval patterns were examined in relation to tidal height, mussel larval abundance did appear to coincide with high tide, on the outside of the site, during the spring tide event (July) on Site 1, Reach Run. Similarly, the outside of the site displayed the greatest size range for larvae over the 12 hours sampled, regardless of tide height. The current speed at the outside of the site was three times lower during the entire sample period which could result in more larvae of differing sizes able to remain at this location of the site. While, in comparison, areas of the site experiencing stronger current speeds would primarily contain larvae capable of swimming within these higher current areas.

Moderate wind speeds were recorded throughout the day, thus it was unlikely that wind speeds during this particular spring tide event were influencing the dispersal of larvae within the site. Future studies should include an analysis of prevailing wind directions, as well as, flux within a site as a measure of the number of larvae that may in fact be coming in contact with a collector over a given period of time. Hence, as displayed during the tidal study of site 1, Reach Run, some other factor such as morphometry or energy of the system may be playing an important role in larval distribution and retention within this site (Andrews, 1979).

Recorded densities of both mussel and clam larvae increased during low tide at station 1, the outside of Jersey Harbour (site 2) during July, 1999. This pattern was expected as this was the dead-end site, such that during low tide (of a spring tide event) all larvae from within the site were transported towards the outside of the site due to the influence of tidal currents. However, as the tide rises, this would not necessarily result in the reverse effect, i.e., increased numbers at the inside of the site, as larvae would be dispersed throughout the site depending on the hydrodynamic processes within the site.

Similar results were observed with the size range of larvae observed at each station. Station 1 consistently displayed the greatest size range of both mussel and clam larvae, with no obvious correlation to tidal height observed. Current speeds were low throughout the site, but were again twice as fast at station 1 than at station 2 (the inside of the site). The higher current speed of station 1 could again explain the higher larval abundances

and greater size range of larvae observed. Thus, for comparative purposes, sampling consistency is very important such that when sampling over a short period of time, knowing where on a site to sample is just as important as knowing when to sample.

In October 1999, during a neap tide on Reach Run, larval abundances were much less at the outside of the site, in comparison to the inside, with the subtle changes in tide experienced on this day not seemingly influencing larval abundances at either station. As well, unlike during a spring tide, the size ranges of larvae found at both stations were quite similar throughout the day.

The geographic uniqueness of each shellfish site was also an important consideration as Reach Run, the 'flow-through' system displayed a smaller variation in calculated tidal height to Jersey Harbour, the 'dead-end' site. Differences observed in larval abundance varied accordingly, with the greatest change in mussel larval abundance over the 12-hour period being observed at Jersey Harbour during a spring tide event. Hence, for Reach Run, in addition to tidal influences some other factor such as morphometry or energy of the system may be playing an important role in larval distribution and retention within this site (Andrews, 1979). Overall, these findings do stress the need for standardized plankton tow sampling with respect to tides to ensure accurate larval predictions are achieved.

4.1.2 Blue Mussel Spat Settlement

Spat settlement was recorded on collectors for all sites, to varying degrees. Despite low larval counts, site 1, Reach Run displayed high spat numbers with a peak of 16,000 spat per collector recorded on September 30, 1998. Interestingly, Little Bay Arm, which had much higher larval counts throughout July, had only comparable settlement rates to this; Little Shellbird Bight recorded 11,000 per collector on August 14, and Shellbird Bight recorded 16,000 spat per collector on August 7. As expected, the lowest spat per collector counts were found on the South coast, i.e, 7,000 spat per collector on October 4. As previously mentioned, future studies to examine flux through these sites would provide further insight as to why these settlement patterns were observed. In essence, wild spat collection whose basic principle is to provide a cheap and manageable substrate for larvae to settle on (Eyster and Pechenik, 1987; King et al., 1989; Mallet and Myrand, 1995) was shown to be a successful method of collection for all sites in this study, with the timing of wild spat collection a crucial factor as variations in settlement times occur from one year to the next (Cheong and Lee, 1984; King et al., 1989).

From Macneill et al. (2000), it is obvious that at least a 50% decrease in number of spat per collector from autumn to the following spring is expected for collectors which generally contain ~15,000 spat or greater, prior to winter. Most collectors in the spring contain ~ 5,000 spat per collector perhaps due to self thinning within the population (Macneill et al., 2000). This self-thinning process, or high drop off observed on collectors over the winter may be part of natural population control (Fréchette et al.,

1996). In essence, a population will adjust itself if conditions for stability become unfavourable, with available food and space being the major limiting factors. Therefore, for all sites in this study, collection was such that in the spring, adequate numbers of spat (~5,000) per collector should be available for socking at all sites.

Metamorphosis can be delayed for several weeks (up to 40 days @10 °C) if a suitable substrate is not found (Bayne, 1965, 1976), yet during this study, spat settlement appeared to occur over most of the sampling period, for all sites, at varying degrees. Interestingly, as the weeks progressed, the size of settled spat also increased indicating that either earlier in the season mussels will settle at smaller sizes if an optimum substrate is found, or, the increased food and temperatures recorded during late summer and early fall allow for faster growth of the spat within the two week sampling period of this study. The range of mussel spat settlement, over the sampling season was similar for all sites: Reach Run (390 μm - 500 μm), Little Shellbird Bight (385 μm - 630 μm), Shellbird Bight (340 μm - 700 μm) and Jersey Harbour (450 μm - 765 μm). Yet, larger recorded average spat sizes in the autumn months indicated that most larvae had grown to settling size by this point. This could also be due to better growing conditions at this time, following a late summer phytoplankton bloom (Scheltema, 1986). Thus, the window of opportunity for optimum collection is narrow, and could be missed entirely if not properly monitored.

4.1.3 Blue Mussel Larval Patterns in Relation to Spat Settlement

Following mussel spawning, the pelagic larvae produced will spend 1 to 4 weeks (Bayne 1965, 1976) actively searching for a suitable substrate on which to settle, with larval settlement and metamorphosis determined by cues in the environment (Bonar et al., 1990; Morse, 1990; Pawlik, 1992; Zimmer-Faust and Tamburri, 1994). It is predicted that through consistent, well-maintained sampling procedures a correlation would exist between the number of mussel larvae on a site and the number of spat that settle (Mason and Drinkwater, 1981). Martel et al. (1994), have recently described a strong positive correlation between concentrations of late-stage veligers of zebra mussels, *Dreisssena polymorpha*, and settlement rates. Similarly, settlement rate and settler density of the barnacle *Semibalanus balanoides* has also been found to be strongly correlated with larval availability (Caffey, 1985; Minchinton and Scheibling, 1991). However, the results of this study displayed site specificity with the number of mussel larvae collected in larval tows seemingly not entirely indicative of the number of spat settling. Future studies to examine larval flux through a site as a measure of current speed, and number of larvae (eg., competent larvae) collected, would be beneficial.

The average length of time from appearance of first larvae (~100-150 μm length) to spat settlement (~250-300 μm) ranged from 4-6 weeks within all sampling regions, with the sites in Green Bay displaying the more typical, single pulse of larvae and spat settlement. As well, peak spat settlement was recorded within a short period of 1-4 weeks following

peak larval abundances, further stressing the need for accurate monitoring within mussel culture sites.

Little Bay Arm had much higher larval abundances, yet more spat were recorded settling on collectors in Reach Run. One possible explanation for this is the site topography, current speeds and/or flux within each site. The sites in Green Bay are flow-through sites, which could mean that greater numbers of larvae would be passing through each site, but settling in areas other than where these collectors were placed. On the other hand, with respect to Reach Run, it is a much larger site, with the possibility that larvae are much more spread out and could be concentrated in certain eddies or high current areas where larvae sometimes prefer to dwell (Bayne, 1964; Mann and Wolf, 1983). It is also interesting to note that larval numbers were very low on the South coast, but settlement was still occurring, with predictions for available seed in the spring still expected to be adequate. Thus, when larvae are present, and the size (developmental stage) of larvae seems to be more important than how many are being sampled using larval tows.

From these results, it appears that broad-scale interpretation is limited as each site will be unique. Studies have described spatio-temporal variability in larval supply directly affecting subsequent settlement (Dadswell et al., 1988; Mallet and Carver, 1989, 1993; Martel, 1993). Reasons for this could be due to reproductive cycles (Davis, 1989), wind

and current patterns or changes in rates of larval mortality (e.g., predation) (Hadfield, 1963; Mileikovsky, 1974; Eckman, 1983; Rodriguez et al., 1993).

4.2 Starfish (*Asterias vulgaris*)

4.2.1 Starfish Larval Patterns

Starfish larvae were easily identified in the larval tows, with the late-stage brachiolaria larvae easily visible to the naked eye when sampled. Starfish generally spawn from late summer to early autumn (Barker and Nichols, 1983; Freeman et al., 2001), with *Asterias vulgaris* producing a pelagic larva which is capable of swimming through the water column as it develops and searches for a suitable substrate on which to settle (Banse, 1985). Evidence of spawning (i.e., appearance of larvae in tows) was recorded during this study along the North coast of Newfoundland from early July to early August.

Starfish larvae were present in three of the four sampling sites, along both regions on the North coast of Newfoundland, Notre Dame Bay and Green Bay. While there was only one larva detected on the South coast for the entire sampling period, on July 22. For the areas where larvae were detected, it appears that starfish in these areas have single spawning events as larvae passed through both regions in a single pulse or wave. Larvae were first detected in Little Shellbird Bight and Shellbird Bight (Green Bay) on June 13 and July 6, respectively, with starfish larval periods lasting for a total of 7-10 weeks.

Similarly, larvae were first detected in Reach Run (Notre Dame Bay) on June 24, displaying a similar 6-7 week larval progression.

It is interesting to note, that while similar temporal patterns for both regions were observed for the starfish larvae, the number of larvae/L recorded in Little Bay Arm (Little Shellbird Bight and Shellbird Bight) was much higher than in Reach Run. Little Shellbird Bight peaked at 9.35 larvae/L on August 14, while Shellbird Bight peaked the following week (August 21) at 9.04 larvae/L. However, Reach Run displayed much lower counts, earlier on July 16, peaking at only 2.67 larvae/L. This is again most likely a result of site topography. Unfortunately, comparisons to other geographical areas could not be completed as there is a lack of published data relating to starfish larval and juvenile distributions and densities.

During the tidal study of 1999, it was reasonable to assume that mussels would be present during both times of the year, but starfish larvae would only be present during the July samples. In fact, starfish larvae were only recorded again in Notre Dame Bay and not along the South coast during early July.

When the larval patterns were examined in relation to tidal height, starfish larval abundance peaked during both high and low tide during the spring tide event (July) on site 1, Reach Run. However, it was the outside of the site that displayed the greatest size

range in larvae over the 12 hours sampled, regardless of tide height. Hence, starfish are perhaps not drifting in the tides as freely as bivalve larvae.

4.2.2 Starfish Juvenile Settlement

Four to six weeks, or ~28-64 days (David et al., 1994; De Vooys, 1999) after spawning the ciliated brachiolaria larvae settle and metamorphose into young starfish (Smith, 1940). Sutterlin et al. (1981), observed settling starfish larvae in Garden Cove, NL, occurring in early autumn, i.e., September and October. Levy (1999) also observed starfish settlement on a site along the South coast of Newfoundland during autumn, with late summer spawning being documented in P.E.I. (MacKinnon et al., 1993). Similar temporal patterns were observed during this study with starfish settlement numbers sporadic and far less than mussel spat settlement.

Starfish juvenile settlement was observed on only two sites along the North coast of Newfoundland, in the Green Bay region. While starfish larvae were recorded at site 1, in Notre Dame Bay, juvenile settlement occurred only on the grower's collectors and not on the ones used for this study. It was noted at the time that due to the fact that Reach Run is such a large site, thousands of collectors are placed in different locations with the ones placed closest to adult mussels generally having more starfish juveniles per collector (unpublished observation). Thus, for this site it appears that some other factor such as current velocity, wind or possibly the proximity of collectors to the adult mussels

influenced where the starfish preferentially settle (Highsmith, 1982; Holm, 1990; Nielsen and Franz, 1995).

The number of starfish juveniles which did settle in Little Bay Arm was very low in comparison to recorded mussel spat settlement. For Little Shellbird Bight (site 2), a peak of juvenile settlement of 3.5 juveniles per collector was recorded on August 21, 1998. While, Shellbird Bight (site 3) experienced slightly higher numbers with a peak of 9.0 juveniles per collector recorded on September 4, 1998. The size range for all settled juveniles was quite narrow, between 1,000 - 1,500 μm, with little variation observed over the sampling season.

4.2.3 Starfish Larval Patterns in Relation to Juvenile Settlement

Starfish larval settlement within the two sites in the Green Bay region was only 1 to 2 weeks later than the peak in starfish larval abundances. Furthermore, once starfish larvae had reached the advanced brachiolaria stage, starfish juvenile settlement was observed within the same week on collectors. Hence, in areas that regularly experience starfish settlement on collectors, careful monitoring for late stage larvae would be a good predictor for timing of juvenile settlement.

As starfish settlement was only recorded on the two sites within close proximity to each other, it is difficult to conclude if number of recorded starfish larvae could be used as a predictor for number of expected settled juveniles. However, the presence of starfish

larvae in tows, and the fact that the developmental stages are easily identifiable does allow for accurate predicting of settlement. This was particularly so for the sites used in this study.

4.3 Blue Mussel - Starfish Interaction

Many marine species have been identified as potential predators of blue mussels (Osman et al., 1992; Ray-Culp et al., 1997; Dolmer, 1998; Miron et al., 2002). The most important one in Newfoundland waters is the predatory starfish. Starfish predation, if present in large enough numbers can completely consume a collector and in the case of larger species, are able to consume mussels through to commercial size (Dare, 1982). Starfish are very effective predators that are capable of adapting to their prey and may even have the ability to change their attack strategies such that when mussel shells were equipped with electronic indicator devices to measure the force applied by starfish, three types of attacking behaviour were described: (1) A short pulse (on small and large mussels), (2) A pulse of long duration (on medium sized mussels), and (3) A change in position to the opposite side of the hinge ligament (on large mussels) (Norberg and Tedengren, 1994). Starfish predation on mussels has also induced phenotypical changes in the mussel themselves (Reimer and Tedengren, 1996, 1997), which may not be commercially desirable.

In this study the appearance of starfish larvae and juveniles coincided and followed peak mussel abundance. Therefore it seems that the onset of starfish spawning is timed to occur at the best opportunity for the newly settled juveniles to feed on large numbers of newly settled mussels, as a preferential source of prey. A peak in starfish abundance during autumn 1997 coincided with its prey (bivalve) settlement in North Wales (Freeman et al., 2001). Unfortunately for mussel growers, to avoid the starfish by delaying the deployment of collectors until after the major starfish settlement period does not seem to be possible as the main opportunity for optimizing mussel spatfall would be lost. On the other hand, if the planktonic larvae of either of these species change their vertical distribution in relation to larval stage or settlement stage (Young, 1982; Dobretsov and Miron, 2001), then a predator-prey avoidance strategy could also affect the results of this study. This may be true for echinoderm larvae as they have been documented as exhibiting weak vertical migration and may tend to stay in the surface layers prior to settlement (Pedrotti and Feneaux, 1992).

Further study is needed to determine if the numbers of settled starfish recorded during this study would qualify as excessive enough to completely clean a collector, and may instead allow for self-thinning of mussel spat over the winter months (Fréchette et al., 1996). In turn, further research into removing newly settled starfish from collectors, such as treating the collectors with lime, might be the best option remaining for limiting heavy starfish predation on affected mussel farms in Newfoundland.

4.4 Environmental Data

The environmental conditions of the four sites sampled varied little during 1998, with all regions having growing conditions conducive for both blue mussels and starfish. Similarly, the environmental data recorded during the tidal studies of 1999 were similar with previous years' data for those times of year.

Blue mussel spawning usually occurs from mid June to late September, when water temperatures are ideal for larval development. However, mussels may spawn at temperatures below 10 °C such as occurs frequently in P.E.I. (Bernard, 1998). Rising, falling and fluctuating temperatures have been reported to stimulate spawning in blue mussels (*Mytilus* sp.) (Seed and Suchanek, 1992). Mussels may be triggered to spawn at temperatures greater than 10 °C; however, temperature alone may not be the only determinant of when a mussel spawns. It is generally believed that many factors acting together will trigger spawning. Both temperature and food supply seem to be particularly important factors influencing gametogenesis and spawning of mussels (Wilson, 1987b; Seed and Suchanek, 1992) with a series of factors working together to determine such events.

By June, 1998, Reach Run and Jersey Harbour had temperatures already above 10 °C, while Little Bay Arm remained quite cooler and did not increase above 10 °C until August. Yet evidence of mussel spawning was observed at all sites in early July, thus it

is most likely that blue mussels do not exhibit a single reproductive strategy, but rather exhibit a variety of patterns depending on the particular environmental regime (Newell et al., 1982).

Mussel growth increases logarithmically with temperature; however, above 20 °C growth rate decreases, and at low temperatures (3 °C) growth may be very slow (Almada-Villela et al., 1982). Seawater temperature is an important factor in regulating the abundance and distribution of *A. irregularis* in coastal waters in North Wales (Freeman et al., 2001). Overall, the results of this study were similar to that of previous studies, displaying conducive temperatures for growth and survival (Mayzaud et al., 1989; Navarro and Thompson, 1995; Parrish et al., 1995; Penney and MacKenzie, 1996; Levy, 1999; Pryor et al., 2001).

Newly settled spat can be intolerant of fluctuations in salinity. Recent studies have shown that even minor reductions in salinity (21-26 ppt) may cause significant detachment of spat from collectors (Mooney, 1997; Burry, 1998). It is recommended that locations with prolonged salinities of 15-20 ppt be avoided for mussel culture (Scarratt, 1993). While low salinity levels may be detrimental to growth and can be lethal under extreme conditions (Almada-Villela, 1984), in P.E.I., mussels survive and grow quite well in salinities 26-28 ppt (Mallet and Myrand, 1995). Recorded salinities throughout Newfoundland were very good and remained consistent at each site, and well within the tolerable range for mussels (27-31 ppt).

In Newfoundland many sites experience two phytoplankton bloom events; one in late winter to early spring (largest of the two) and one in late summer to early autumn (Clemens et al., 2000; Pryor et al., 2001). The clearance rate of Newfoundland mussels may fluctuate between 1.5 and 2.0 litres per hour and show relatively little seasonal variation (Thompson, 1984), with food availability being the determining factor in many areas of the world with respect to gonad growth (Seed and Suchanek, 1992). Hence, the late winter bloom event provides the much needed resources for gonad development through the spring months, with spawning occurring in early-mid summer. Timing gametogenesis during or directly following the spring phytoplankton bloom ensures adequate food levels will exist for planktonic larvae (MacDonald and Thompson, 1986; Jaramillo and Navarro, 1995).

Overall, peaks in water temperature throughout the summer months, in correlation with the appearance of a late summer to early autumn bloom present prime growing conditions for larvae of both species. The occurrence of larger spat settling late in the sampling season could be due to better growth rates due to environmental conditions, i.e., late summer phytoplankton bloom (Scheltema, 1986).

The swimming speeds of bivalve larvae range from 0.17 to 10.0 mm/s (Mann and Wolf, 1983). These speeds permit vertical positioning if larvae are able to respond to tidally induced cues such as changes in salinity, temperature, pressure or current velocities.

Laboratory studies reported in Newell et al. (1991) indicate tidally related response of bivalve larvae to salinity (Haskin, 1964), temperature (Mann and Wolf, 1983) and hydrostatic pressure (Bayne, 1964; Mann and Wolf, 1983). Penney (1993) confirmed extreme variability in depth distributions of planktonic mussel veligers in Charles Arm, with a significant depth relationship to proportion of mussel veligers greater than 250 μm observed. Those mussel veligers greater than 250 μm tended to increase from bottom to top of the water column, which may indicate an affinity for near surface depths by settlement-size larvae. Similar evidence has also been documented for starfish larvae, as Pedrotti and Feneaux (1992) describe echinoderm larvae exhibiting weak vertical migration and a tendency to stay in the surface layers prior to settlement.

Tremblay and Sinclair (1992) found that in mixed areas of the water column on Georges Bank scallop larvae were distributed evenly but in stratified waters larvae were concentrated above the pycnocline. In areas where the pycnocline was well developed the differences in the centre of mass of the larvae were associated with the differences in the position of the pycnocline. As these sites are relatively shallow (10-30 m), mixing may eliminate the presence of a consistent pycnocline, yet in response to food availability (chlorophyll-a concentrations), veligers may in fact demonstrate vertical migration (Scrope-Howe and Jones, 1986).

Throughout 1999, the major environmental parameter that may have affected the larval data recorded along the South coast was the wind. Wind speeds were very high for the

entire sampling season, and while not outlined in this report, they were predominantly directed off-shore or away from this site. Extreme high winds will continuously mix a small harboured site such as Jersey Harbour, making the predictability of larvae and spat difficult. It was interesting to note that during 1999, when the tidal study was completed on this site, wind events had been much calmer, and subsequent larval abundances were much higher. Tides did have an effect on bivalve larval retention and settlement in England; however, the influence of winds was predicted to be considerably more important, causing up to a 3-fold greater variability in the predicted number of settled larvae (Young et al., 1998). Hudon and Fradette (1993) demonstrated the importance of wind-induced advection with their field study of larval decapod dispersal. Future larval studies should therefore consider the importance of wind, both speed and direction, through a site.

Spatially, throughout the province it appears that environmental conditions have allowed mussel populations, and in essence starfish populations to flourish. All regions displayed good growing conditions to support blue mussel aquaculture.

4.5 Implications to Mussel Farming in Newfoundland

The timing, occurrence and relationship of abundance between larvae and juveniles of mussels and starfish were site specific. For sites 2 (Little Shellbird Bight) and 3 (Shellbird Bight), it was observed that when larvae were in the water as well as how

many larvae were present both aided the prediction of timing and numbers of mussels settled. However, in comparison, for sites 1 and 4, the presence of larvae was only indicative of timing of settlement but not number settled. When analyzing starfish it was evident that the timing of starfish settlement coincided with mussel settlement, so starfish avoidance may not be possible. Since the inter-relationship between mussels and starfish was site specific, each mussel grower will have to understand the characteristics of their individual sites in order to maximize their mussel spat settlement.

Growers may need to develop an autumn monitoring program in areas heavily hit by starfish predation to determine if an intervention before the winter months is warranted. Starfish will continue to forage and eat throughout the winter months, even if in limited amounts (O'Neill et al., 1983) therefore only a few starfish per collector may have the ability to clean the collector of most of its newly settled spat. Yet, further work is needed to determine how many starfish is really too many.

In areas where multiple spawning events occur, such as site 1, Reach Run, mussel collectors could be deployed later in the season, after starfish juveniles have settled. Only one spawning event was recorded for starfish on all three sites where starfish larvae were found. This would be a production decision based on the possibility of having some larger spat in the autumn months following summer growth but risk starfish predation, or delay deploying collectors until starfish juveniles have settled. By deploying the collectors at this time, the spat will be smaller in the autumn months, but with predation

at a minimum, spat numbers and size should be very good in the following spring. However, the proximity of a predator to a prey (starfish present on a mussel collector) will inhibit the growth of the prey as they will not be feeding as effectively as if no predator was within close proximity (Norberg and Tedengren, 1994).

This study demonstrated the importance of a standardized and accurate method for monitoring larval abundances on shellfish culture sites throughout Newfoundland. Growers should consistently sample at the same stage of tidal height and location on their site in order to achieve accurate relative larval abundances for every sampling period, as variations were recorded during the short-term sampling periods. Thus, knowing when and where mussel larvae, and such biofouling agents as clams and predatory starfish, are passing through a shellfish site will aid in optimizing spatfall on Newfoundland mussel culture sites.

5.0 CONCLUSIONS

1. Weekly plankton tow sampling was successful for sampling planktonic larvae in all three sampling regions. Larvae were easily identified for mussels, starfish, and other fouling species such as clams, and are found throughout each sampling site. Consistency in net tow methodology, timing and location within each site aided in obtaining consistent larval numbers for each region.

2. Starfish spawning events coincide with, and/or directly follow, that of their main prey species, the blue mussel. Further work into multiple spawning events and avoidance strategies of starfish settlement would be beneficial.

3. Both temporal and spatial differences exist when monitoring planktonic larvae during a 12-hour tidal cycle. Consistent monitoring during the same tidal height, within a site may alleviate the problem of within site differences in future studies.

4. Environmental conditions within the three regions of the province during both 1998, as well as the sampling for the tidal studies during 1999 were conducive for optimum growth for blue mussels and starfish species studied.

5. Furthermore, while the objective of this study was to monitor the larvae of the blue mussels and predatory starfish species, it became evident that many other species can be effectively monitored in this fashion, such as the saxicave clam

larvae (*Hiatella* sp.), which is a common fouling organism along the South coast of Newfoundland. Thus, each shellfish farm should monitor for many different larval species if optimal mussel spatfall is to be achieved.

6. While number of larvae/L may indicate number of settling spat and/or juveniles, monitoring larval development will allow for accurate predictions of when settlement will occur.

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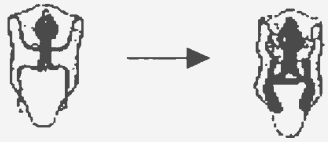
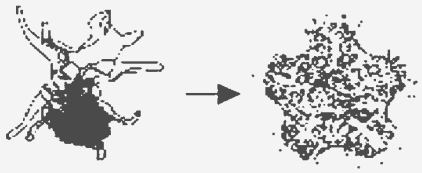
7.0 TABLES

Table 1. Production in tonnes and value of the blue mussel, *Mytilus edulis/Mytilus trossulus*, in Atlantic Canada, for 2002. Key: NL - Newfoundland and Labrador, NB - New Brunswick, NS - Nova Scotia, PEI - Prince Edward Island. (Source: Department of Fisheries and Oceans Statistical Service Website, www.dfo-mpo.gc.ca/communic/statistics/aqua/index_e.htm, May, 2004)

	NL	**NB**	**NS**	**PEI**	**Total**
tonnes	**1,700**	**637**	**1,073**	**16,785**	**20,195**
$000	**5,500**	**801**	**2,288**	**22,202**	**30,791**

Table 2. Six developmental stages used in the identification of starfish larvae (*Asterias vulgaris*) (Adapted from Winsor, 1976).

Developmental Stage	Pictorial depiction	Approximate size
Early Bipinnaria		250 - 300 μm
Mid Bipinnaria		300 - 450 μm
Advanced Bipinnaria		450 - 600 μm
Early Brachiolaria		600 - 800 μm
Advanced Brachiolaria to Setting Stage		800 – 1,200 μm

Notes:

Advanced brachiolaria stage = metamorphosing bipinnaria

The bipinnaria larva becomes a brachiolaria larva when the brachiolaria complex has developed (David et al., 1994).

The advanced brachiolaria stage has 2 well marked regions: 1. Anterior larval body, 2. Posterior, rounded adult primordium.

8.0 FIGURES

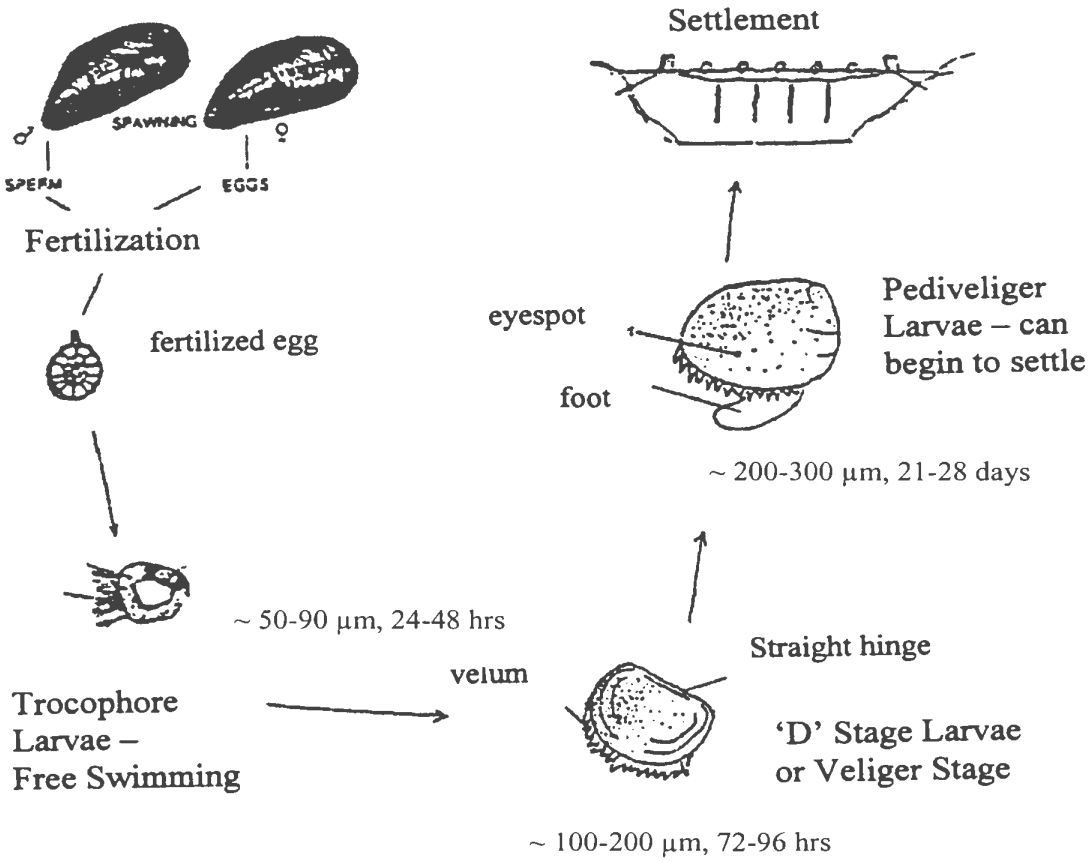


Figure 1. Life cycle of the blue mussel, *Mytilus edulis/Mytilus trossulus* (Macneill et al., 2000).

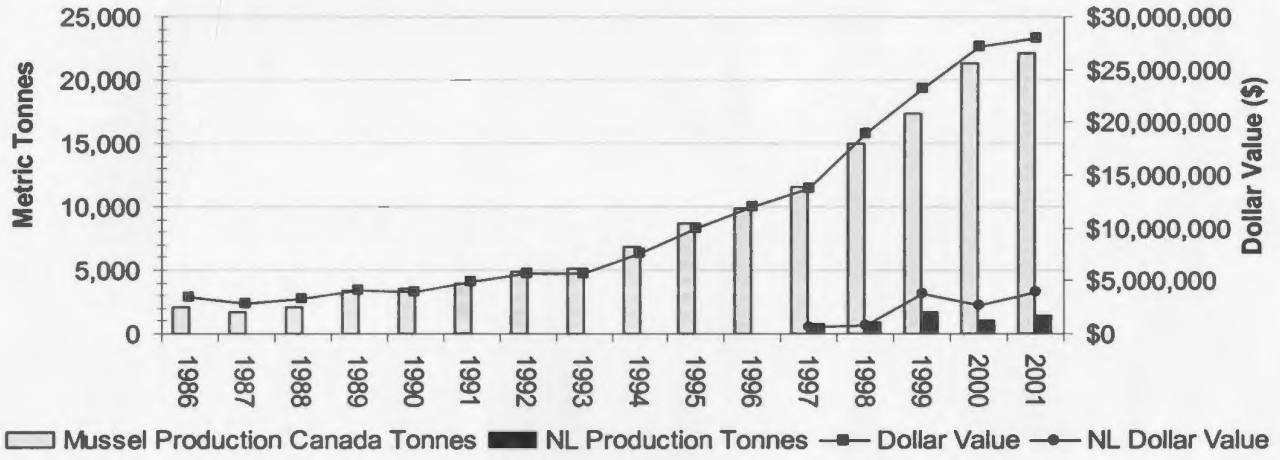


Figure 2. Canadian and Newfoundland blue mussel production and value for years 1986-2001. (Source: Department of Fisheries and Oceans Statistical Service Website, www.dfo-mpo.gc.ca/communic/statistics/aqua/index_e.htm, May, 2004).

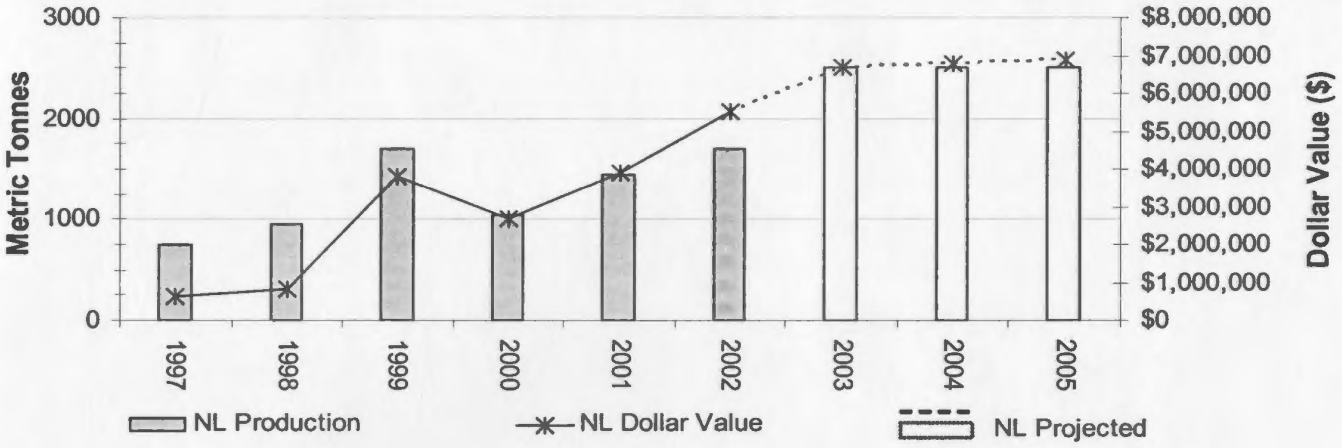


Figure 3. Newfoundland blue mussel production and value for years 1997-2002, with projected values for years 2003-2005. (Source: Department of Fisheries & Aquaculture, NL).

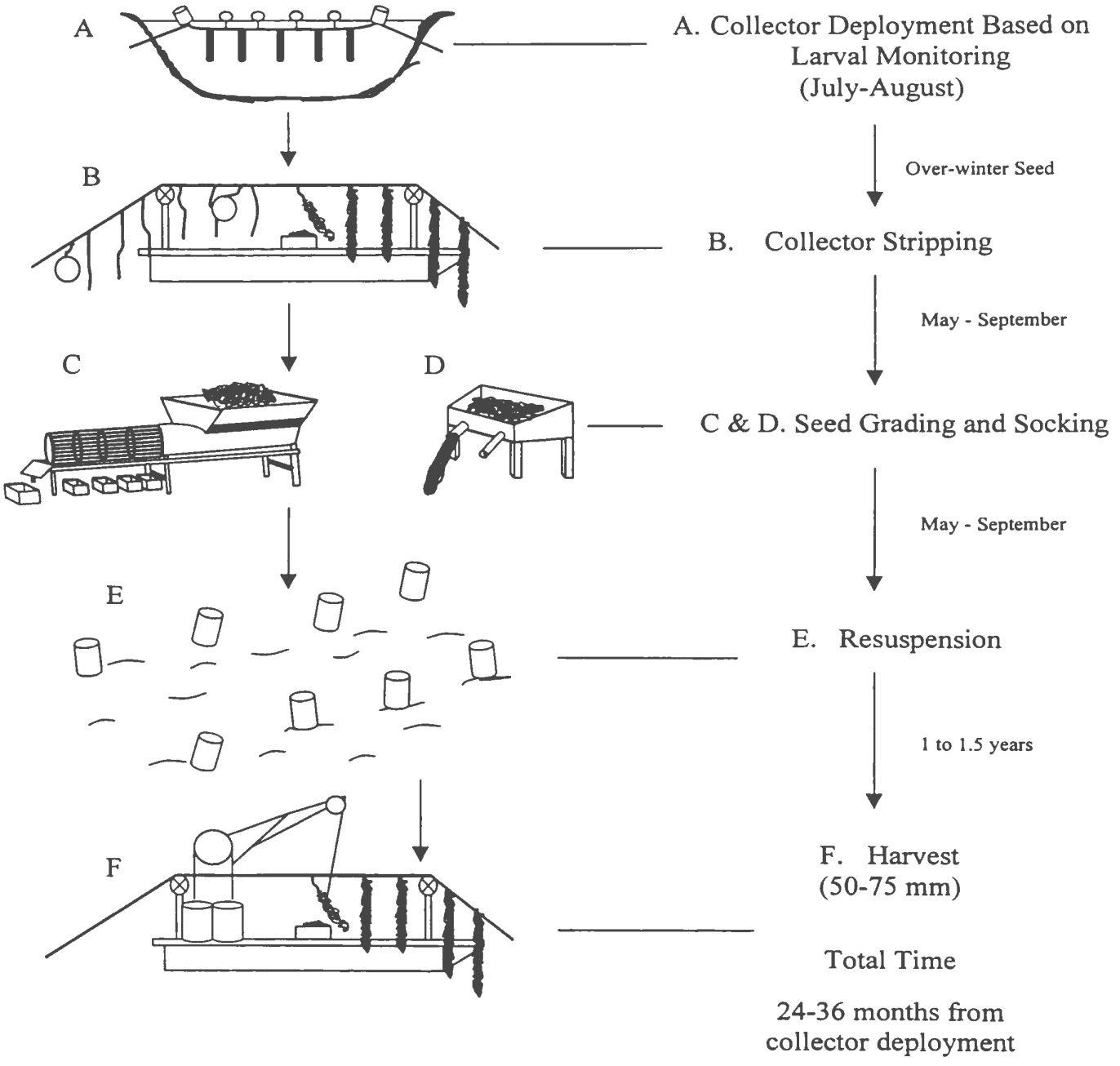


Figure 4. Mussel farming process in Newfoundland (Macneill et al., 2000).

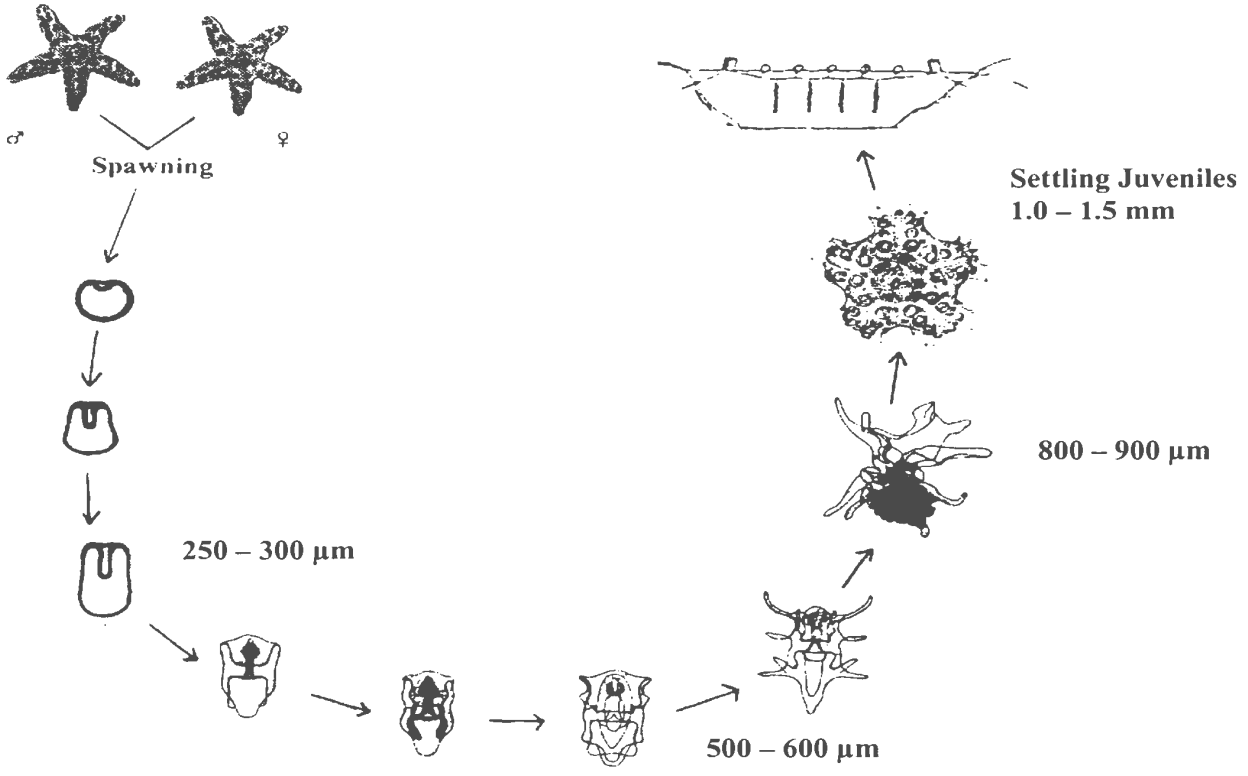


Figure 5. Life cycle of the predatory starfish, *Asterias vulgaris* (Adapted from Winsor, 1976).

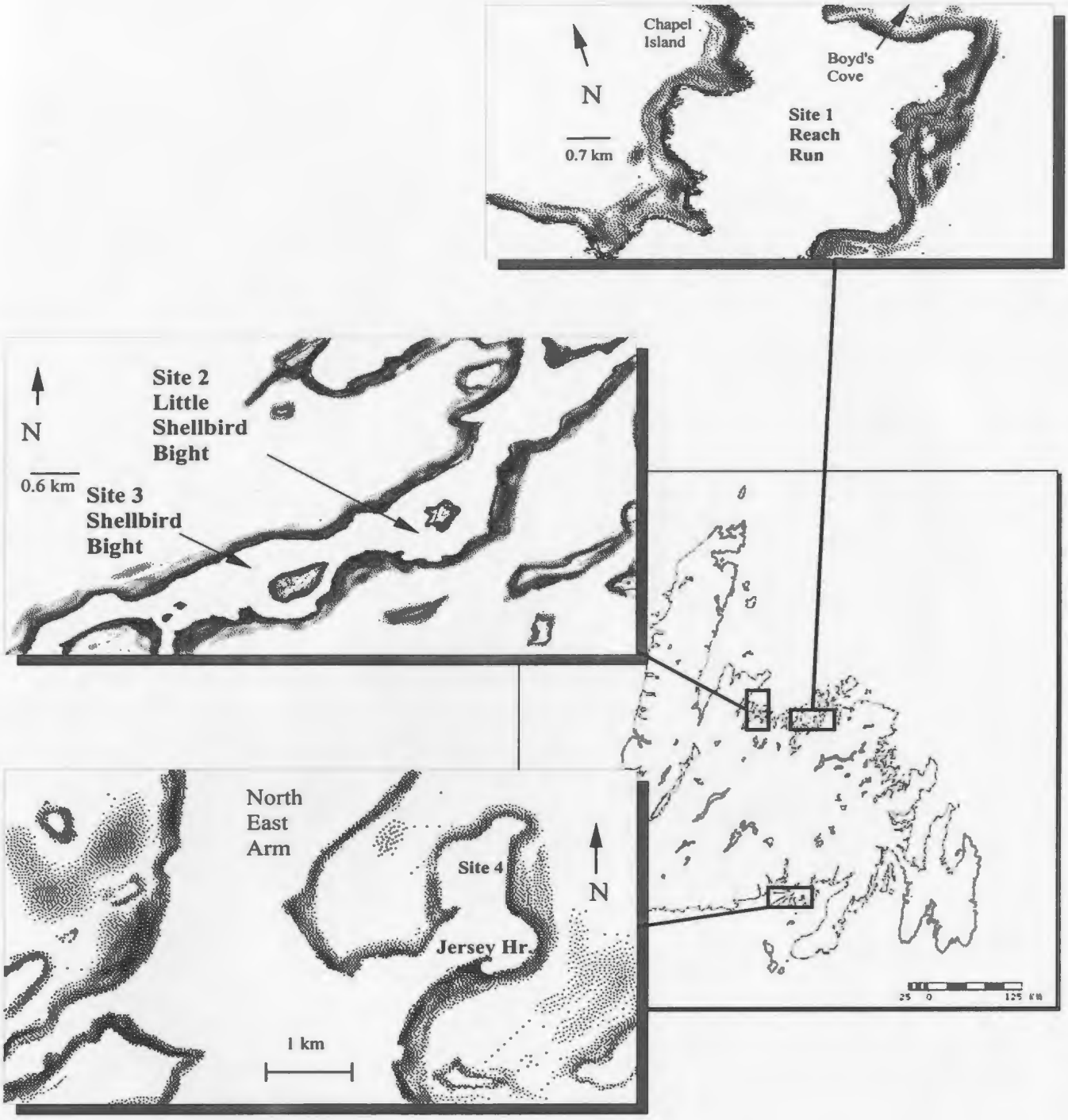
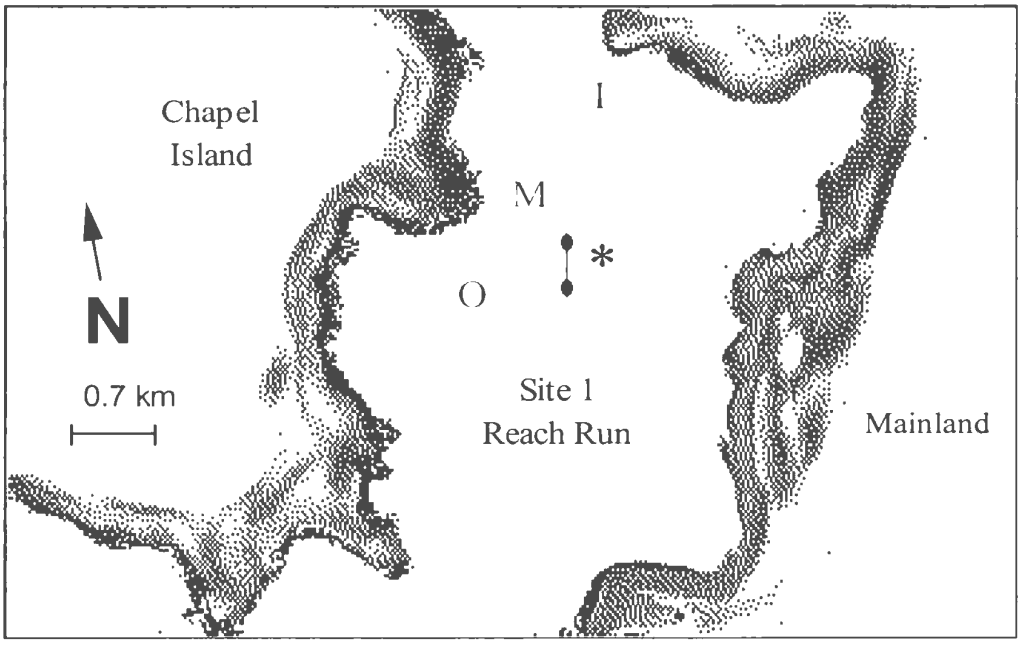


Figure 6. Geographical location of the four study sites; site 1 (Reach Run), site 2 (Little Shellbird Bight), site 3 (Shellbird Bight) and site 4 (Jersey Harbour).



I - Inside
M Middle
O - Outside

● ● = Collector Line

Figure 7.1. Location of vertical plankton tow sampling stations (inside, middle, outside) and collector line placement within site 1, Reach Run. Approximate latitude and longitude of the middle of the site (*) is 49.4150°, 54.6866°, respectively.

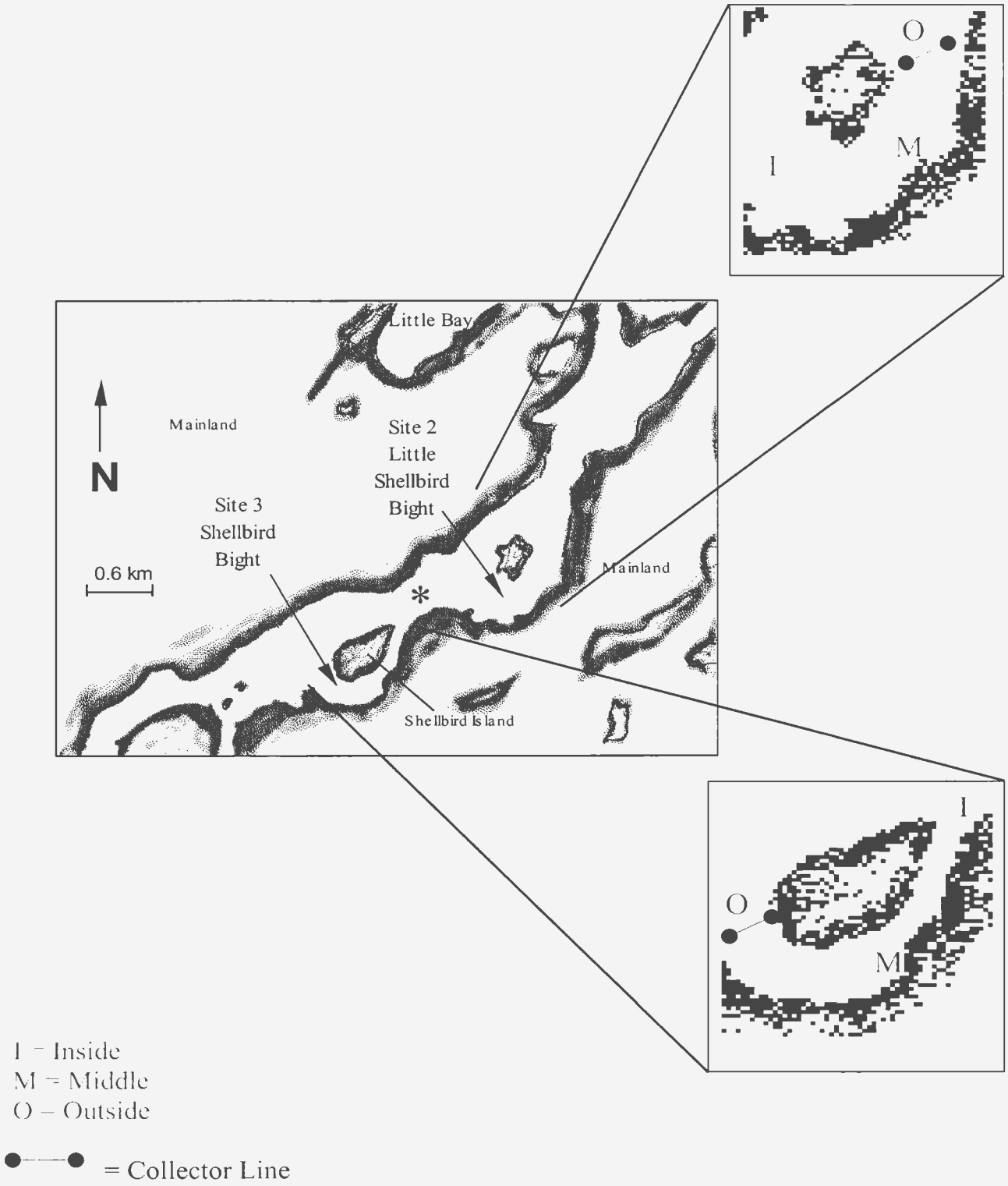
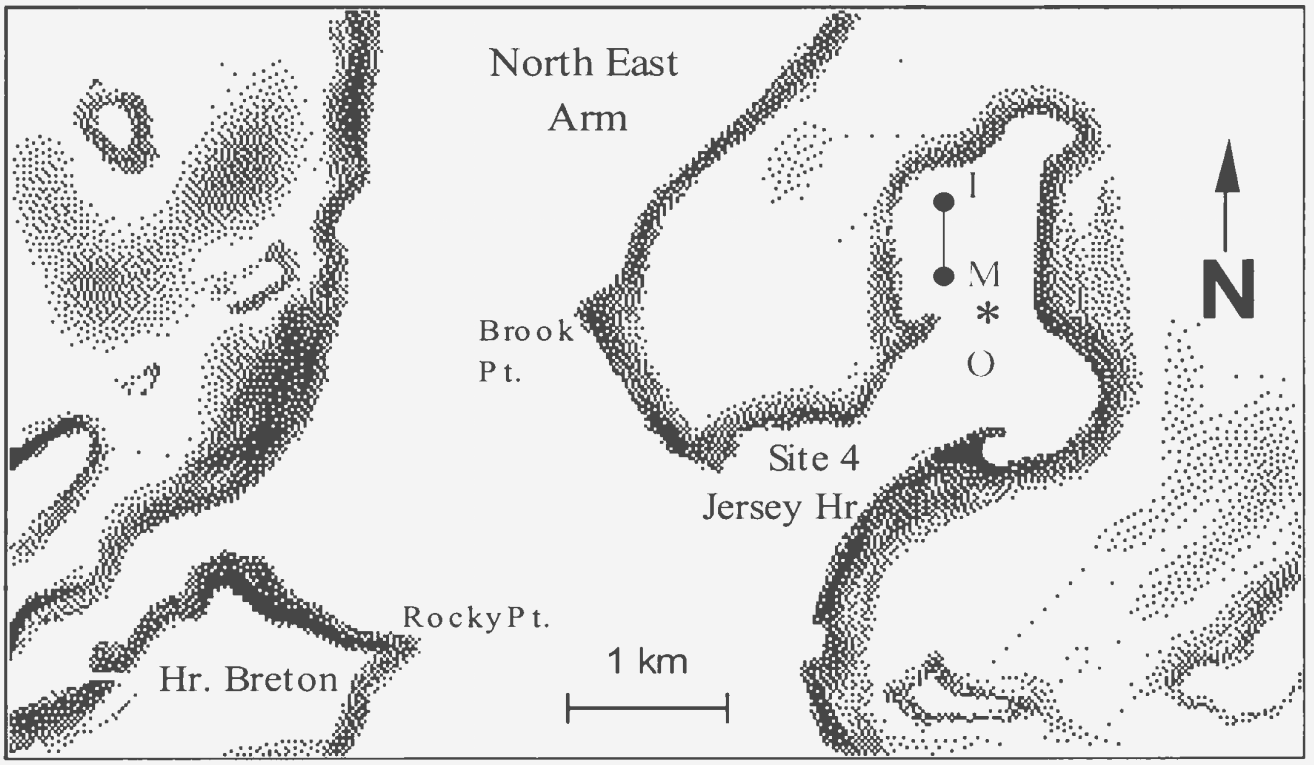


Figure 7.2. Location of vertical plankton tow sampling stations (inside, middle, outside) and collector line placement within site 2, Little Shellbird Bight and site 3, Shellbird Bight. Approximate latitude and longitude of the middle of the bay (*) is 49.5852°, 55.9421°, respectively.



I = Inside
M = Middle
O = Outside

●——● = Collector Line

Figure 7.3. Location of vertical plankton tow sampling stations (inside, middle, outside) and collector line placement within site 4, Jersey Harbour. Approximate latitude and longitude of the middle of the site (*) is 47.5462°, 55.7326°, respectively.

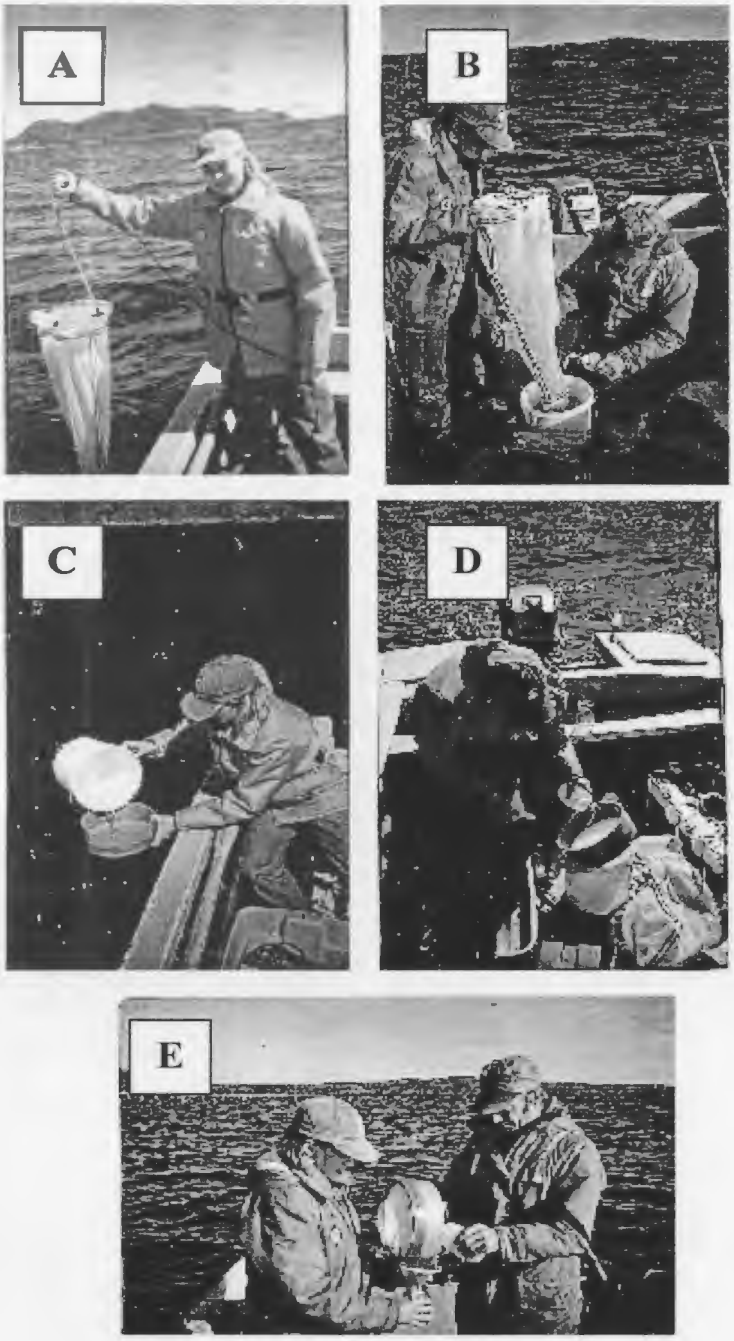
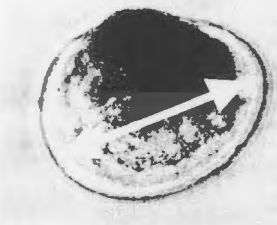


Figure 8. Plankton tow procedures using a 100-µm-mesh plankton net (A), which was lowered, vertically, to a depth of 10 m. The sample was then washed into a bucket (B), which was filtered through an 80-µm-mesh screen (C). This sample was then rinsed into a labeled 500 mL sample jar (D & E) and preserved in alcohol.

(A) "D" Shaped – Veliger – 115 μm x 88 μm – 4 days (20X)

(B) 173 μm x 142 μm – 8 days (20X)

(C) 200 μm x 169 μm – 10 days (20X)



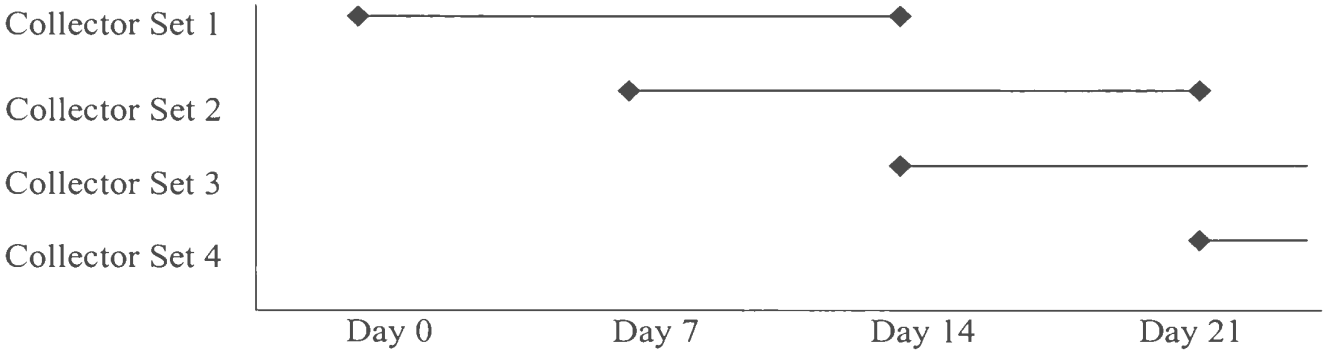
(D) Setting Larva – Eyed – 312 μm x 297 μm – 21 days (10X)

Figure 9. Shell lengths and shell heights of different sizes of blue mussel larvae (*Mytilus edulis*). Arrows indicate how larval shell lengths (anterior – posterior axis) were measured for each stage of blue mussel larval development (A-D). (Note: Larval pictures adapted from Doiron, S., 1997, Dept. of Fisheries and Aquaculture, Shippagan, NB).

A

B

Figure 10. (A) Two meter rope collectors used for evaluation of blue mussel and starfish settlement. Bottom end of collector was weighted with a stone in socking material, with polypropylene twine threaded through the top end to secure the collector to the mainline. (B) Each collector was attached to the mainline, approximately 60 cm apart.

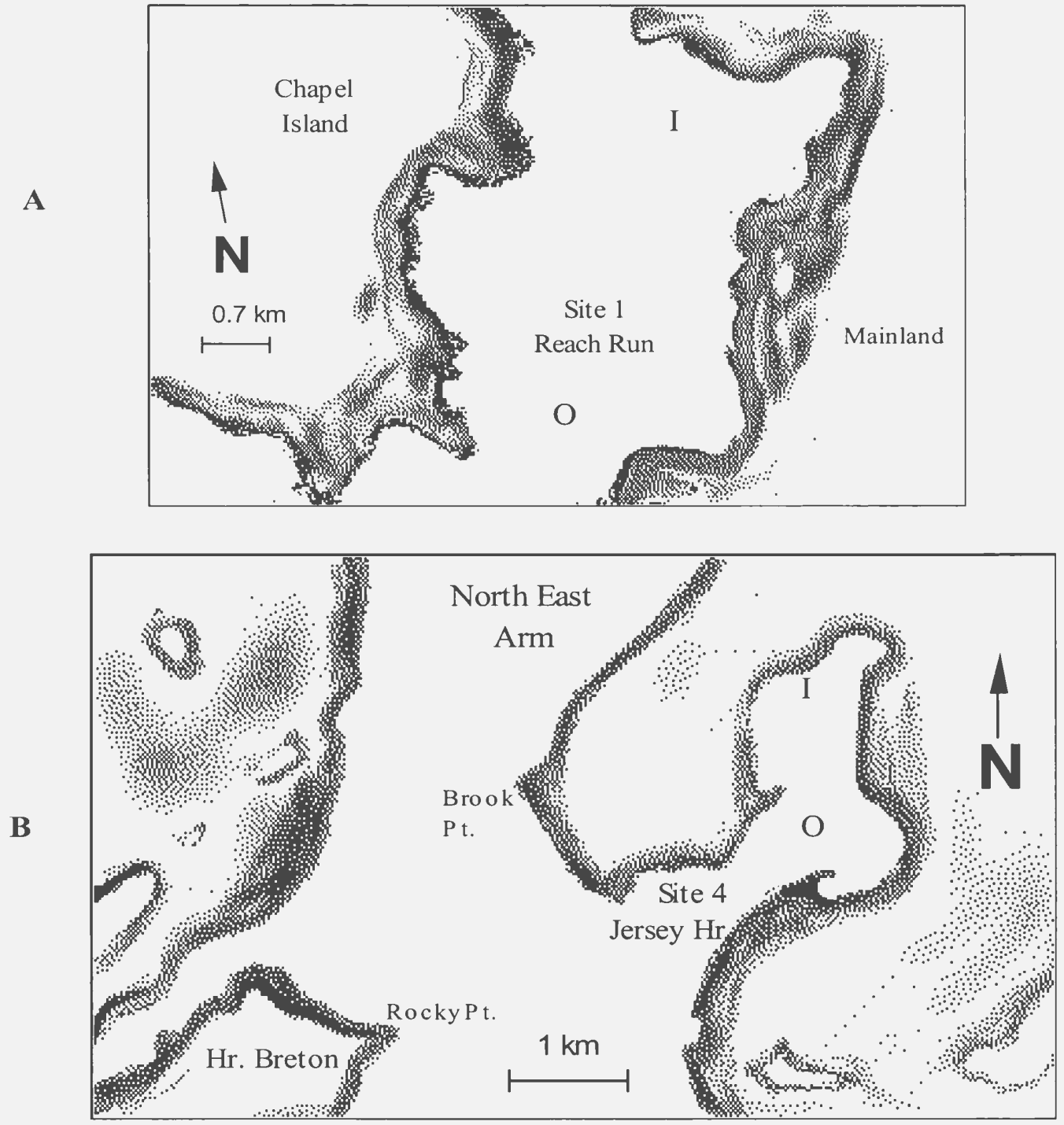


Key:

Day 0 - 5 rope collectors (Set 1) deployed.
Day 7 - 5 rope collectors (Set 2) deployed totaling 10 collectors on site.
Day 14 - First 5 collectors (Set 1) retrieved and 5 more collectors (Set 3) deployed.
Day 21 - Second set of collectors (Set 2) retrieved and 5 more collectors (Set 4) deployed.

This was then repeated for the deployment of a total of 18 sets of collectors.

Figure 11. Collector sampling regime to monitor blue mussel spat and starfish juvenile settlement on each sampling site.



I = Inside
O = Outside

Figure 12. Location of sampling stations within site 1 (A) Reach Run, and site 2 (B) Jersey Harbour for the 12-hour tidal cycle study. Vertical plankton tow sampling and Seabird CTD casts (inside and outside) as well as location of S4 current meter (outside) for each site are outlined. (Note: For site 1, inside = station 1 and outside = station 2. While for site 2, outside = station 1 and inside = station 2.)

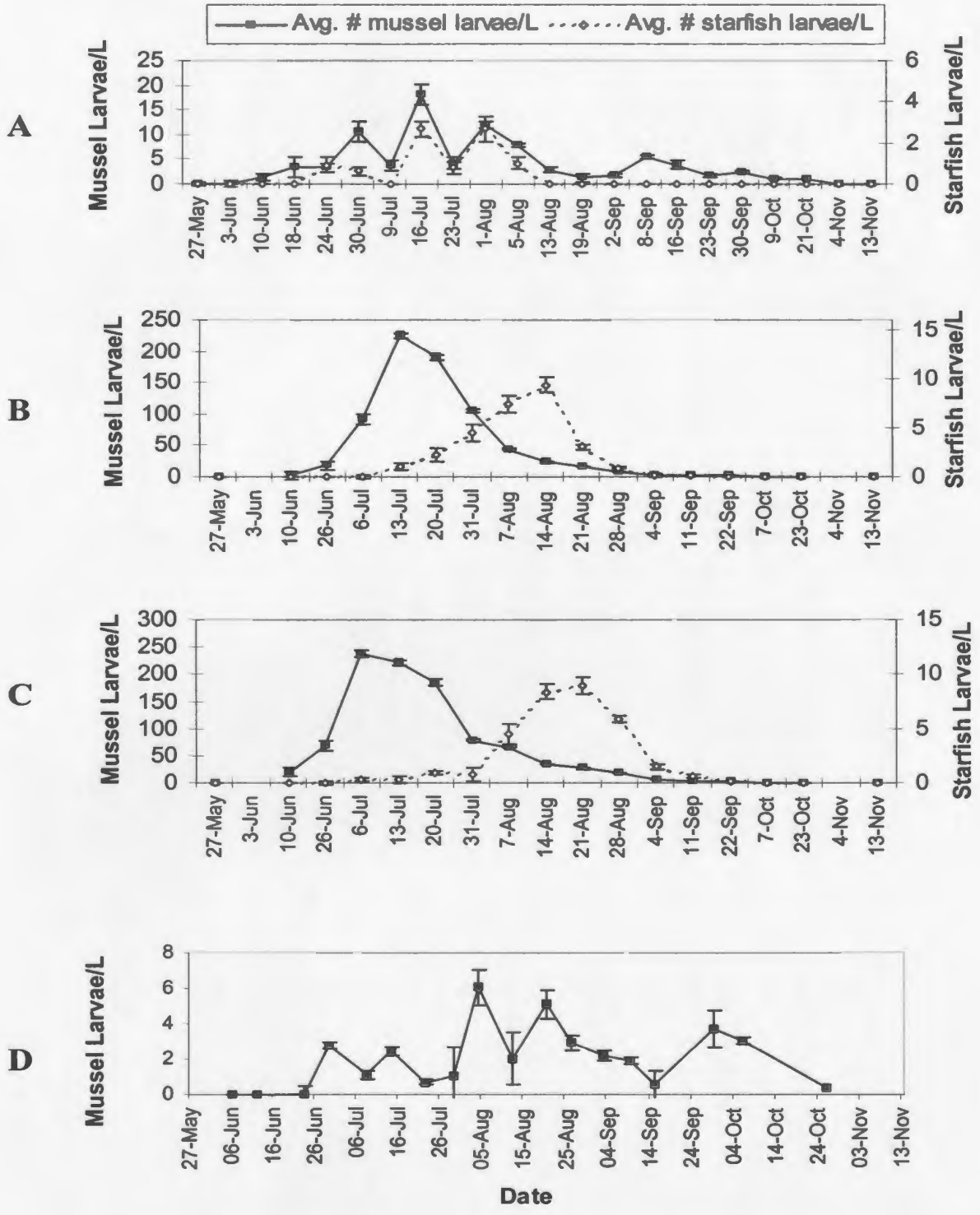
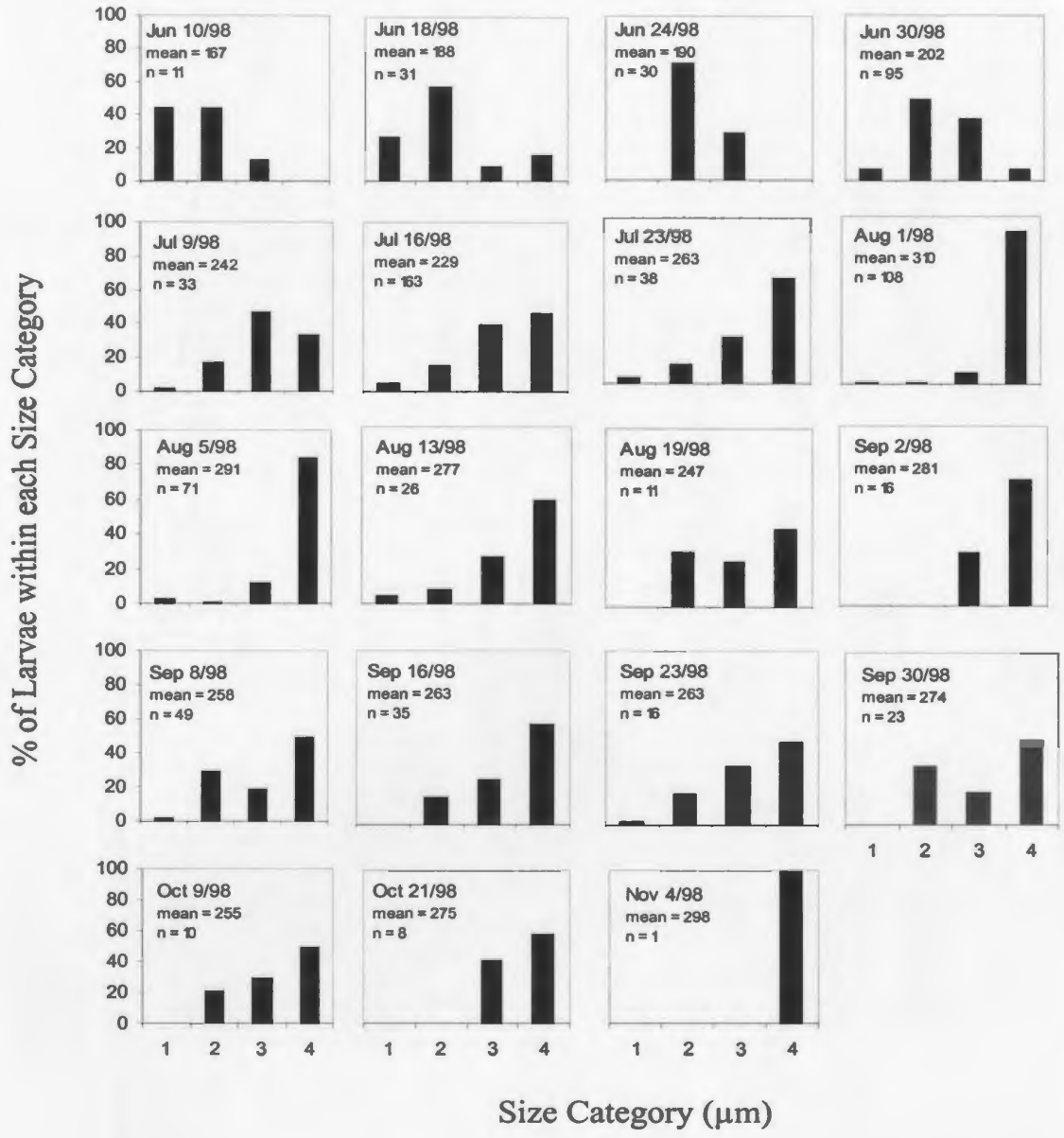


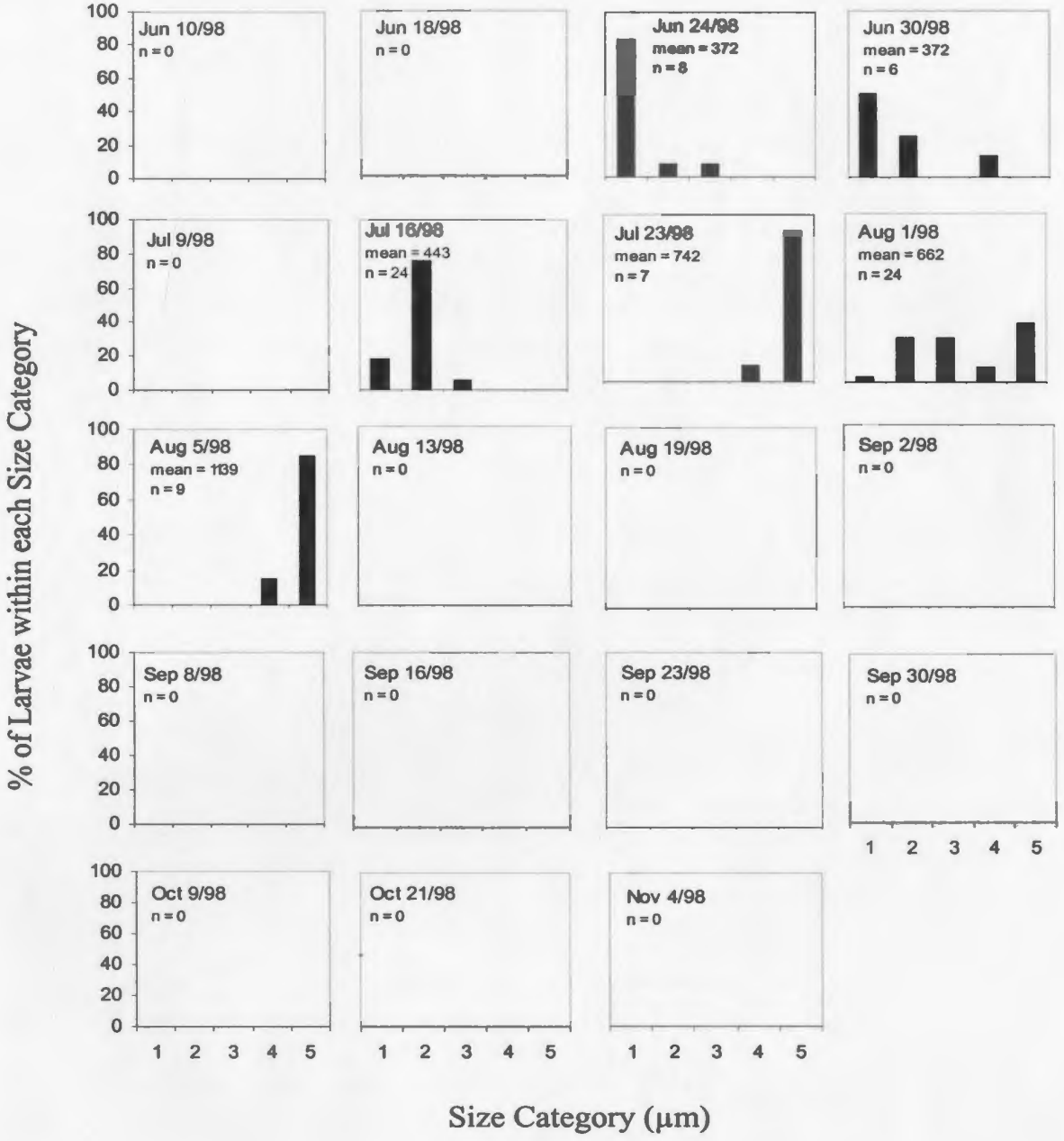
Figure 13. Average number of blue mussel larvae/L and starfish larvae/L recorded during 1998; A = site 1 - Reach Run, B = site 2 - Little Shellbird Bight, C = site 2 - Shellbird Bight, and D = site 4 - Jersey Harbour. Vertical bars are ± standard error. (Note: Scales of y-axis are different for each site and no starfish were found at site 4.)



Key:

Category 1 = % Larvae < 150 μm
Category 2 = % Larvae 151 μm – 200 μm
Category 3 = % Larvae 201 μm – 250 μm
Category 4 = % Larvae >251 μm

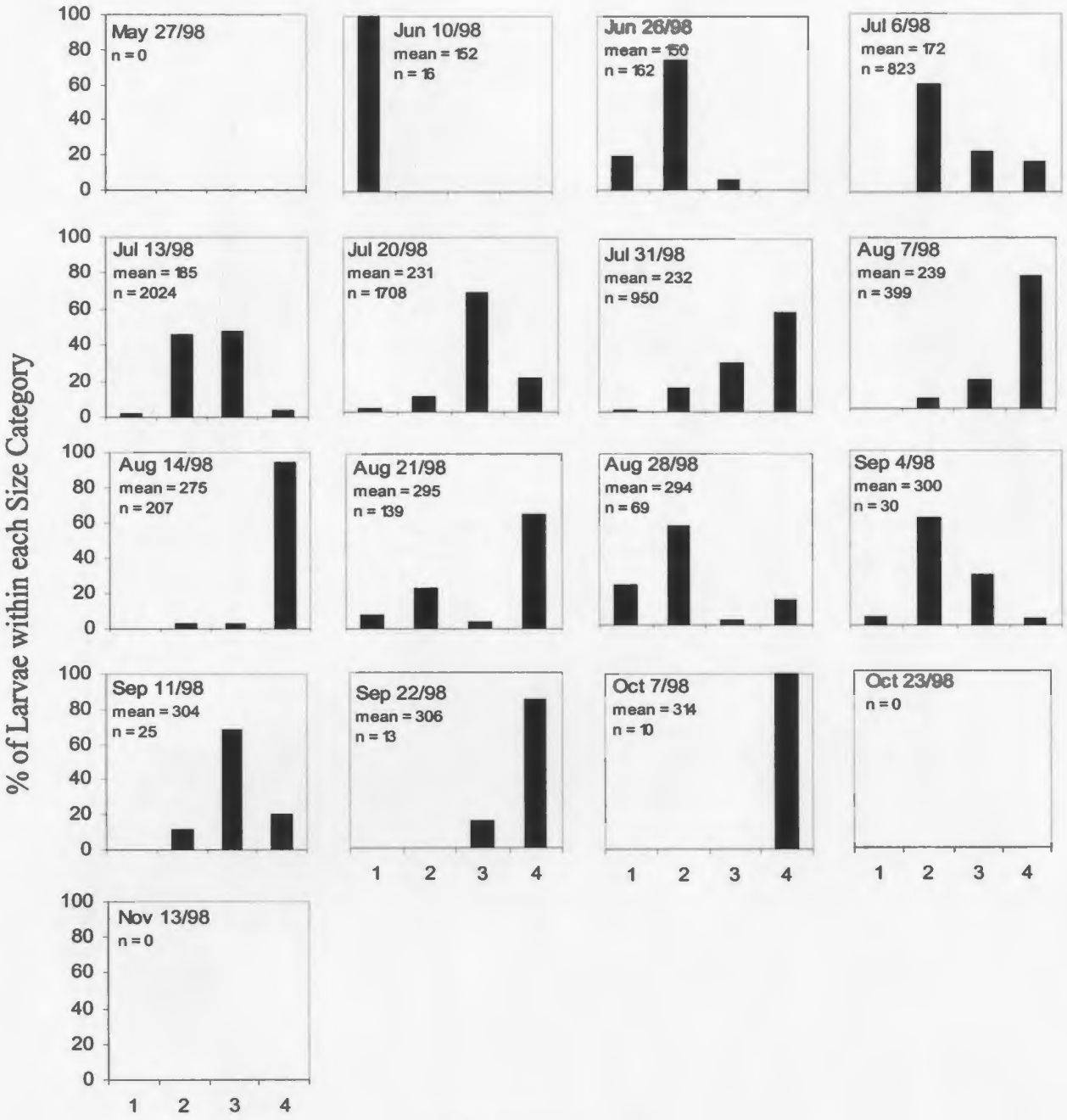
Figure 14. Percentage of mussel larvae/L recorded in four size categories ranging from <150 μm to >250 μm for site 1, Reach Run.



Key:

Category 1 = Early Bipinnaria
Category 2 = Mid Bipinnaria
Category 3 = Advanced Bipinnaria
Category 4 = Early Brachiolaria
Category 5 = Advanced Brachiolaria

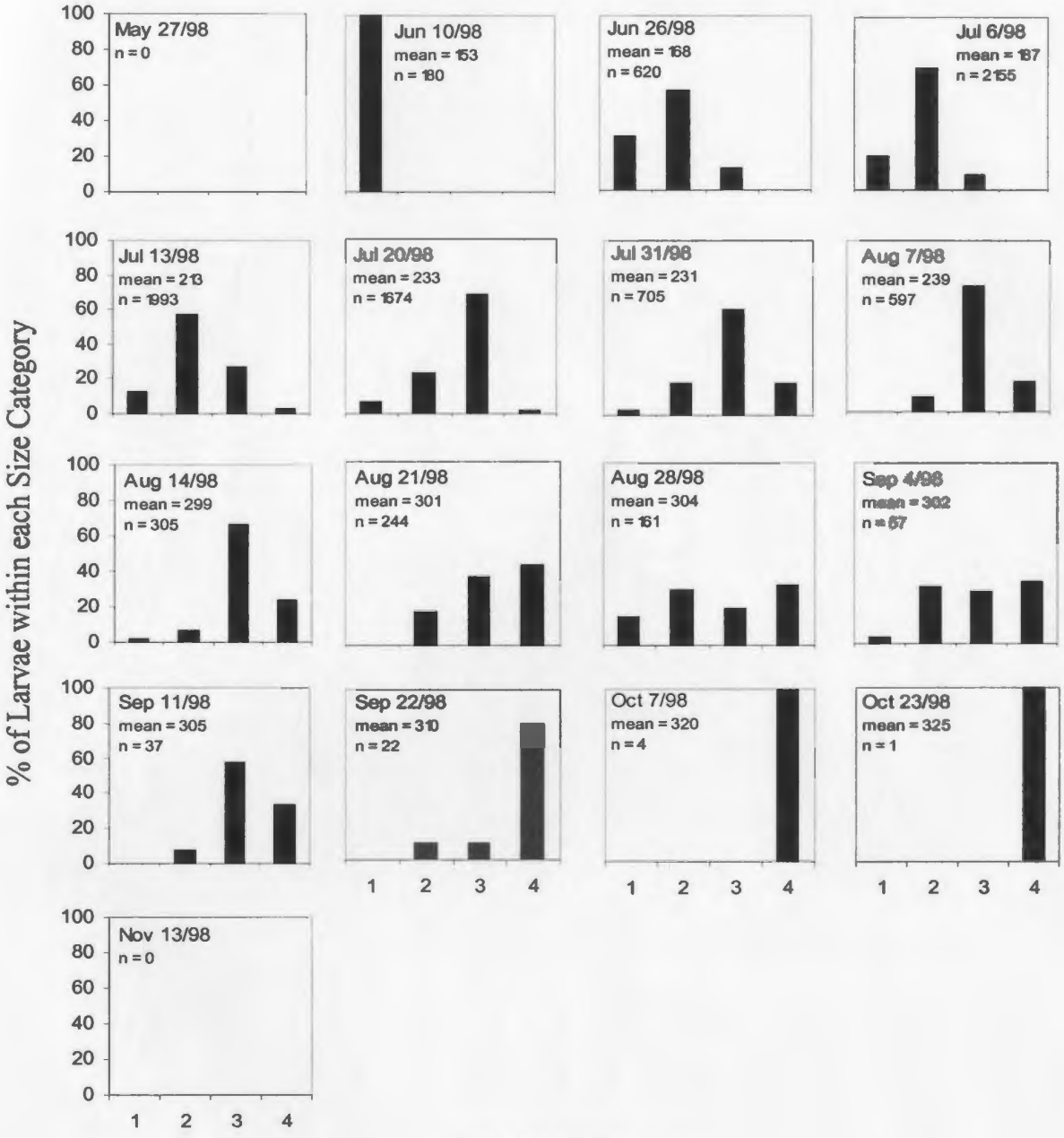
Figure 15. Percentage of starfish larvae/L recorded in five developmental categories ranging from early bipinnaria to advanced brachiolaria for site 1, Reach Run.



Key:

Category 1 = % Larvae < 150 µm
Category 2 = % Larvae 151 µm – 200 µm
Category 3 = % Larvae 201 µm – 250 µm
Category 4 = % Larvae >251 µm

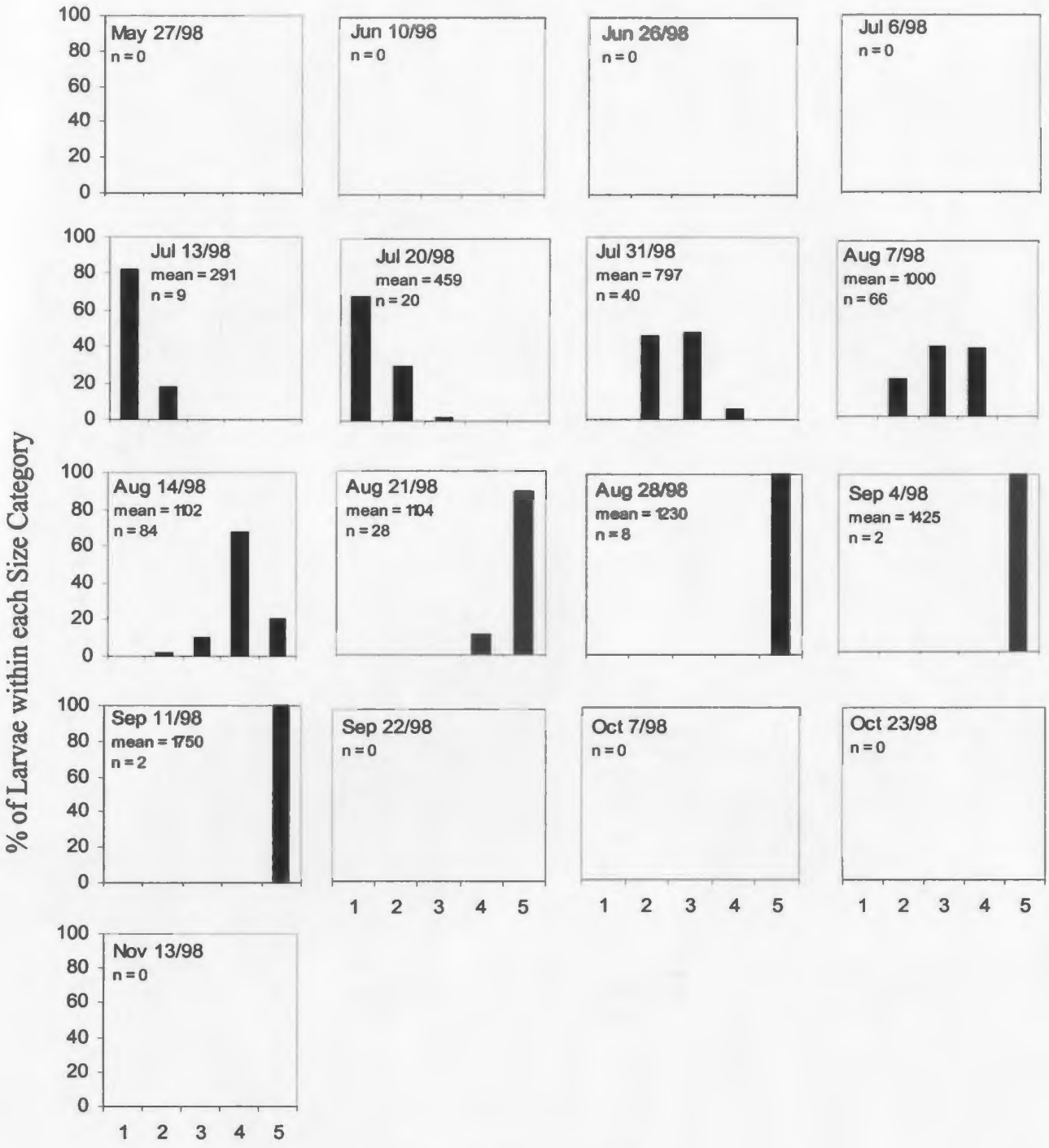
Figure 16. Percentage of mussel larvae/L recorded in four size categories ranging from <150 µm to >250 µm for site 2, Little Shellbird Bight.



Key:

Category 1 = % Larvae < 150 µm
Category 2 = % Larvae 151 µm – 200 µm
Category 3 = % Larvae 201 µm – 250 µm
Category 4 = % Larvae >251 µm

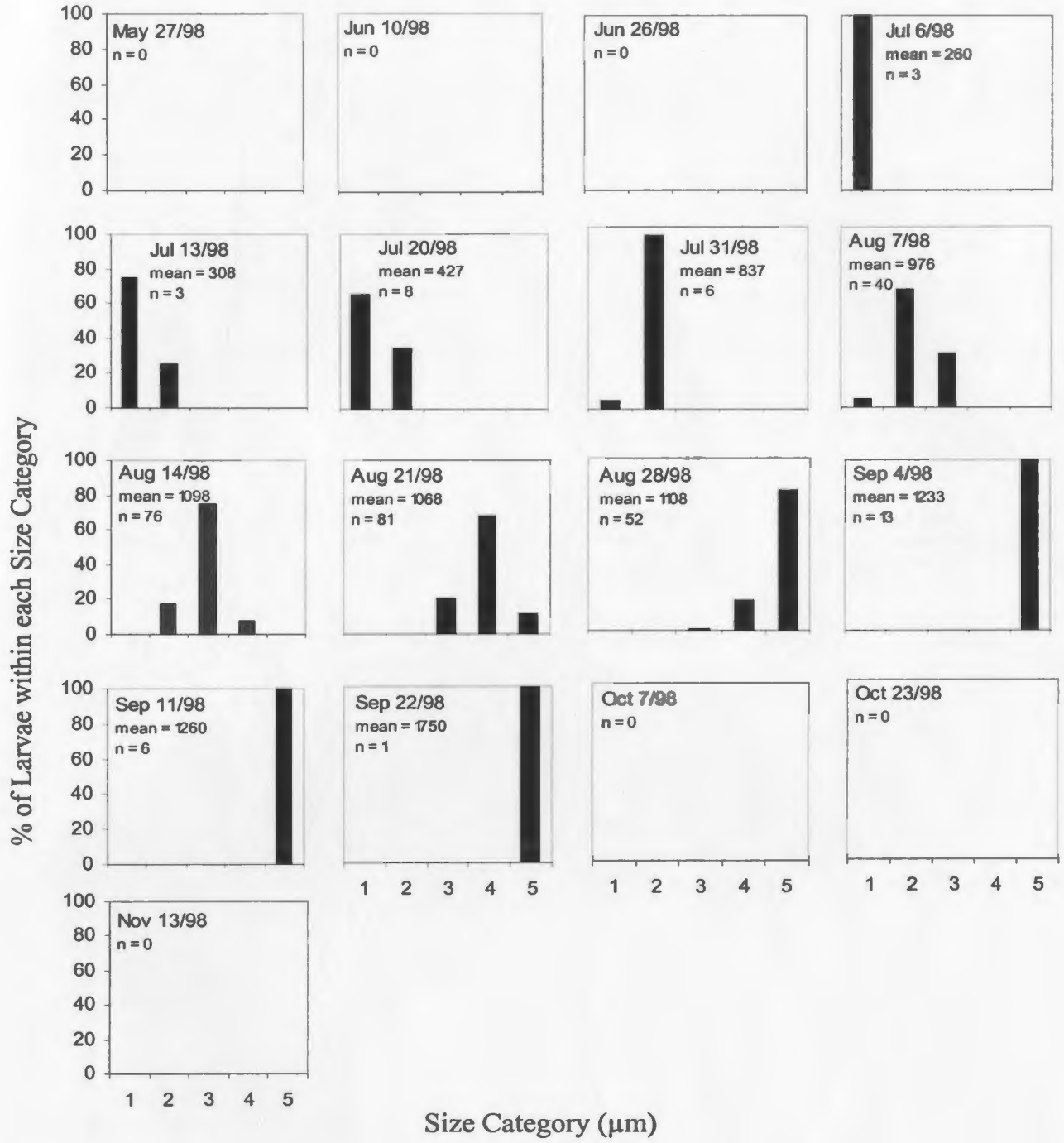
Figure 17. Percentage of mussel larvae/L recorded in four size categories ranging from <150 µm to >250 µm for site 3, Shellbird Bight.



Key:

Category 1 = Early Bipinnaria
Category 2 = Mid Bipinnaria
Category 3 = Advanced Bipinnaria
Category 4 = Early Brachiolaria
Category 5 = Advanced Brachiolaria

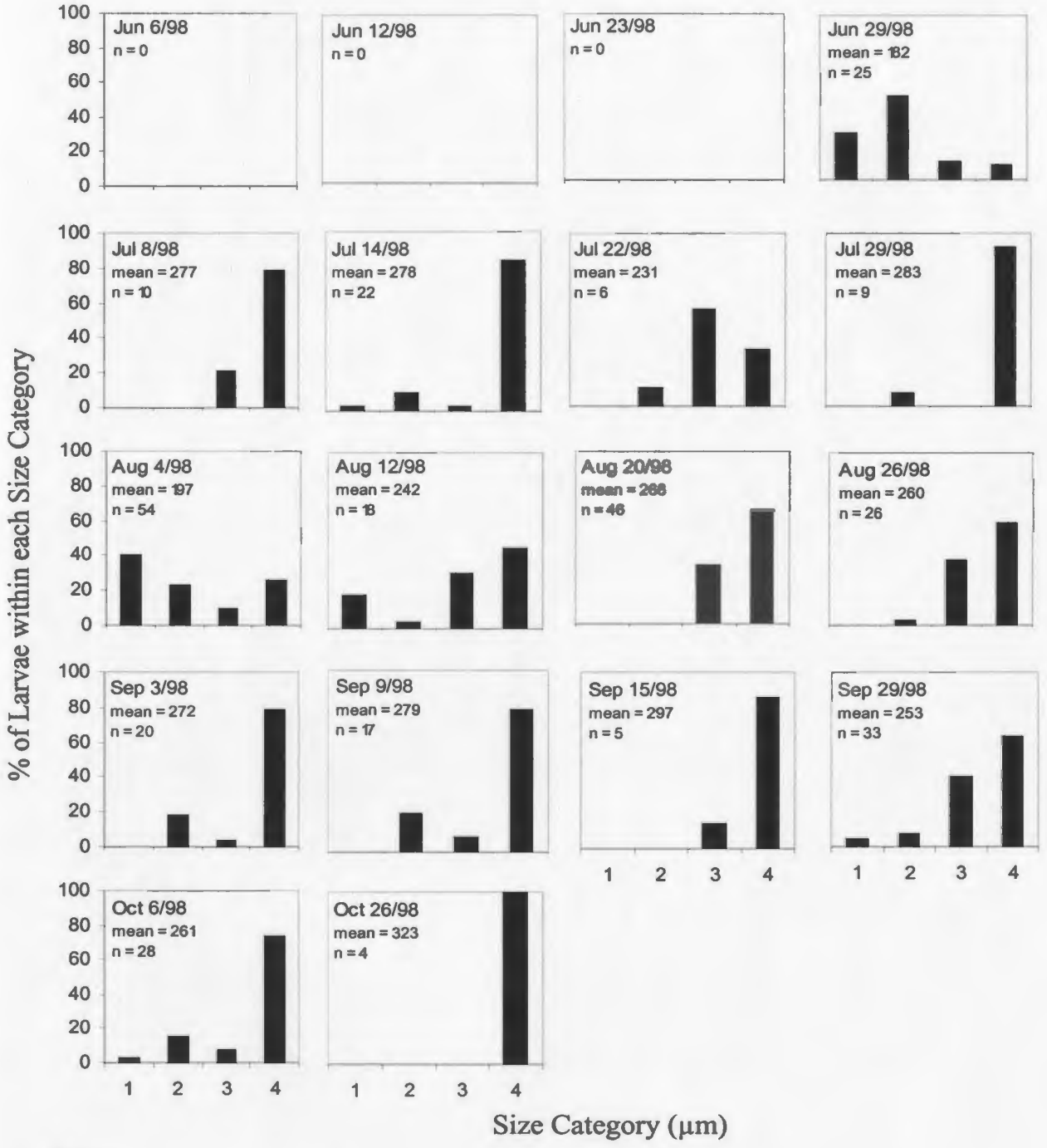
Figure 18. Percentage of starfish larvae/L recorded in five developmental categories ranging from early bipinnaria to advanced brachiolaria for site 2, Little Shellbird Bight.



Key:

Category 1 = Early Bipinnaria
Category 2 = Mid Bipinnaria
Category 3 = Advanced Bipinnaria
Category 4 = Early Brachiolaria
Category 5 = Advanced Brachiolaria

Figure 19. Percentage of starfish larvae/L recorded in five developmental categories ranging from early bipinnaria to advanced brachiolaria for site 3, Shellbird Bight.



Key:

Category 1 = % Larvae < 150 µm
Category 2 = % Larvae 151 µm – 200 µm
Category 3 = % Larvae 201 µm – 250 µm
Category 4 = % Larvae >251 µm

Figure 20. Percentage of mussel larvae/L recorded in four size categories ranging from <150 µm to >250 µm for site 4, Jersey Harbour.

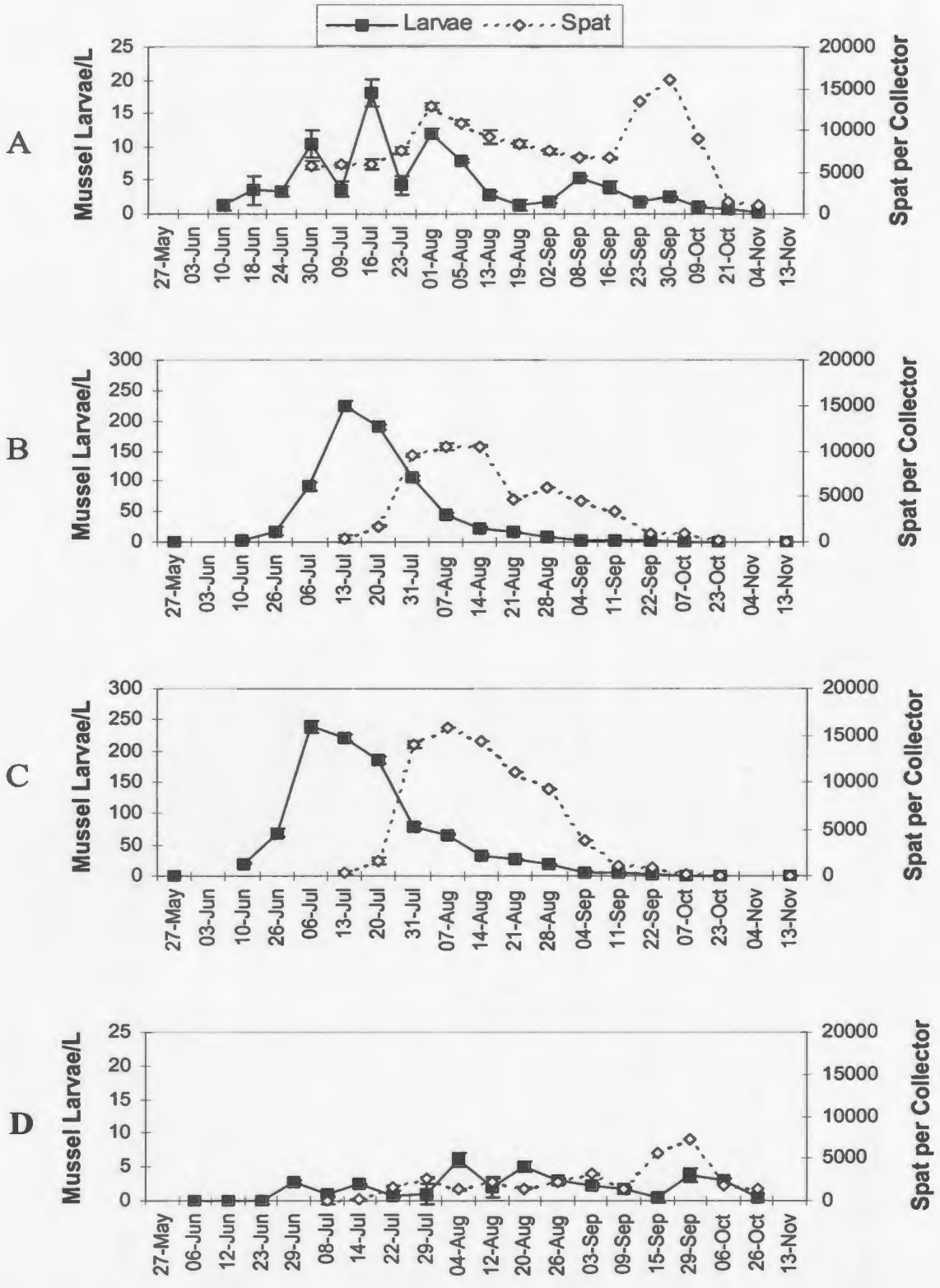


Figure 21. Average number of blue mussel larvae/L in relation to average number of settled mussel spat per 1 m collector for A = site 1 - Reach Run, B = site 2 - Little Shellbird Bight, C = site 3 - Shellbird Bight and D = site 4 - Jersey Harbour, during 1998. Vertical bars are ± standard error. (Note: Scales of y-axis are different for each site.)

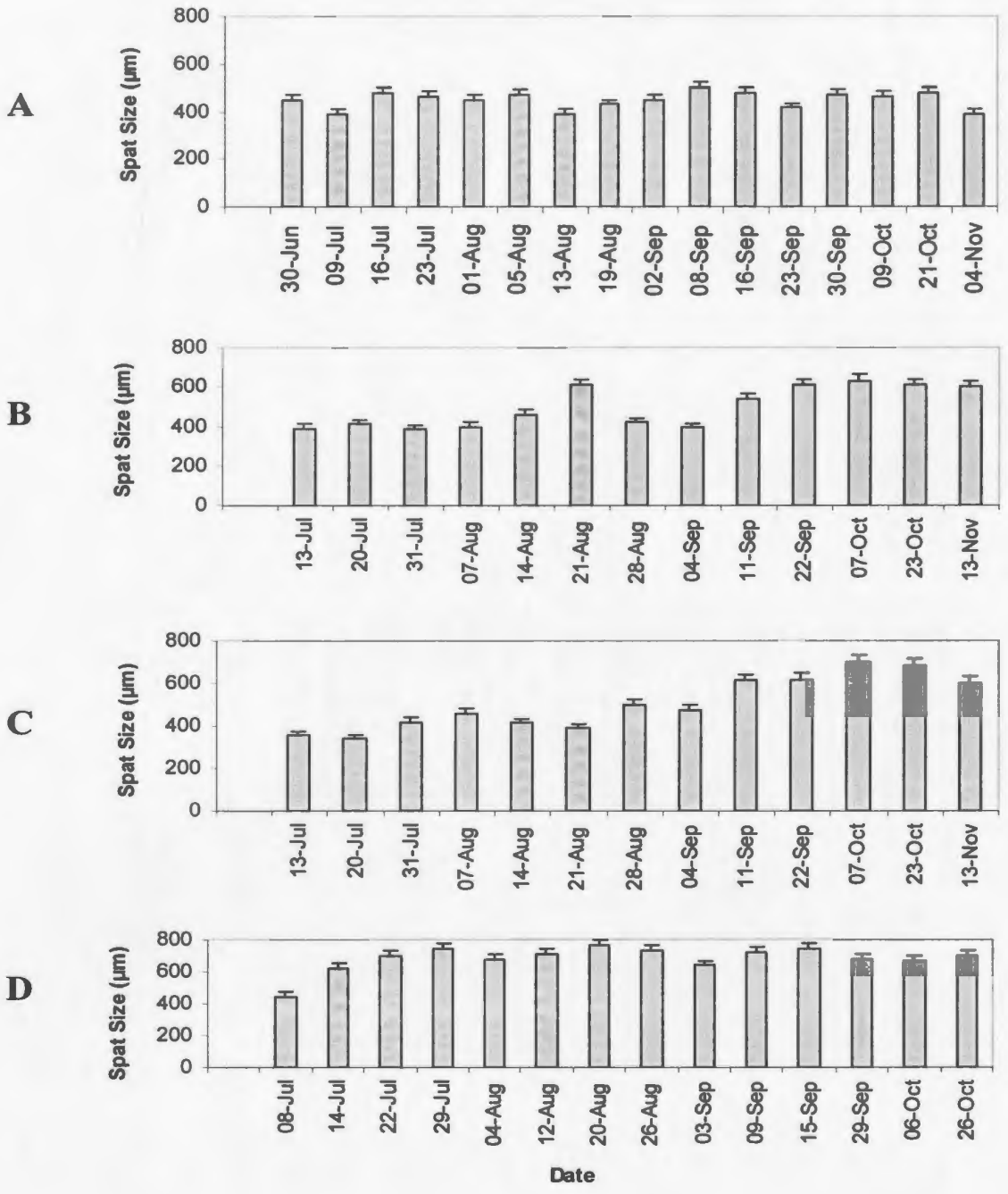


Figure 22. Average size of settled mussel spat (µm) for A = site 1 - Reach Run, B = site 2 - Little Shellbird Bight, C = site 3 - Shellbird Bight and D = site 4 - Jersey Harbour. Vertical bars are ± standard error. (Note: Date = retrieval date of collector). Average deployment time = 14 days.

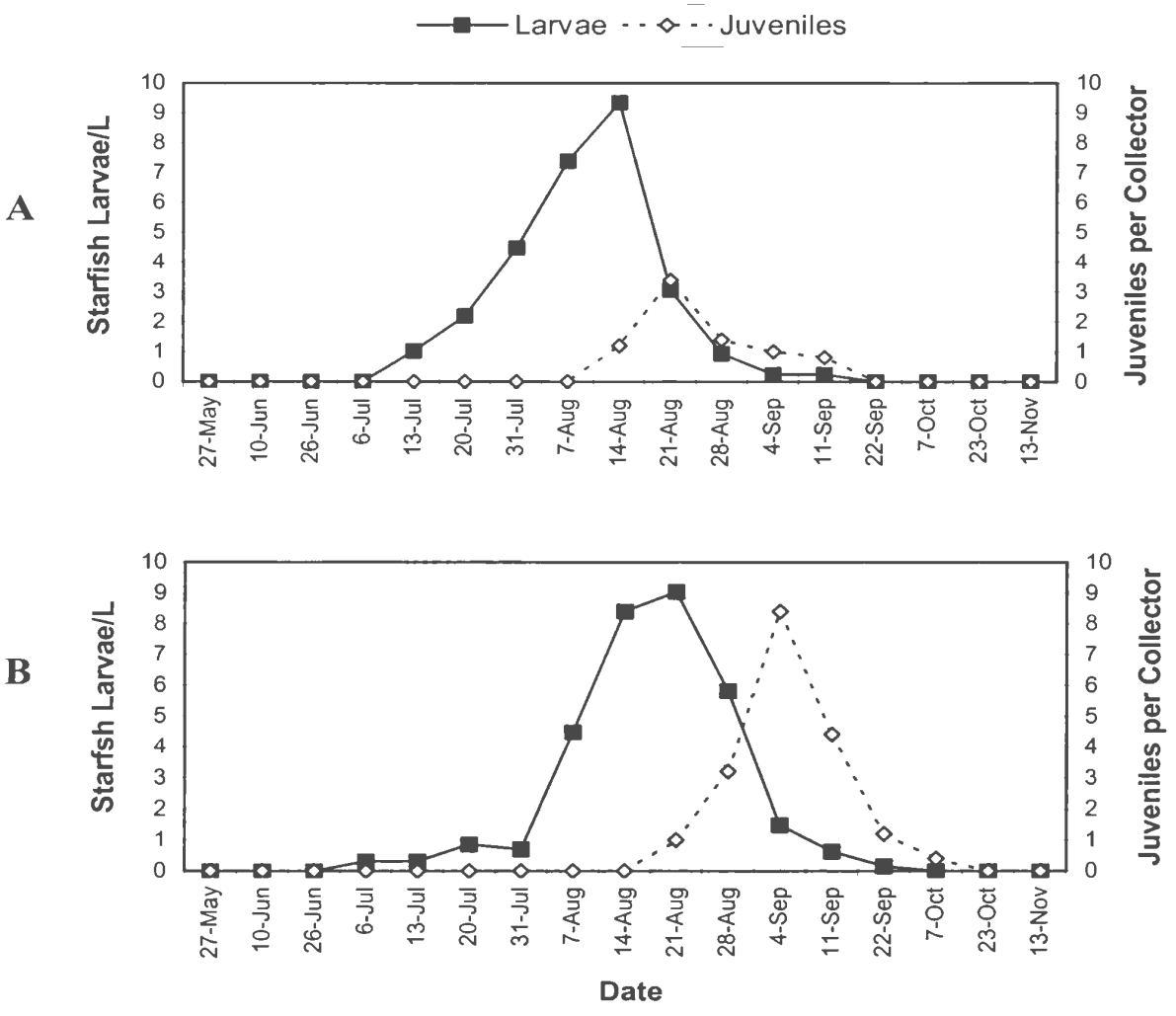


Figure 23. Average number of starfish larvae/L in relation to average number of settled starfish juveniles (per 1 m collector) for A = site 2 - Little Shellbird Bight and B = site 3 - Shellbird Bight during 1998. Vertical bars are ± standard error. (Note: No starfish juveniles were recorded at Site 1 or Site 4.)

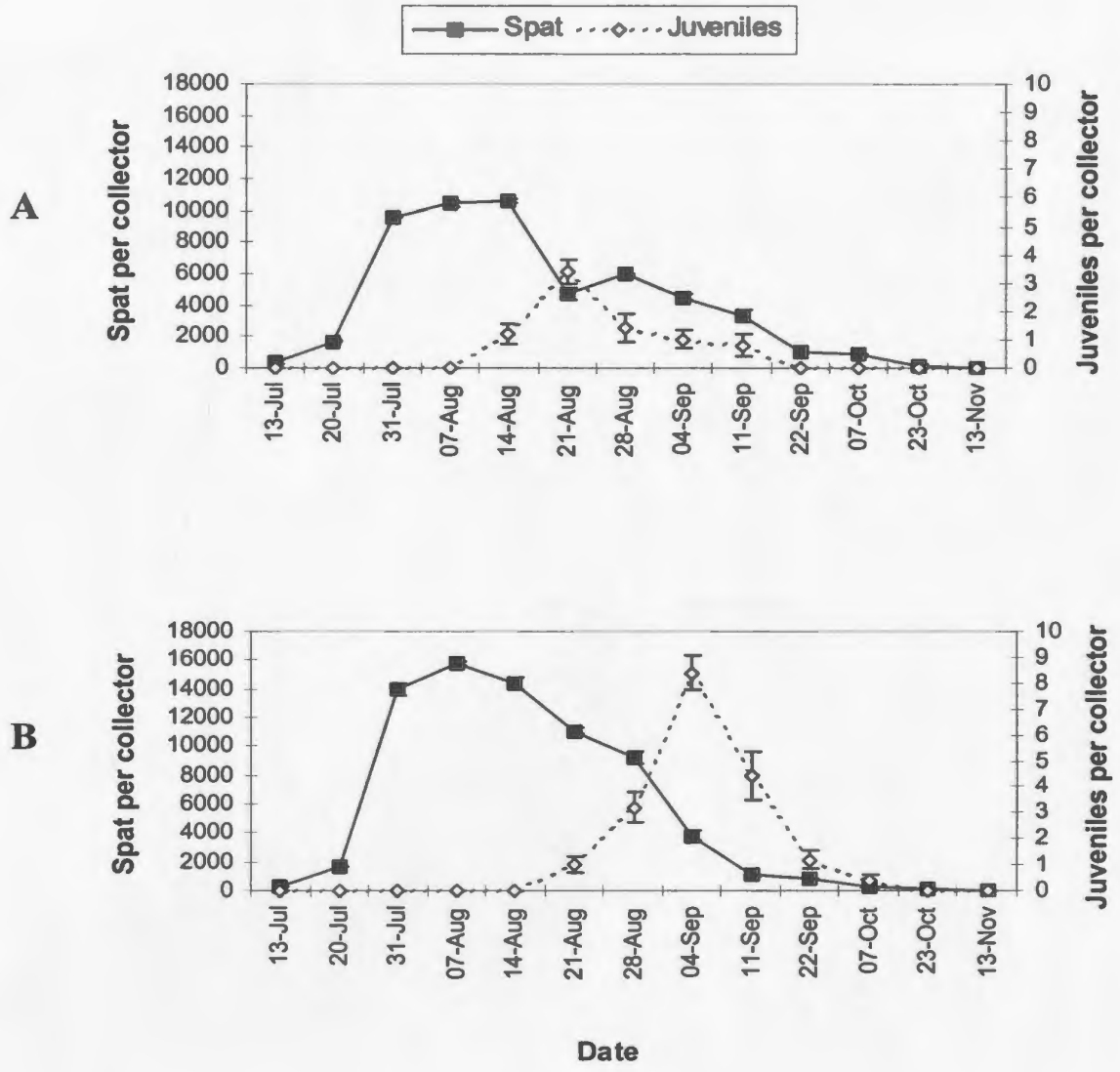


Figure 24. Average number of settled blue mussel spat in relation to average number settled starfish juveniles, per 1 m collector, for A = site 2 - Little Shellbird Bight and B = site 3 - Shellbird Bight during 1998. Vertical bars are ± standard error. (Note: No starfish juveniles were recorded on Site 1 or Site 4.)

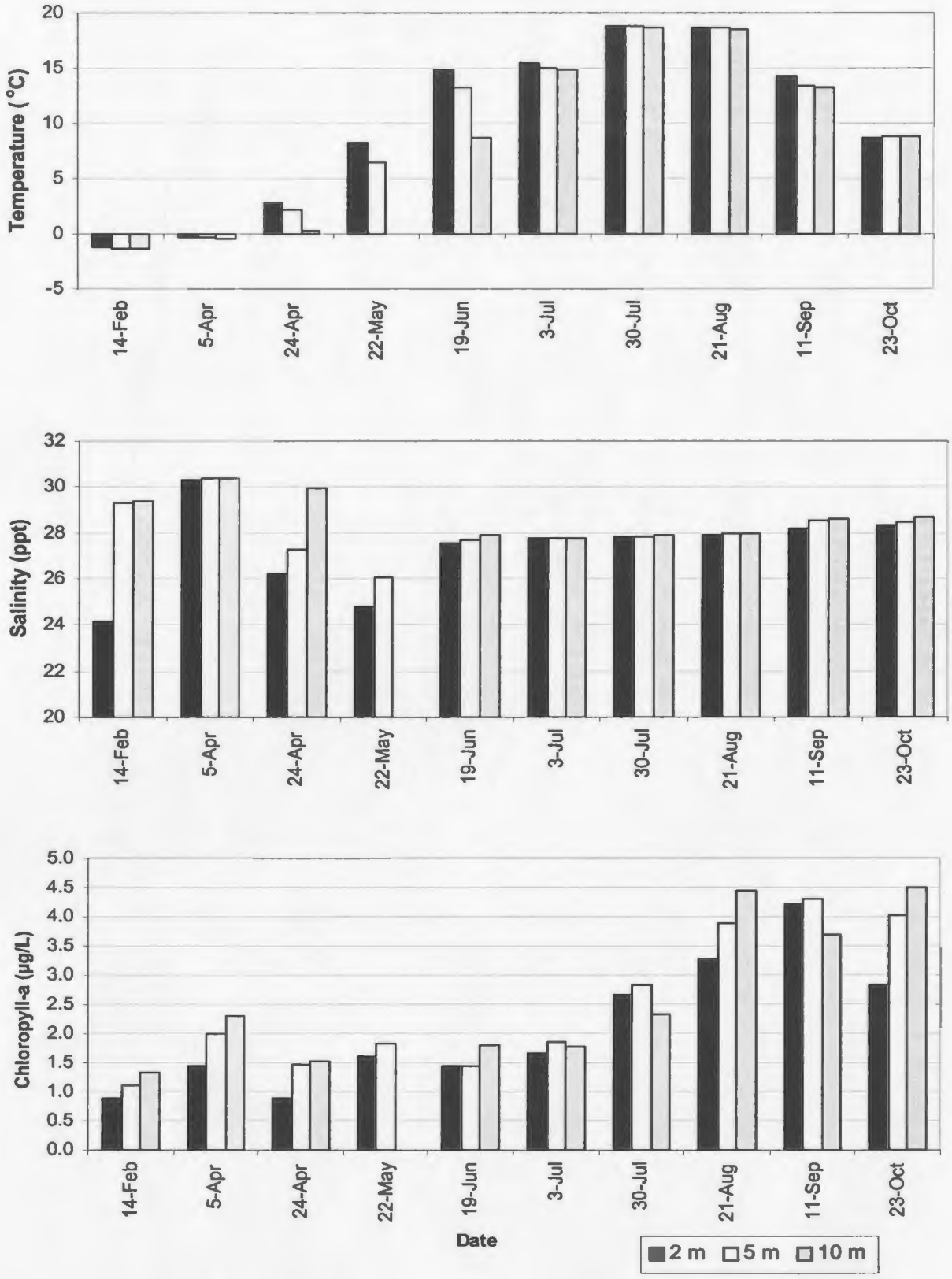


Figure 25. Reach Run (site 1), temperature (°C), salinity (ppt) and chlorophyll-a (µg/L) at 2 m, 5 m and 10 m depths, as recorded using a CTD (Seabird) during 1998. Each bar represents the average of three CTD casts per sample date.

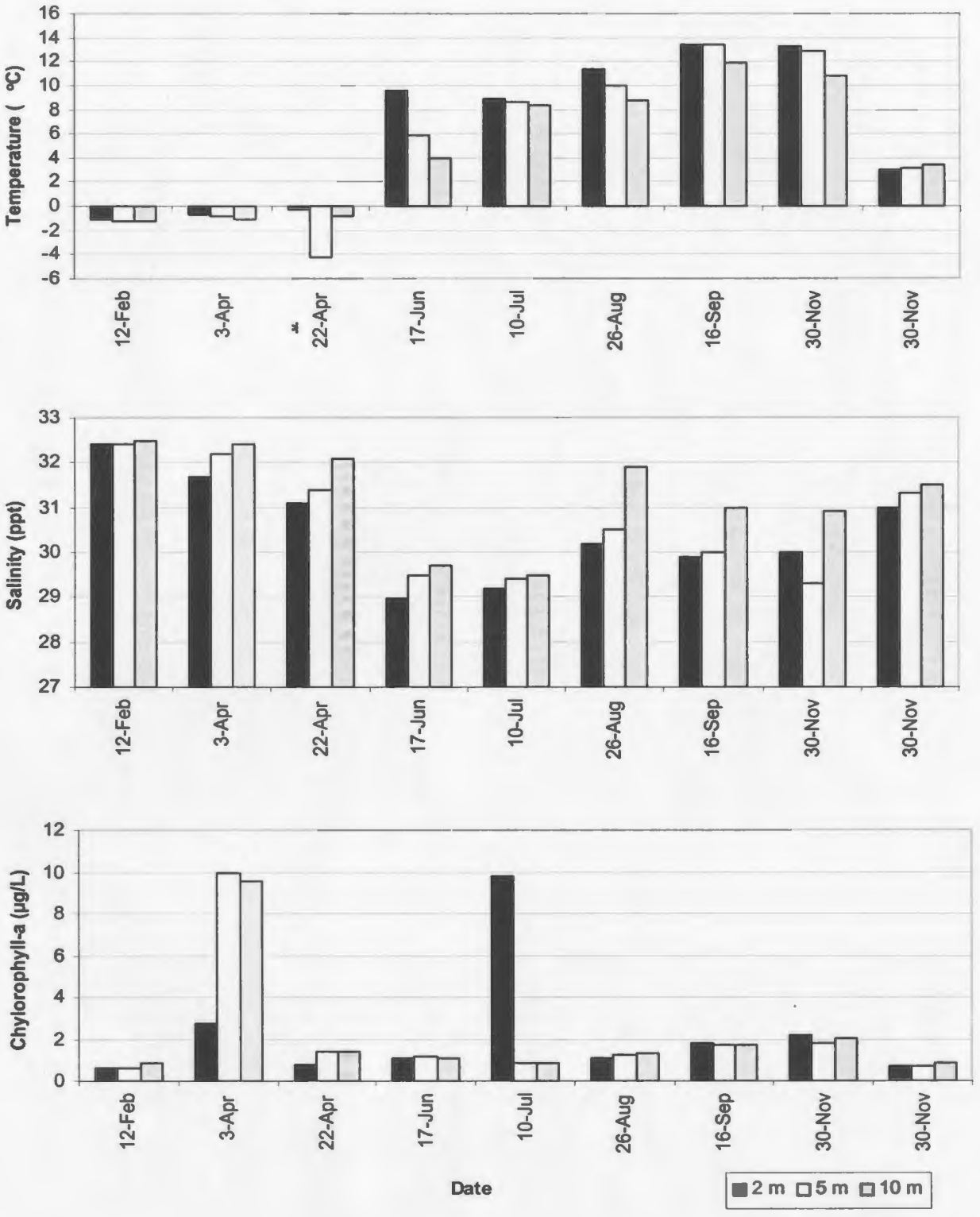


Figure 26. Little Bay Arm (sites 2 and 3), temperature (°C), salinity (ppt) and chlorophyll-a (µg/L) at 2 m, 5 m and 10 m depths, as recorded using a CTD (Seabird) during 1998. Each bar represents the average of six CTD casts per sample date. (*Note: A problem occurred with the temperature sensor on this day.)

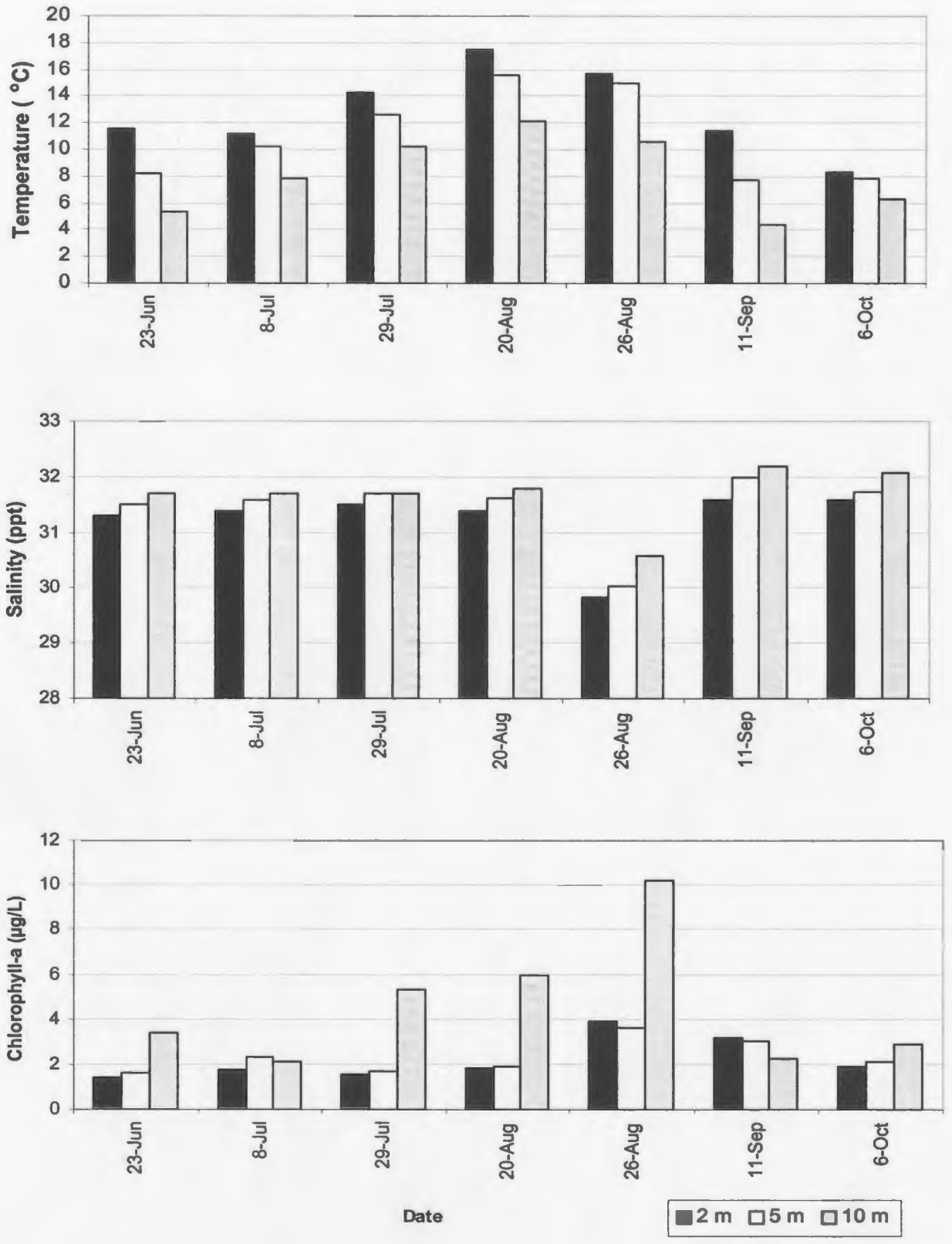


Figure 27. Jersey Harbour (site 4), temperature (°C), salinity (ppt) and chlorophyll-a (µg/L) at 2 m, 5 m and 10 m depths, as recorded using a CTD (Seabird) during 2000. Each bar represents the average of three CTD casts per sample date.

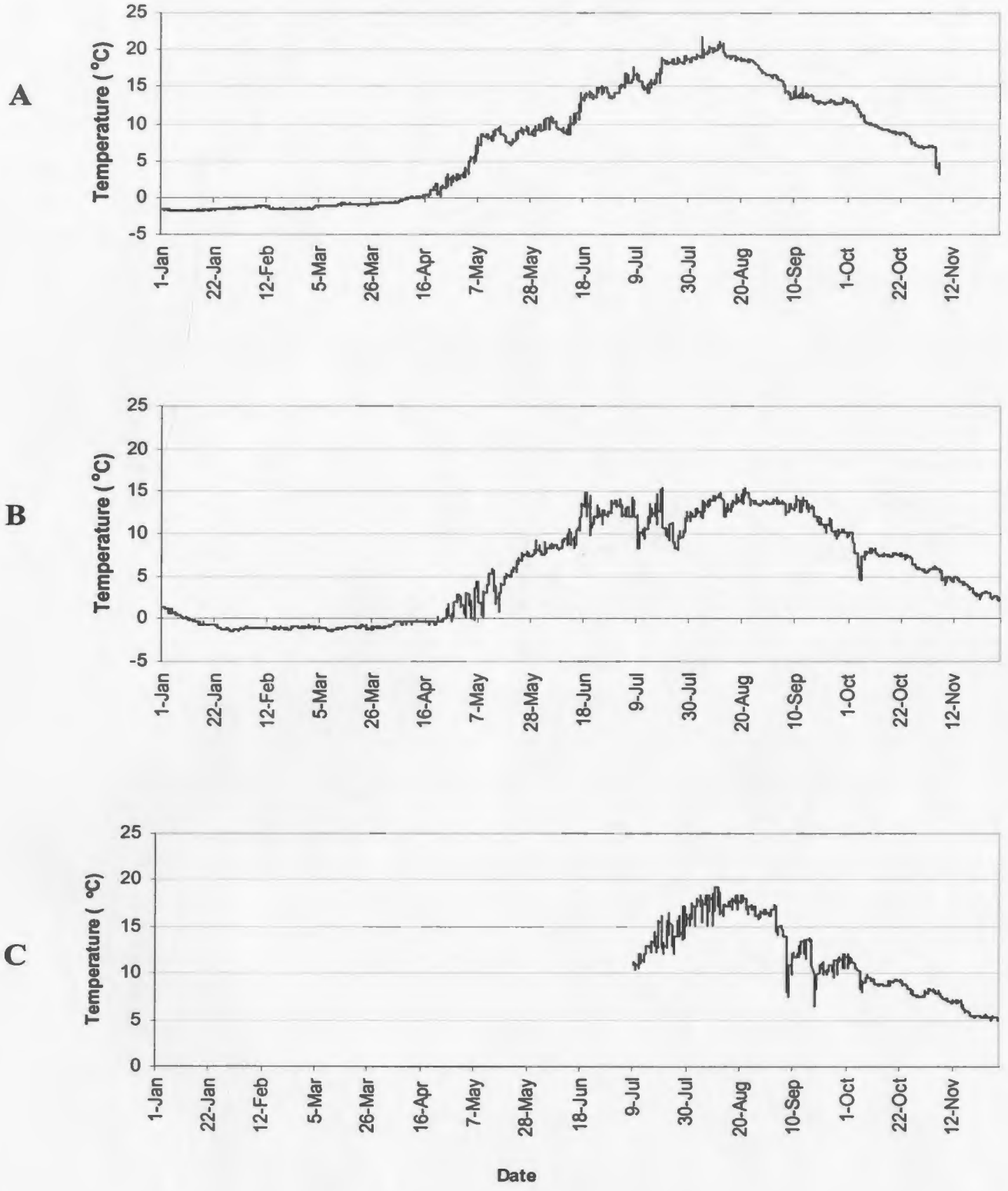


Figure 28. Temperature (°C) data recorded using a temperature data logger for 1998 at approximately 2 m depth, with recordings every 45 minutes; A = site 1 - Reach Run, B = sites 2 and 3 - Little Bay Arm and C = site 4 - Jersey Harbour.

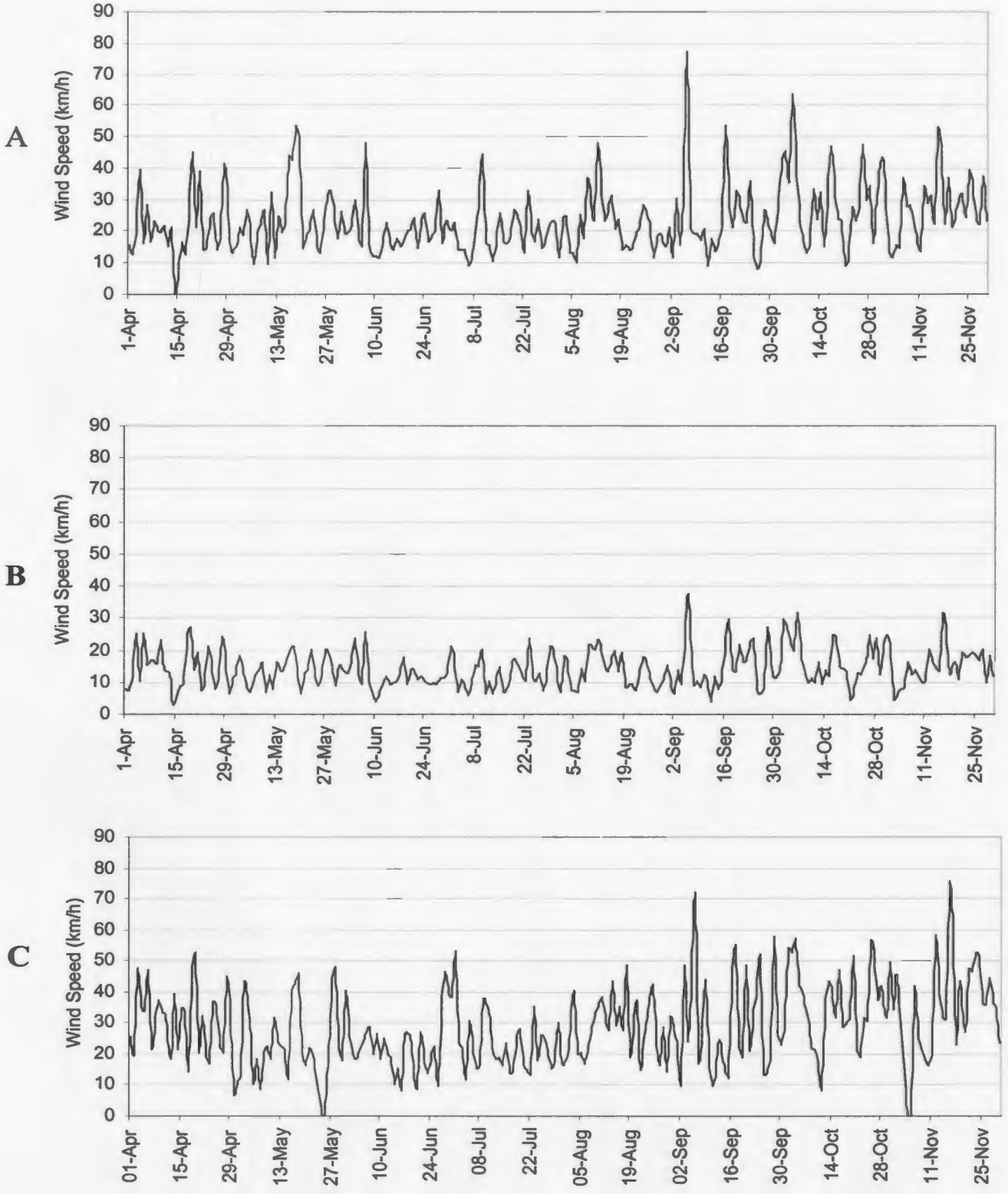


Figure 29. Average daily (24 hour period) wind speed (km/h) for (A) Twillingate, Notre Dame Bay, (B) La Scie, Green Bay and (C) Sagona Island, South Coast, for April through November 1998. Data obtained from Environment Canada, Gander, NL.

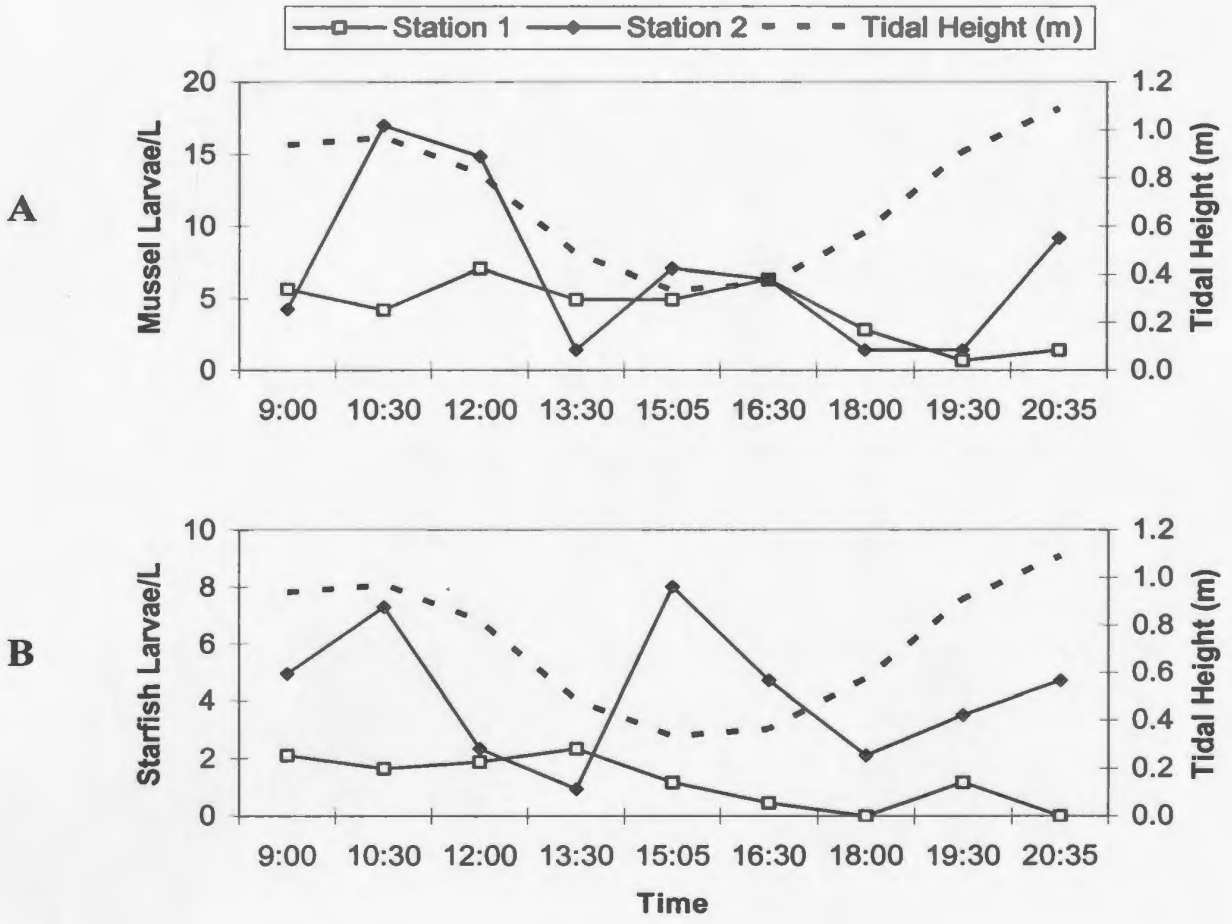


Figure 30. Tidal cycle study for Reach Run (site 1) on July 2, 1999. (A) Mussel larvae/L for station 1 and station 2 in relation to tidal height, and (B) Starfish larvae/L for station 1 and station 2 in relation to tidal height.

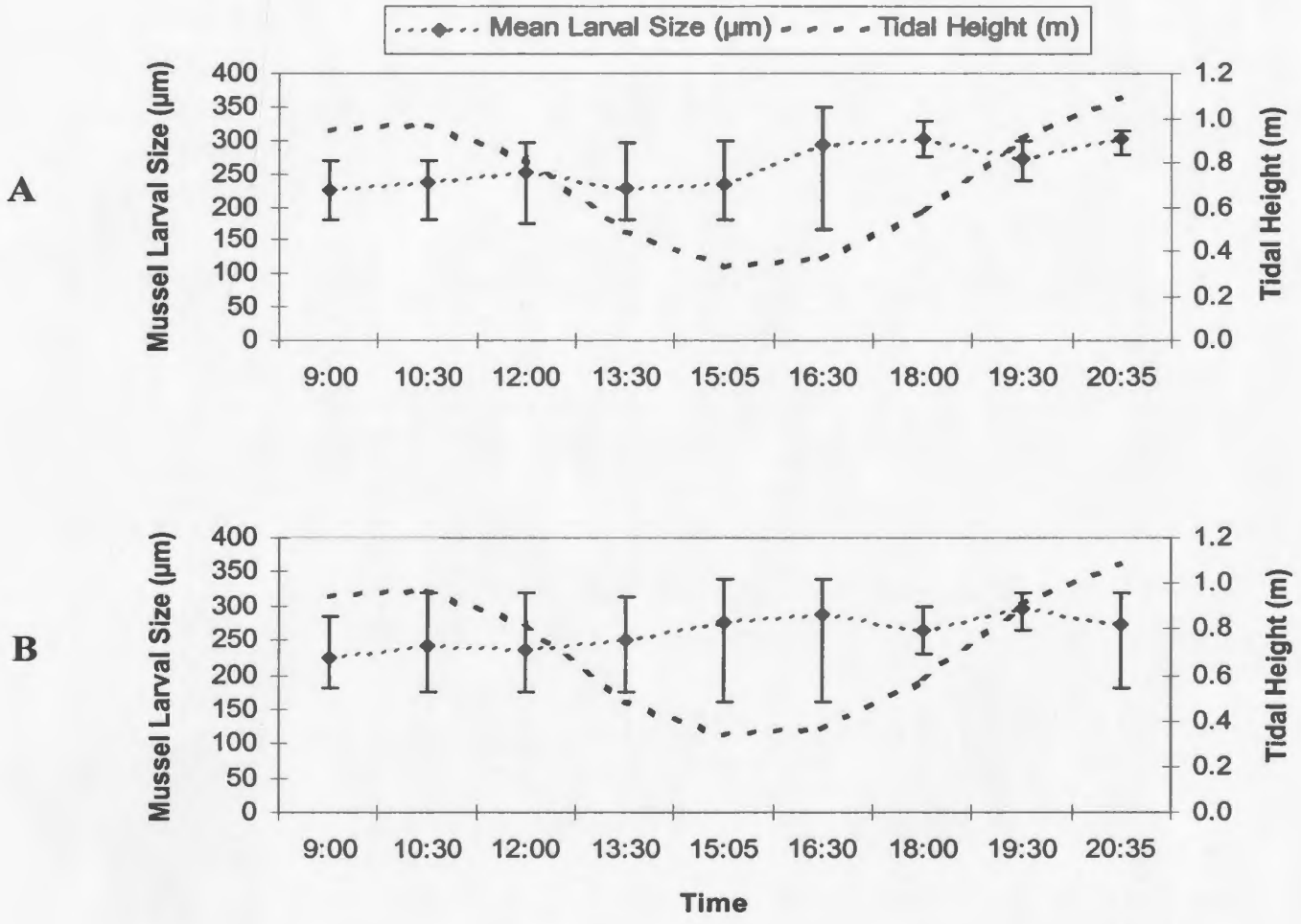


Figure 31. Mean mussel larval size (µm) in relation to tidal height (m) on July 2, 1999 for site 1, Reach Run, at (A) Station 1 and (B) Station 2. Vertical bars indicate mussel larval size range (min-max).

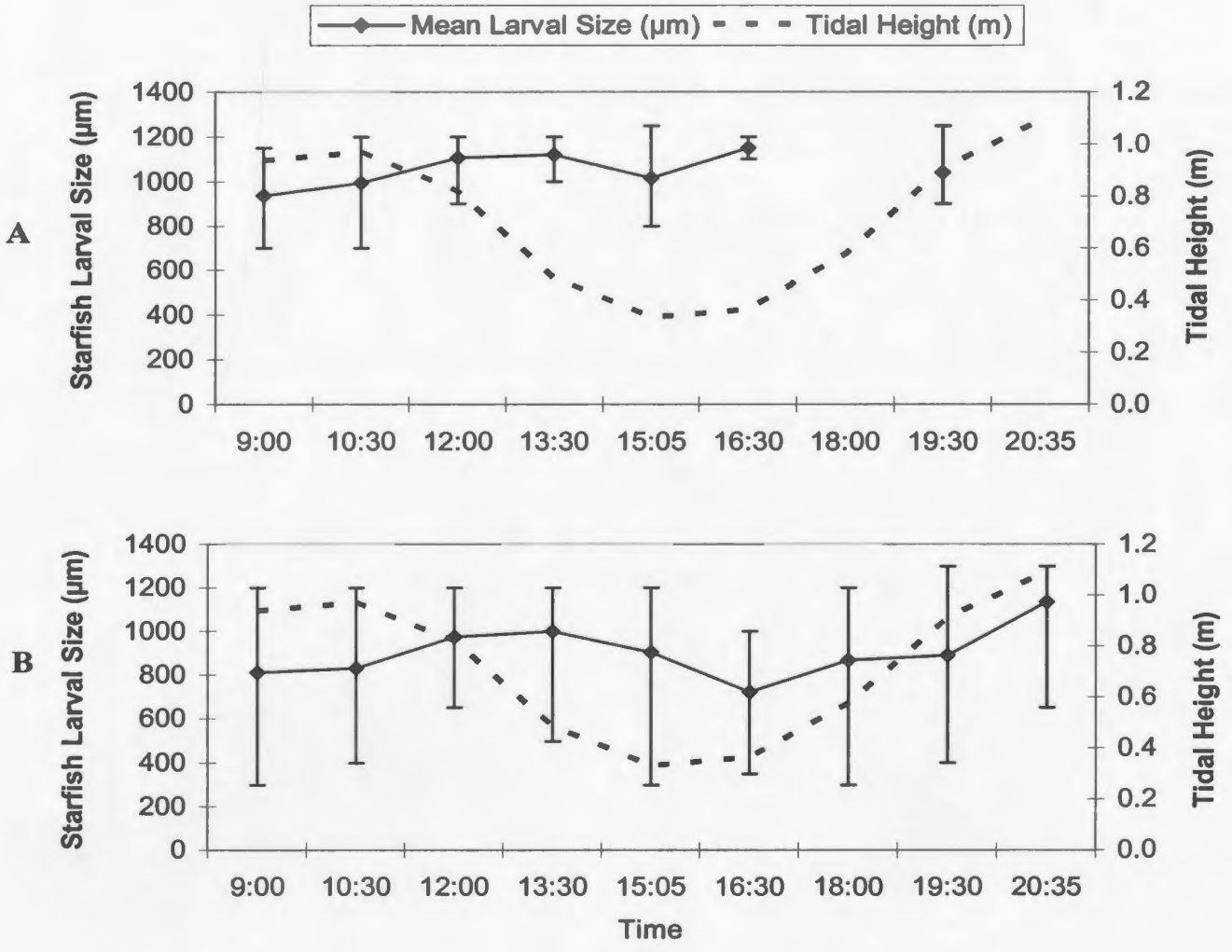


Figure 32. Mean starfish larval size (µm) in relation to tidal height (m) on July 2, 1999 for site 1, Reach Run, at (A) station 1 and (B) station 2. Vertical bars indicate starfish larval size range (min-max).

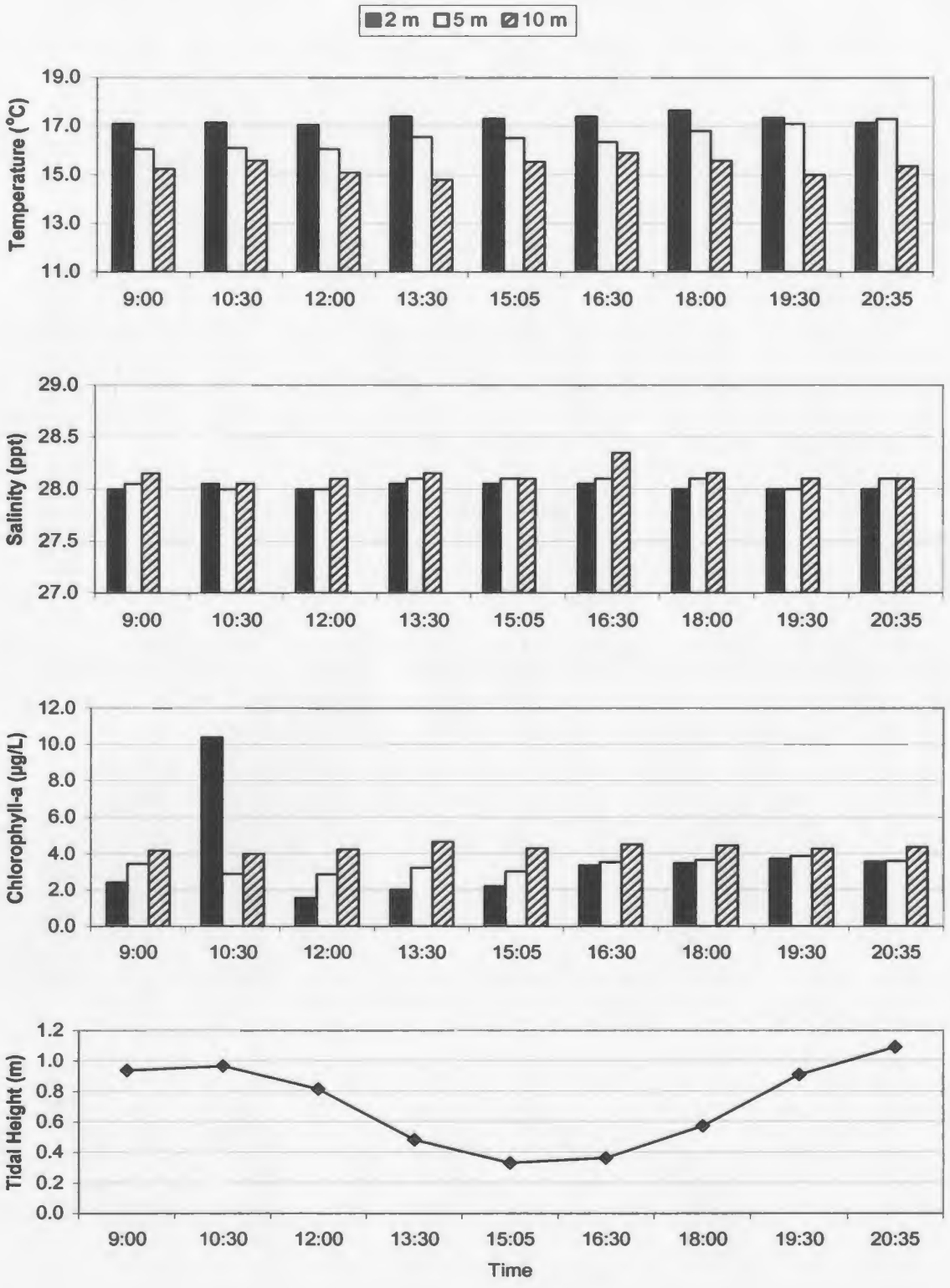


Figure 33. Reach Run (site 1), temperature (°C), salinity (ppt) and chlorophyll-a (µg/L) at 2 m, 5 m and 10 m depths, as recorded using a CTD (Seabird), in relation to tidal height (m) on July 2, 1999. Each bar represents the average of two CTD casts (one at the inside and one at the outside of the site) per sample time.

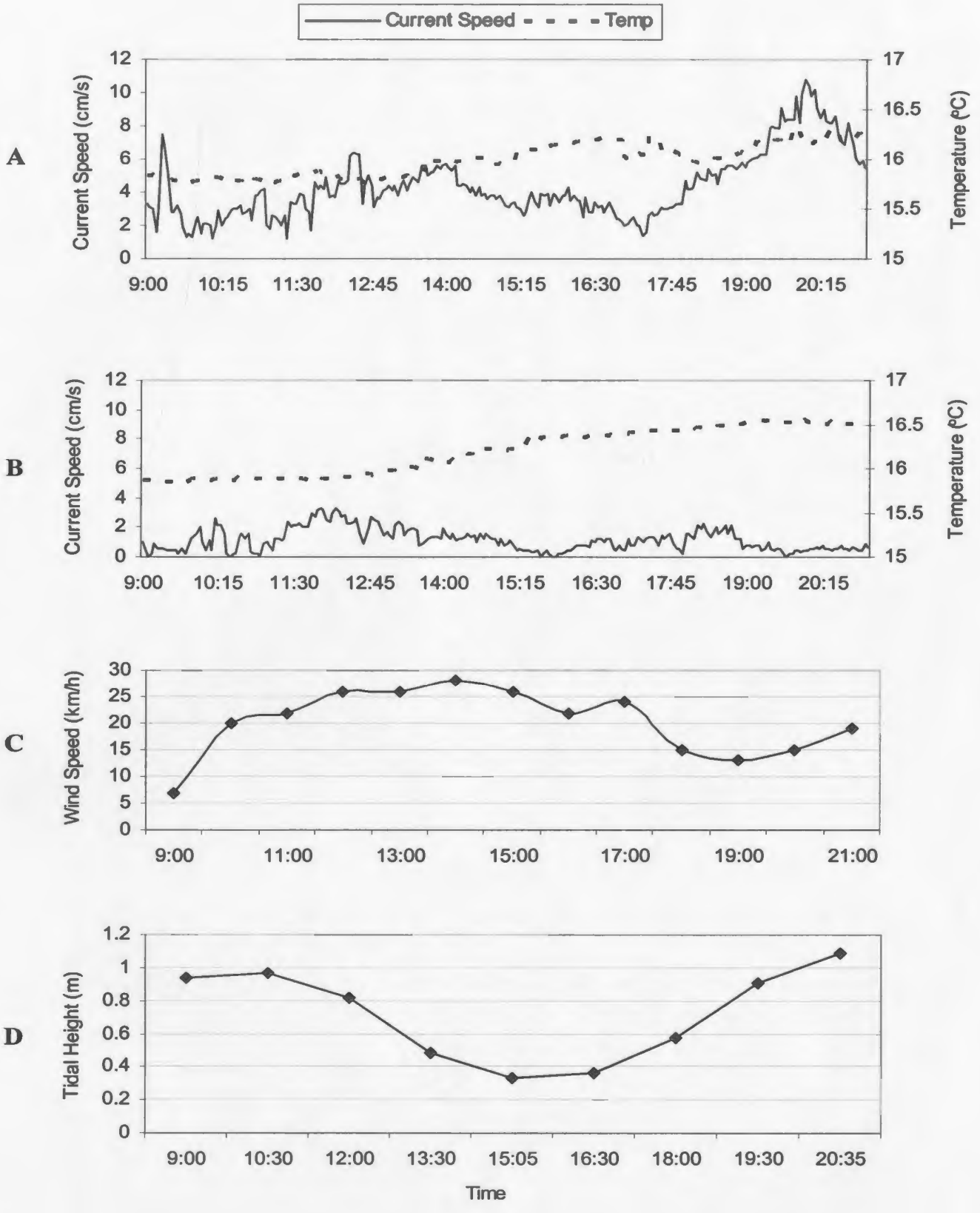


Figure 34. Current speed (cm/s) and temperature (°C) data as recorded using a S4 current meter, at 2 meters depth, for site 1, Reach Run on July 2, 1999 for (A) station 1 and (B) station 2. (C) Wind speed data for Twillingate, from Environment Canada (Gander Weather Office). (D) Tidal height (m) for the 12-hour sampling period.

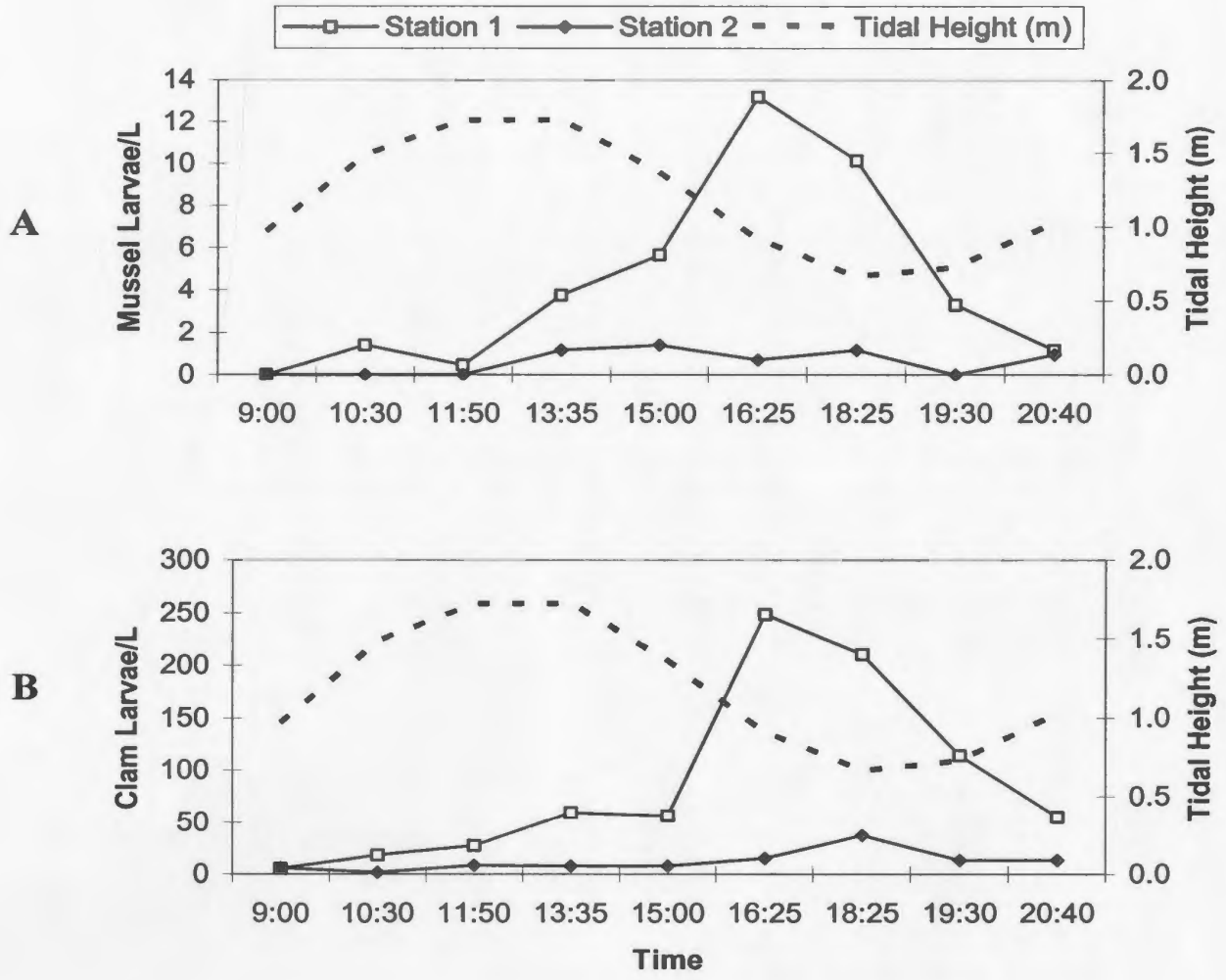


Figure 35. Tidal cycle study for Jersey Hr. (site 2) on July 5, 1999. (A) Mussel larvae/L for station 1 and station 2 in relation to tidal height, and (B) Clam larvae/L for station 1 and station 2 in relation to tidal height.

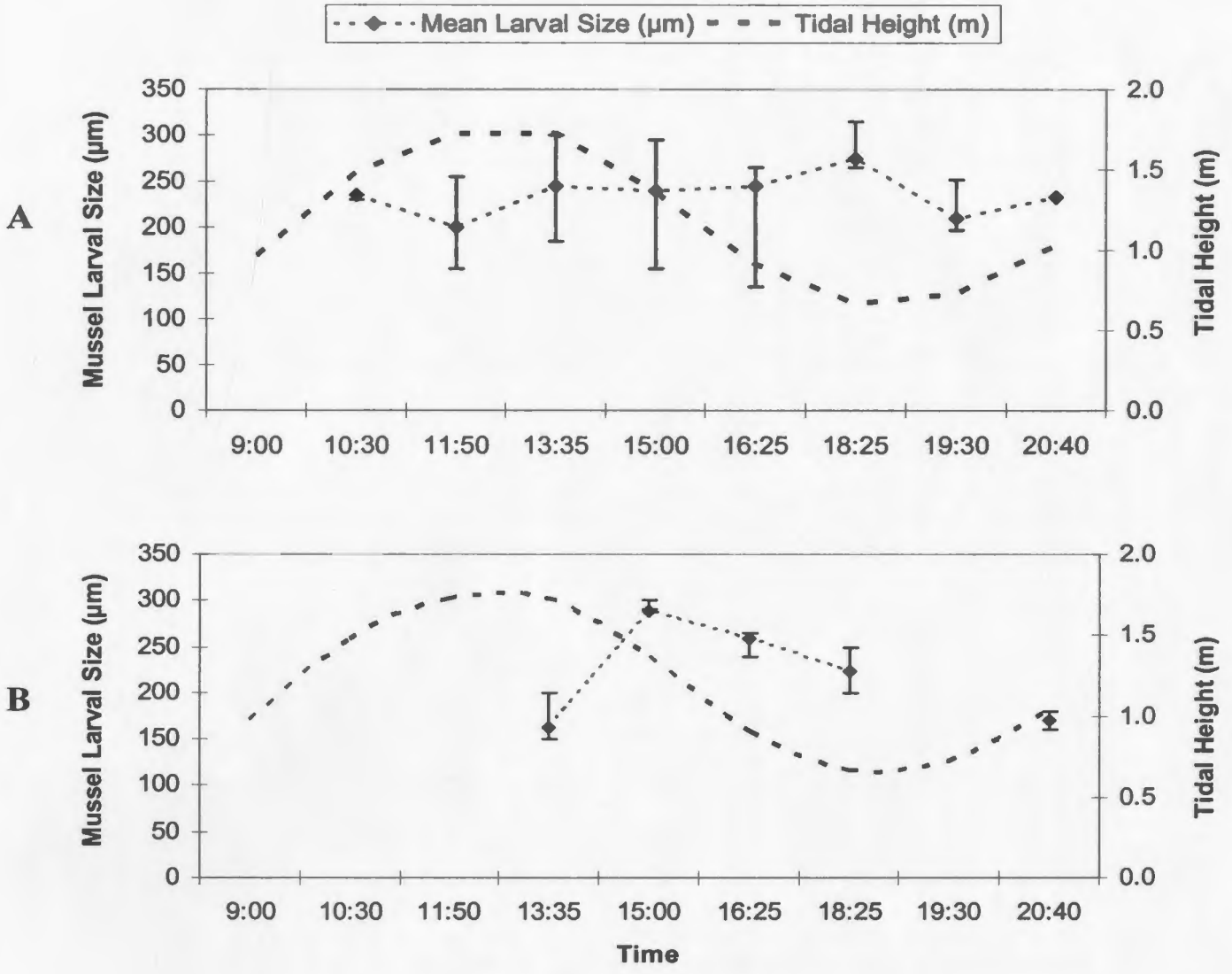


Figure 36. Mean mussel larval size (µm) in relation to tidal height (m) on July 5, 1999 for site 2, Jersey Hr., at (A) Station 1 and (B) Station 2. Vertical bars indicate mussel larval size range (min-max).

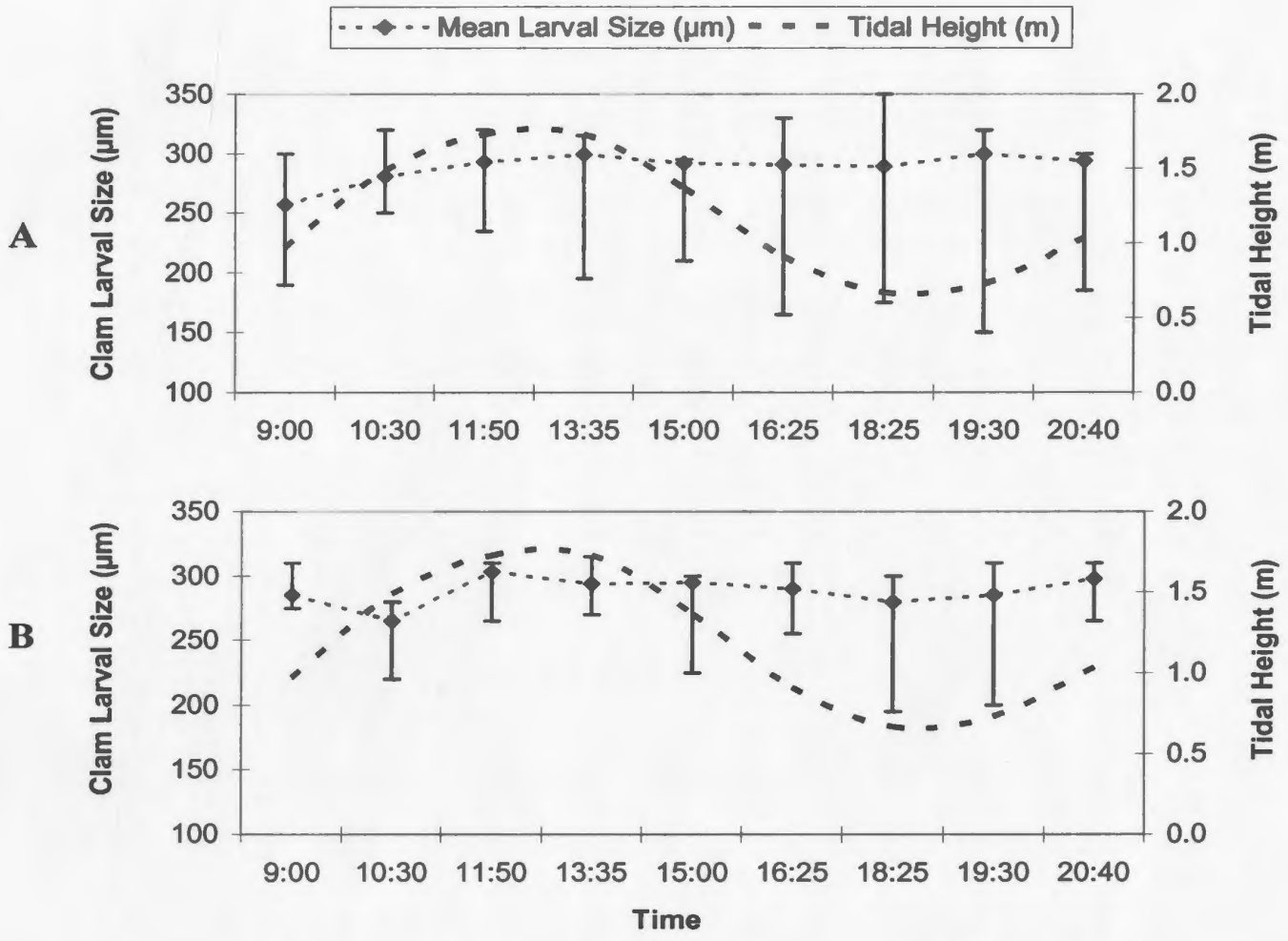


Figure 37. Mean clam larval size (µm) in relation to tidal height (m) on July 5, 1999 for site 2, Jersey Hr., at (A) Station 1 and (B) Station 2. Vertical bars indicate clam larval size range (min-max).

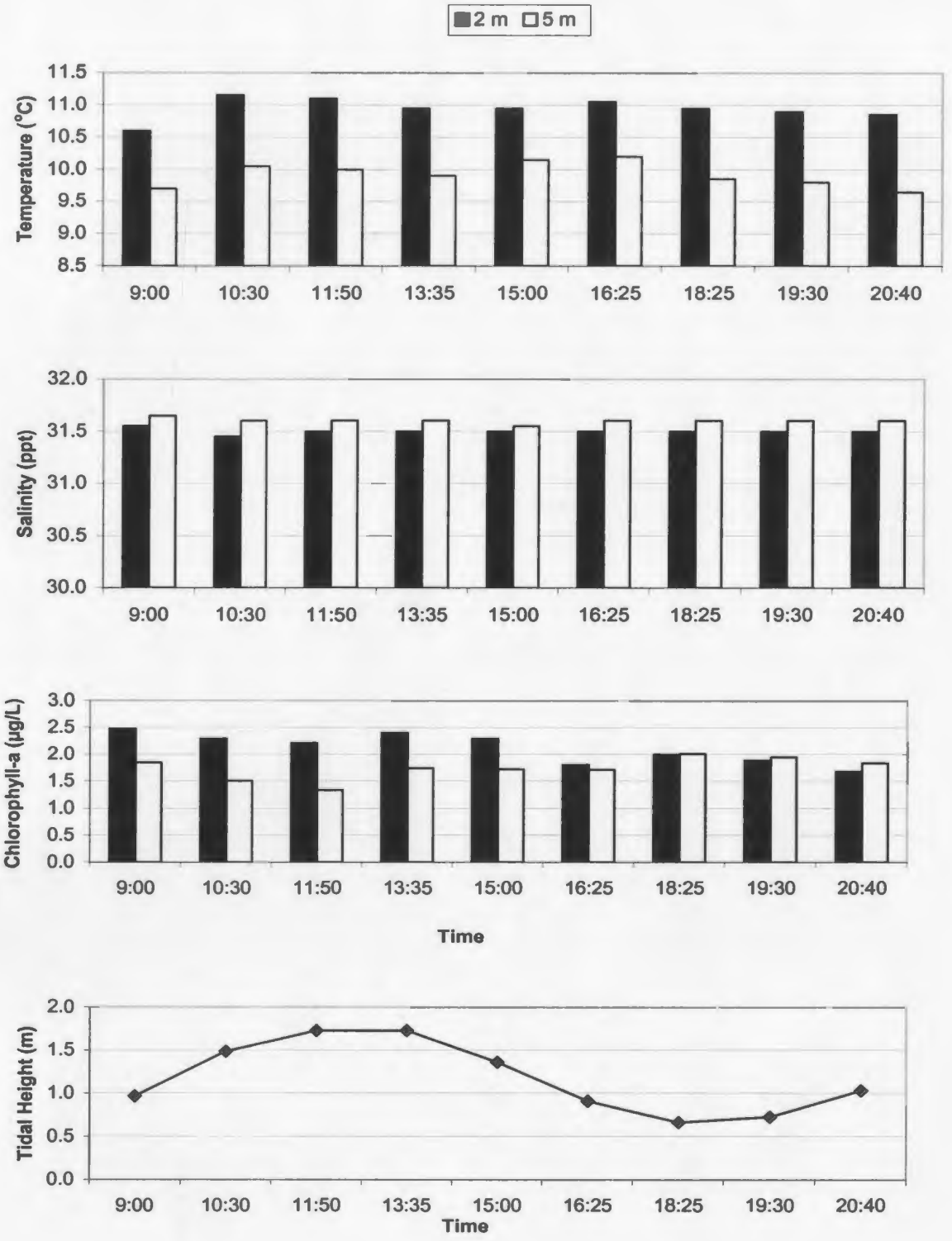


Figure 38. Jersey Hr. (site 2), temperature (°C), salinity (ppt) and chlorophyll-a (µg/L) at 2 m and 5 m depths, as recorded using a CTD (Seabird), in relation to tidal height (m) on July 5, 1999. Each bar represents the average of two CTD casts (one at the inside and one at the outside of the site) per sample time. Note: Depths were not deep enough on this site to sample 10 m depths.

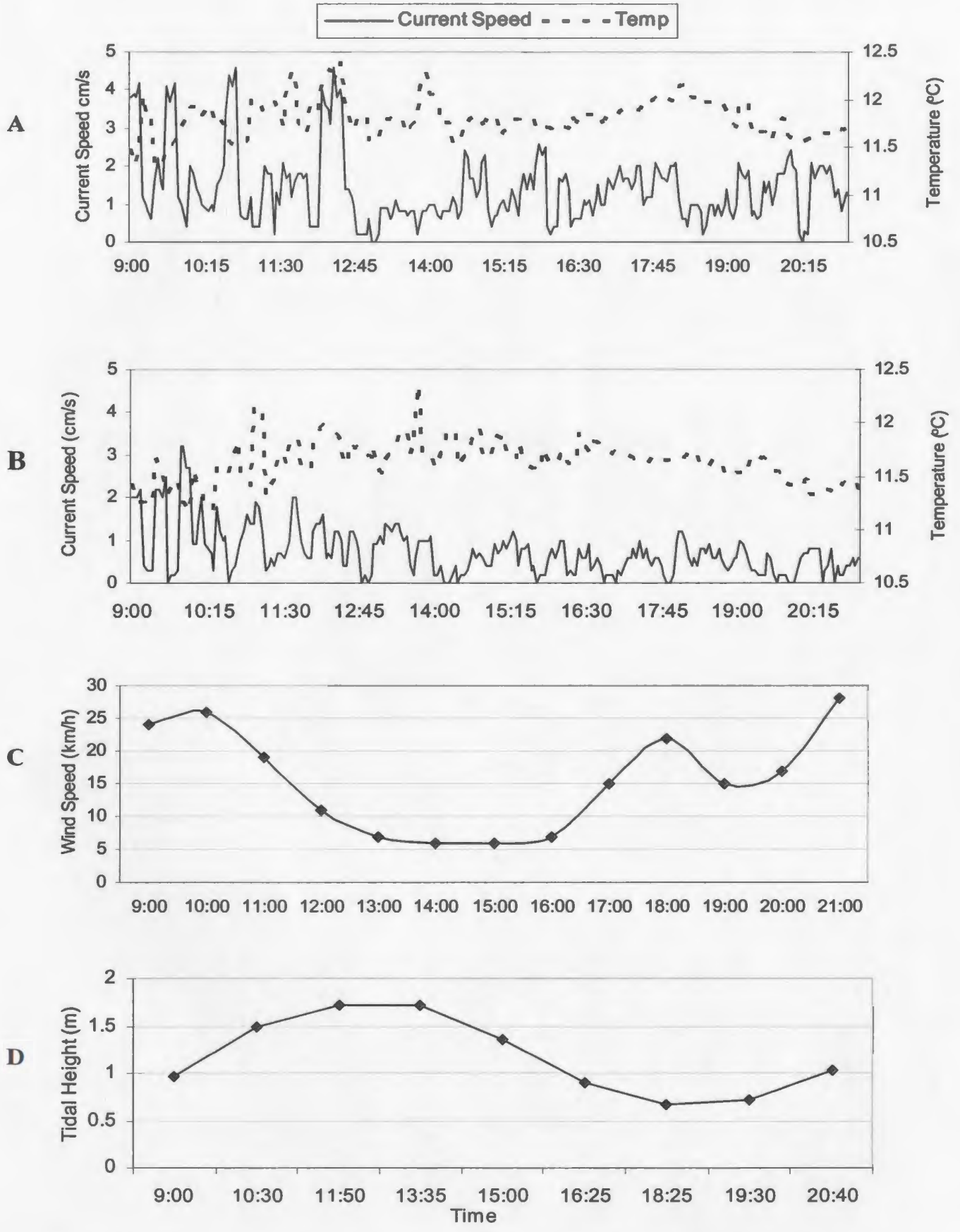


Figure 39. Current speed (cm/s) and temperature (°C) data as recorded using a S4 current meter, at 2 meters depth, for site 2, Jersey Hr. on July 5, 1999 for (A) station 1 and (B) station 2. (C) Wind speed data for Sagona Island, from Environment Canada (Gander Weather Office). (D) Tidal height (m) for the 12-hour sampling period.

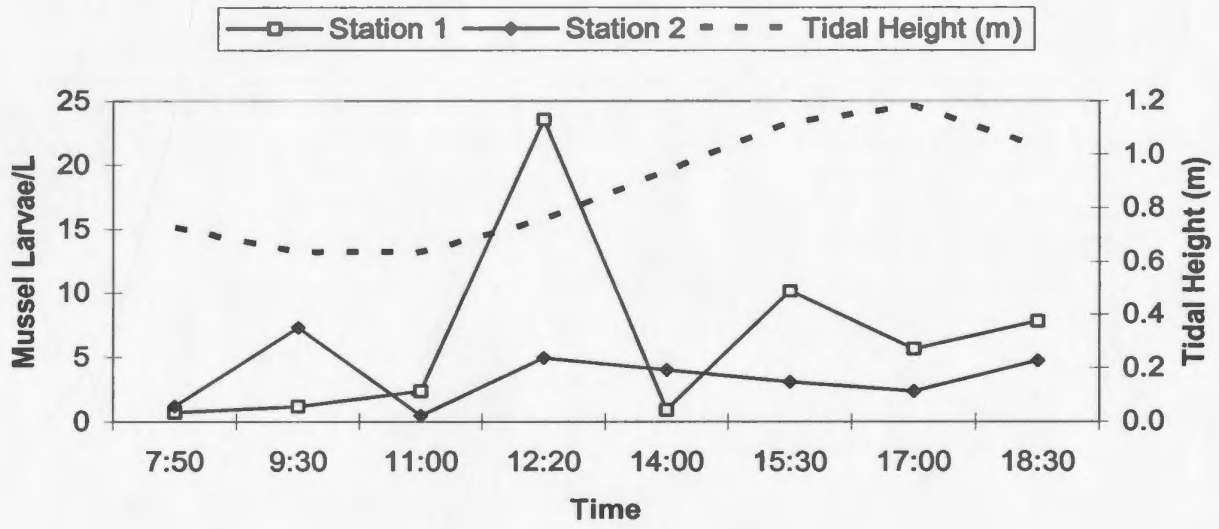


Figure 40. Tidal cycle study for Reach Run (site 1) on October 5, 1999, mussel larvae/L for station 1 and station 2 in relation to tidal height. No other larvae were observed on this site.

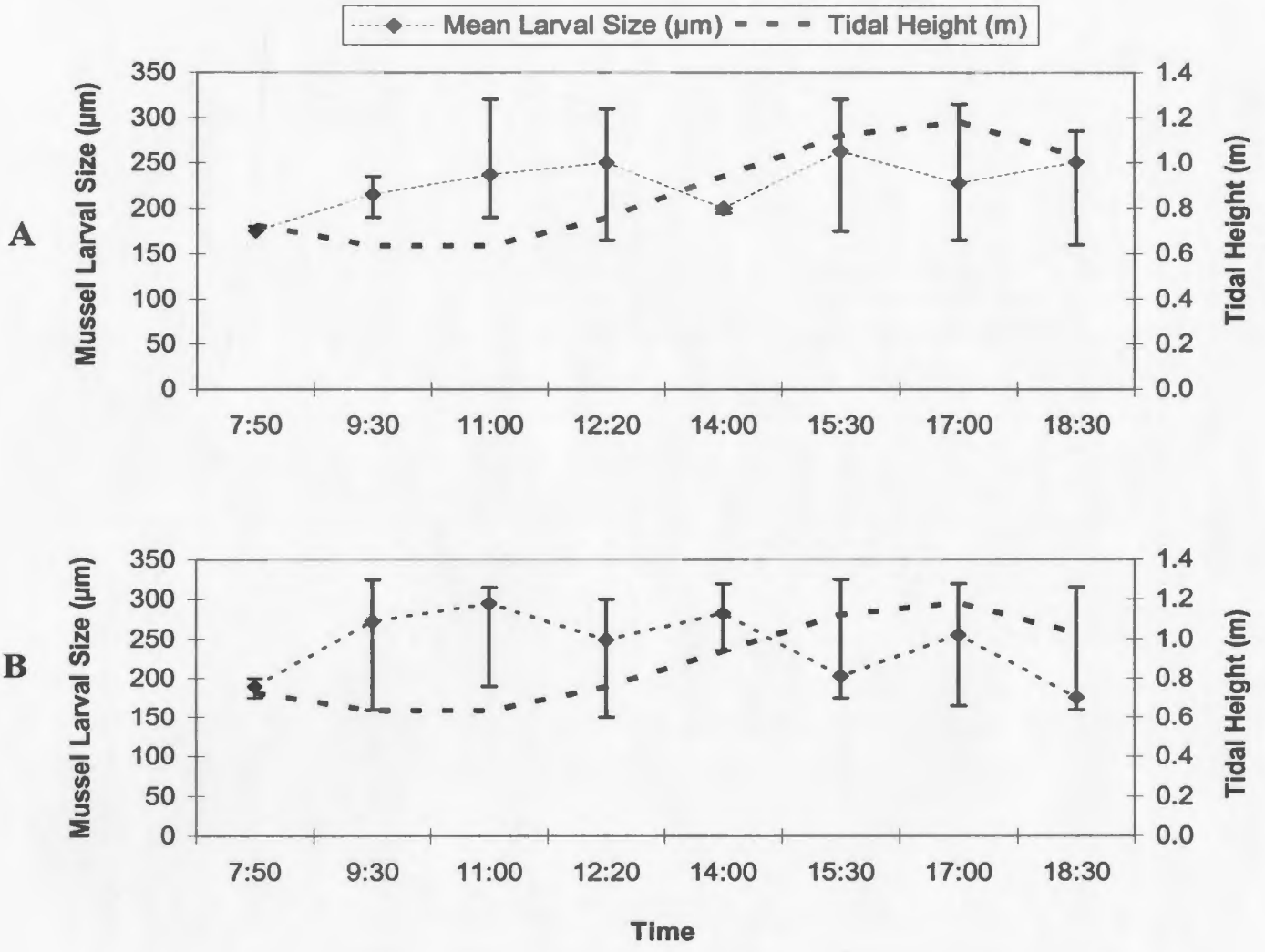


Figure 41. Mean mussel larval size (µm) in relation to tidal height (m) on October 5, 1999 for site 1, Reach Run, at (A) station 1 and (B) station 2. Vertical bars indicate mussel larval size range (min-max).

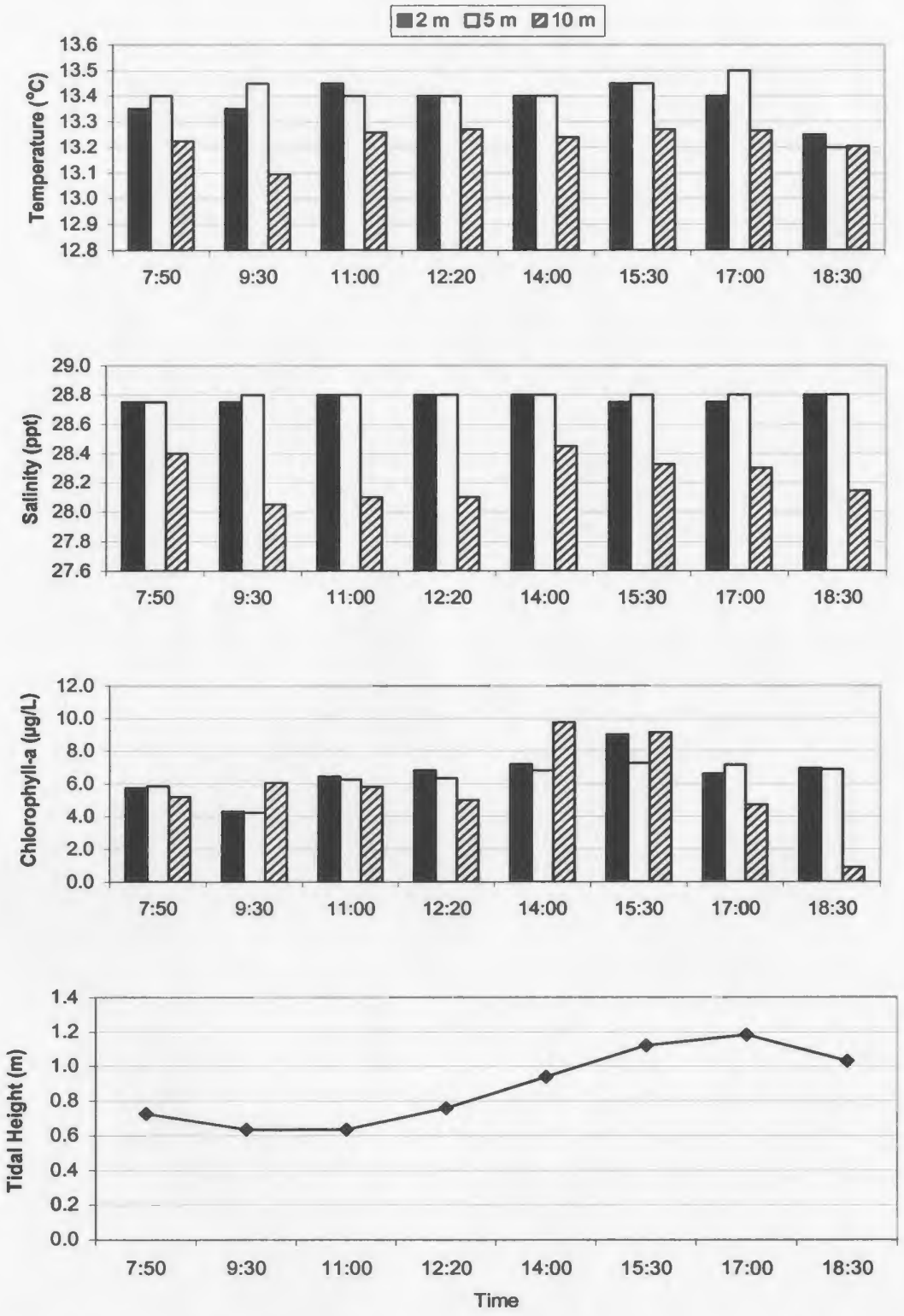


Figure 42. Reach Run (site 1), temperature (°C), salinity (ppt) and chlorophyll-a (µg/L) at 2 m, 5 m and 10 m depths, as recorded using a CTD (Seabird), in relation to tidal height (m) on October 5, 1999. Each bar represents the average of two CTD casts (one at the inside and one at the outside of the site) per sample time.

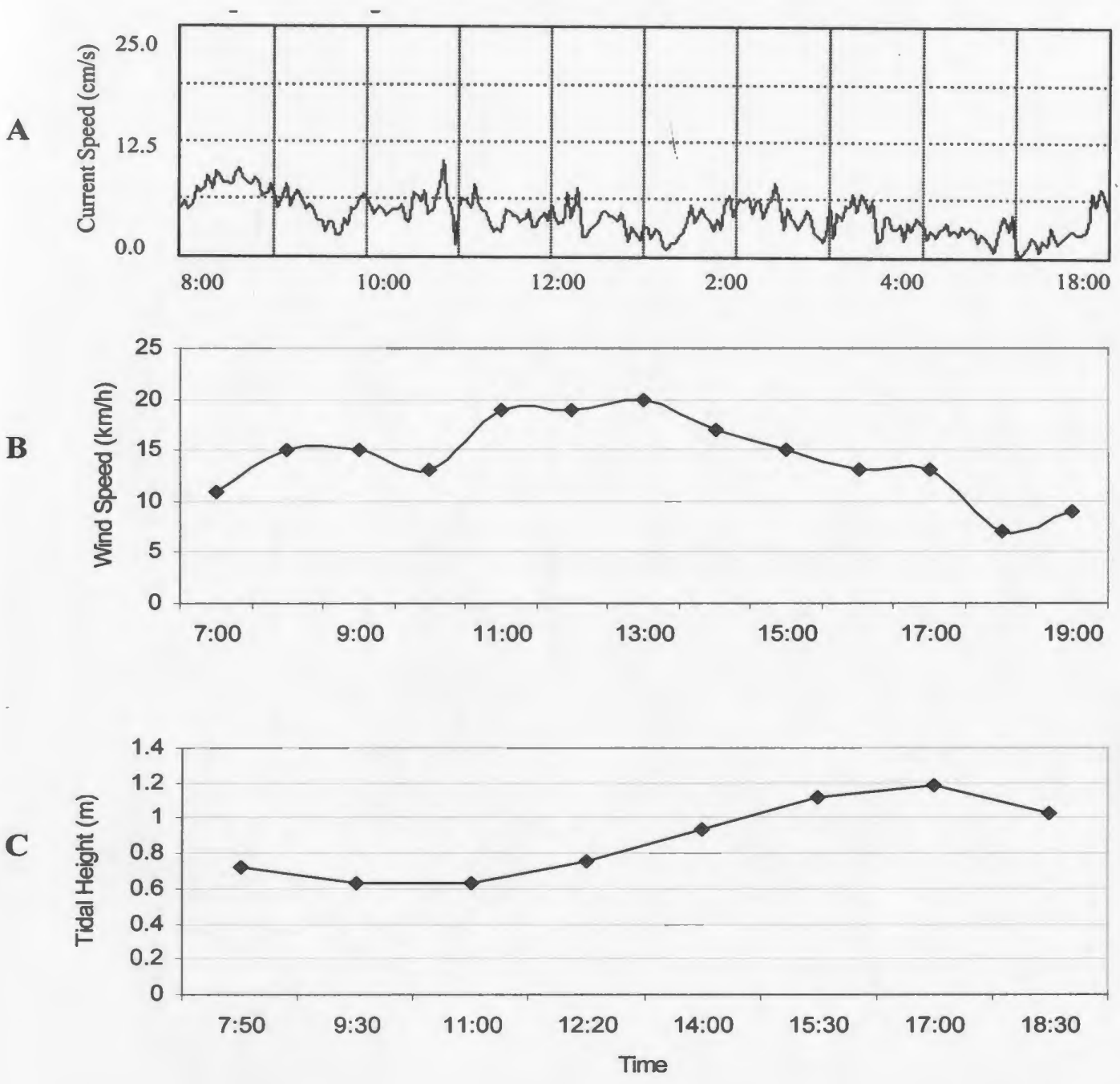


Figure 43. Current speed (cm/s) for Station 1, as recorded using a S4 current meter, at 2 meters depth for site 1, Reach Run, on October 5, 1999. (B) Wind speed data for Twillingate, from Environment Canada (Gander Weather Office) and (C) Tidal height (m) for the 12-hour sampling period. (Note: problems were experienced with the data collected by the S4 current meters at this site such that (A) above is a graph generated by the InterOcean Systems software, without Temperature displayed, and no data could be retrieved for Station 2, on this day.)

9.0 APPENDICES

Appendix 1.0

1.1a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 1, Reach Run. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater**									Avg. # mussel larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
10-Jun	0.00	0.71	0.71	2.12	1.41	3.54	0.71	0.71	1.41	1.26	1.05	0.35
18-Jun	7.07	3.54	2.83	2.12	7.07	2.83	2.83	1.41	1.41	3.46	2.16	0.72
24-Jun	2.12	2.83	2.12	2.83	2.12	1.41	6.37	7.07	2.83	3.30	2.00	0.67
30-Jun	9.90	8.49	9.20	2.12	4.95	14.15	21.93	5.66	18.39	10.53	6.49	2.16
9-Jul	2.83	3.54	2.83	2.83	2.12	6.37	3.54	0.71	8.49	3.69	2.34	0.78
16-Jul	19.81	25.47	8.49	11.32	13.44	17.68	25.47	19.81	21.22	18.08	5.96	1.99
23-Jul	1.41	10.61	5.66	7.07	2.83	2.12	0.71	4.24	3.54	4.24	3.12	1.04
1-Aug	7.07	5.66	13.44	4.24	19.81	21.93	11.32	13.44	11.32	12.03	6.01	2.00
5-Aug	14.15	12.73	7.78	6.37	4.24	7.07	5.66	2.12	10.61	7.86	3.95	1.32
13-Aug	4.24	4.24	1.41	1.41	8.49	1.41	1.41	2.12	1.41	2.91	2.41	0.80
19-Aug	2.83	0.71	0.71	2.83	0.71	1.41	0.00	1.41	0.71	1.26	0.99	0.33
2-Sep	3.54	1.41	2.83	2.83	1.41	2.12	0.71	0.00	1.41	1.81	1.12	0.37
8-Sep	6.37	7.07	4.24	2.12	10.61	7.07	4.24	3.54	3.54	5.42	2.60	0.87
16-Sep	2.83	4.24	5.66	2.83	3.54	3.54	4.24	5.66	2.83	3.93	1.12	0.37
23-Sep	2.12	1.41	1.41	3.54	2.83	1.41	1.41	0.71	1.41	1.81	0.87	0.29
30-Sep	3.54	7.78	5.66	1.41	0.71	1.41	0.71	0.00	1.41	2.52	2.63	0.88
9-Oct	0.71	0.00	0.00	1.41	0.71	0.00	2.12	1.41	3.54	1.10	1.18	0.39
21-Oct	0.71	0.71	0.00	0.71	0.71	1.41	1.41	1.41	0.71	0.86	0.47	0.16
4-Nov	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.71	0.00	0.16	0.31	0.10

Total sample days = 19
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.1b. Summary of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 1, Reach Run. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Starfish larvae/L original seawater**									Avg. # starfish larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
10-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-Jun	0.71	0.00	0.00	0.71	0.00	0.71	2.12	2.83	1.41	0.94	1.00	0.33
30-Jun	0.71	1.41	1.41	0.71	0.00	0.00	0.00	0.71	0.71	0.63	0.55	0.18
9-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16-Jul	0.71	4.24	3.54	2.12	3.54	2.83	2.83	1.41	2.83	2.67	1.11	0.37
23-Jul	0.00	0.00	1.41	1.41	0.00	0.00	0.71	1.41	2.12	0.79	0.83	0.28
1-Aug	1.41	1.41	0.00	4.24	2.12	2.12	4.24	2.83	5.66	2.67	1.76	0.59
5-Aug	2.12	2.83	0.71	0.71	1.41	0.71	0.00	0.71	0.00	1.02	0.94	0.31
13-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4-Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total sample days = 19
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.2a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 2, Little Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater**									Avg. # mussel larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
27-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Jun	2.83	2.12	2.12	3.54	0.71	1.41	1.41	0.71	1.41	1.81	0.94	0.31
26-Jun	10.61	9.90	10.61	21.22	65.78	21.93	6.37	10.61	4.95	18.00	18.86	6.29
6-Jul	69.32	81.35	84.88	105.40	118.13	113.18	69.32	101.86	79.22	91.41	18.58	6.19
13-Jul	195.23	203.72	194.53	223.53	242.63	232.02	233.43	258.19	240.50	224.86	22.48	7.49
20-Jul	212.92	201.60	195.23	185.33	183.21	165.52	198.06	188.16	177.55	189.73	14.04	4.68
31-Jul	113.18	88.42	108.93	123.79	114.59	91.96	118.84	91.25	99.03	105.55	13.16	4.39
7-Aug	51.64	43.15	38.20	41.03	47.39	42.44	64.37	33.95	36.78	44.33	9.24	3.08
14-Aug	31.12	22.64	19.10	28.29	20.51	23.34	19.81	20.51	21.93	23.03	4.08	1.36
21-Aug	18.39	19.10	14.15	12.73	9.90	15.56	21.93	13.44	14.15	15.48	3.70	1.23
28-Aug	7.07	9.20	11.32	5.66	4.95	7.78	9.90	7.07	6.37	7.70	2.08	0.69
4-Sep	4.95	2.83	3.54	3.54	4.24	5.66	2.83	0.71	2.12	3.38	1.49	0.50
11-Sep	3.54	0.71	3.54	0.71	2.83	2.83	7.07	2.12	1.41	2.75	1.95	0.65
22-Sep	1.41	1.41	2.12	2.83	1.41	0.71	0.71	0.71	2.12	1.49	0.75	0.25
7-Oct	0.00	1.41	1.41	0.71	2.12	1.41	0.00	0.71	2.12	1.10	0.80	0.27
23-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total sample days = 17
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered $= \pi(0.15)^2 (10\ m) = 0.70685\ m^3 \times 1000 = 706.85$ litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.2b. Summary of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 2, Little Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Starfish larvae/L original seawater**									Avg. # starfish larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
27-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Jul	0.00	1.41	2.12	0.00	0.71	1.41	1.41	1.41	0.71	1.02	0.72	0.24
20-Jul	0.00	0.71	1.41	3.54	2.83	2.83	2.12	3.54	2.83	2.20	1.25	0.42
31-Jul	2.83	1.41	2.12	5.66	7.78	6.37	4.24	5.66	4.24	4.48	2.09	0.70
7-Aug	6.37	5.66	9.20	11.32	10.61	7.07	6.37	4.95	4.95	7.39	2.40	0.80
14-Aug	7.07	6.37	7.78	12.73	11.32	8.49	9.90	13.44	7.07	9.35	2.62	0.87
21-Aug	2.83	1.41	3.54	4.95	7.78	1.41	0.71	2.83	2.12	3.07	2.18	0.73
28-Aug	0.71	0.00	0.00	1.41	0.71	1.41	1.41	0.71	2.12	0.94	0.71	0.24
4-Sep	0.00	0.00	0.00	0.71	0.00	0.71	0.00	0.00	0.71	0.24	0.35	0.12
11-Sep	0.00	0.00	0.00	0.00	1.41	0.00	0.00	0.71	0.00	0.24	0.50	0.17
22-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total sample days = 17
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.3a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 3, Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater**									Avg. # Mussel larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
27-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Jun	18.39	14.15	22.64	26.88	14.85	23.34	19.81	19.10	20.51	19.96	4.03	1.34
26-Jun	53.05	70.74	92.66	93.37	77.81	45.27	42.44	51.64	92.66	68.85	21.27	7.09
6-Jul	188.87	203.72	219.28	260.31	277.29	244.04	255.36	248.99	257.48	239.48	29.15	9.72
13-Jul	225.65	208.67	203.01	260.31	232.72	229.19	212.21	203.01	218.58	221.48	18.20	6.07
20-Jul	190.99	181.09	176.84	211.50	202.31	193.11	156.33	187.45	174.01	185.96	16.30	5.43
31-Jul	67.20	56.59	65.08	82.76	91.25	91.96	113.18	66.49	70.74	78.36	17.88	5.96
7-Aug	72.86	64.37	60.13	71.44	77.81	63.66	60.83	58.00	67.91	66.33	6.63	2.21
14-Aug	28.29	26.17	39.61	47.39	39.61	42.44	29.00	25.47	26.88	33.87	8.34	2.78
21-Aug	33.25	30.42	28.29	26.88	29.71	26.17	20.51	23.34	25.47	27.12	3.84	1.28
28-Aug	12.73	20.51	17.68	20.51	21.93	22.64	14.15	12.73	18.39	17.92	3.87	1.29
4-Sep	7.78	7.07	5.66	7.07	6.37	9.20	3.54	6.37	4.24	6.37	1.73	0.58
11-Sep	4.24	5.66	2.12	6.37	3.54	3.54	4.24	4.95	2.83	4.17	1.34	0.45
22-Sep	4.24	2.12	1.41	1.41	3.54	2.83	1.41	2.83	2.12	2.44	1.01	0.34
7-Oct	0.00	0.71	0.00	0.71	0.71	1.41	0.00	0.71	0.00	0.47	0.50	0.17
23-Oct	0.00	0.00	0.00	0.71	0.00	0.00	0.71	0.00	0.00	0.16	0.31	0.10
13-Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total sample days = 17
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.3b. Summary of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 3, Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Starfish larvae/L original seawater**									Avg. # Starfish larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
27-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-Jul	0.00	0.71	0.71	0.00	1.41	0.00	0.00	0.00	0.00	0.31	0.51	0.17
13-Jul	0.00	0.71	0.00	0.00	0.71	0.71	0.71	0.00	0.00	0.31	0.37	0.12
20-Jul	0.00	0.00	1.41	2.12	1.41	0.71	1.41	0.71	0.00	0.86	0.77	0.26
31-Jul	0.00	0.71	0.00	0.71	1.41	1.41	0.71	0.71	0.71	0.71	0.50	0.17
7-Aug	4.24	5.66	4.24	6.37	5.66	7.07	2.83	2.12	2.12	4.48	1.84	0.61
14-Aug	7.78	6.37	5.66	9.90	12.73	9.20	7.07	12.73	4.24	8.41	2.99	1.00
21-Aug	10.61	9.20	7.78	5.66	12.03	9.90	6.37	11.32	8.49	9.04	2.17	0.72
28-Aug	4.24	4.95	4.95	6.37	11.32	7.07	5.66	4.24	3.54	5.82	2.34	0.78
4-Sep	2.12	0.71	0.71	3.54	2.12	1.41	1.41	0.71	0.71	1.49	0.97	0.32
11-Sep	0.00	0.71	0.00	0.71	1.41	1.41	0.00	0.71	0.71	0.63	0.55	0.18
22-Sep	0.00	0.00	0.00	0.71	0.00	0.00	0.71	0.00	0.00	0.16	0.31	0.10
7-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total sample days = 17
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.4a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 4, Jersey Harbour. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater**									Avg. # mussel larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
6-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Jun	1.41	3.54	2.12	3.54	4.24	3.54	4.24	0.71	1.41	2.75	1.34	0.45
8-Jul	1.41	0.71	0.71	0.71	1.41	0.71	2.12	0.71	1.41	1.10	0.51	0.17
14-Jul	1.41	2.83	2.12	2.12	2.12	3.54	3.54	2.12	2.12	2.44	0.72	0.24
22-Jul	0.71	0.71	0.71	0.00	1.41	0.00	1.41	0.00	1.41	0.71	0.61	0.20
29-Jul	1.41	0.71	1.41	1.41	1.41	1.41	0.71	0.71	0.00	1.02	0.51	0.17
4-Aug	8.49	12.73	14.85	2.83	2.83	1.41	4.24	2.12	4.95	6.05	4.88	1.63
12-Aug	5.66	8.49	1.41	0.00	0.00	2.12	0.71	0.00	0.00	2.04	3.03	1.01
20-Aug	5.66	7.07	2.12	15.56	2.12	1.41	4.24	4.95	2.83	5.11	4.34	1.45
26-Aug	0.71	2.12	0.71	1.41	1.41	3.54	3.54	8.49	4.24	2.91	2.46	0.82
3-Sep	2.12	1.41	1.41	2.83	1.41	0.00	3.54	2.83	4.24	2.20	1.30	0.43
9-Sep	1.41	0.71	2.12	3.54	1.41	2.12	2.12	2.12	1.41	1.89	0.79	0.26
15-Sep	0.00	0.00	0.71	1.41	0.71	0.00	1.41	0.00	0.71	0.55	0.59	0.20
29-Sep	2.12	2.83	2.12	4.95	4.24	2.12	0.71	8.49	5.66	3.69	2.39	0.80
6-Oct	2.12	9.90	6.37	1.41	0.71	2.12	2.12	2.12	0.71	3.07	3.06	1.02
26-Oct	0.71	0.00	0.00	0.00	0.71	0.00	0.00	1.41	0.71	0.39	0.51	0.17

Total sample days = 18
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered $= \pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

1.4b. Summary of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 4, Jersey Harbour. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Starfish larvae/L original seawater**									Avg. # starfish larvae/L	S.D.	S.E.
	Inside			Middle			Outside					
	SS1*	SS2	SS3	SS1	SS2	SS3	SS1	SS2	SS3			
6-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-Jul	0.00	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.08	0.24	0.08
29-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total sample days = 18
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

Appendix 2.0

2.1a. Summary of average shell length (µm) of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 1, Reach Run. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (µm) Mussel larvae			Avg. Size (µm) Mussel larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
10-Jun	170	167	163	167	20.0	145	210
18-Jun	174	209	182	188	45.8	125	280
24-Jun	179	201	190	190	23.7	155	250
30-Jun	200	205	202	202	34.5	145	275
9-Jul	247	235	243	242	46.4	145	340
16-Jul	248	227	211	229	36.0	130	330
23-Jul	261	291	237	263	72.7	125	560
1-Aug	322	202	306	310	45.4	140	400
5-Aug	289	288	296	291	31.6	205	360
13-Aug	290	262	277	277	71.7	145	450
19-Aug	271	245	225	247	75.7	155	420
2-Sep	275	299	268	281	46.2	220	400
8-Sep	250	248	277	258	68.1	140	425
16-Sep	276	255	257	263	54.6	175	360
23-Sep	269	290	229	263	47.5	175	340
30-Sep	224	307	290	274	65.1	160	400
9-Oct	275	245	245	255	43.7	170	340
21-Oct	288	268	271	275	39.1	195	288
4-Nov	-	295	300	298	3.5	295	300

Total sample days = 19

2.1b. Summary of average length (μm) of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 1, Reach Run. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (μm) Starfish larvae			Avg. Size (μm) Starfish larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
10-Jun	-	-	-	-	-	-	-
18-Jun	-	-	-	-	-	-	-
24-Jun	300	525	292	372	124.4	200	700
30-Jun	540	300	275	372	247.0	250	900
9-Jul	-	-	-	-	-	-	-
16-Jul	373	454	503	443	166.1	200	750
23-Jul	675	775	867	772	266.5	500	1500
1-Aug	599	720	669	662	240.1	300	1200
5-Aug	1067	1250	1100	1139	164.8	900	1500
13-Aug	-	-	-	-	-	-	-
19-Aug	-	-	-	-	-	-	-
2-Sep	-	-	-	-	-	-	-
8-Sep	-	-	-	-	-	-	-
16-Sep	-	-	-	-	-	-	-
23-Sep	-	-	-	-	-	-	-
30-Sep	-	-	-	-	-	-	-
9-Oct	-	-	-	-	-	-	-
21-Oct	-	-	-	-	-	-	-
4-Nov	-	-	-	-	-	-	-

Total sample days = 19

2.2a. Summary of average shell length (μm) of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 2, Little Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (μm) Mussel larvae			Avg. Size (μm) Mussel larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
27-May	-	-	-	-	-	-	-
10-Jun	153	142	162	152	18.9	125	190
26-Jun	152	151	149	150	17.5	125	190
6-Jul	162	176	179	172	23.8	125	250
13-Jul	177	183	194	185	23.4	125	250
20-Jul	222	235	235	231	22.8	175	290
31-Jul	229	239	229	232	21.3	175	290
7-Aug	228	243	245	239	20.4	175	290
14-Aug	248	283	297	275	34.0	200	325
21-Aug	291	301	292	295	15.3	250	325
28-Aug	302	298	283	294	14.8	250	325
4-Sep	299	301	300	300	9.5	275	315
11-Sep	310	302	299	304	7.5	285	315
22-Sep	296	303	319	306	17.1	275	340
7-Oct	322	313	308	314	11.2	300	340
23-Oct	-	-	-	-	-	-	-
13-Nov	-	-	-	-	-	-	-

Total sample days = 17

2.2b. Summary of average length (μm) of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 2, Little Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (μm) Starfish larvae			Avg. Size (μm) Starfish larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
27-May	-	-	-	-	-	-	-
10-Jun	-	-	-	-	-	-	-
26-Jun	-	-	-	-	-	-	-
6-Jul	-	-	-	-	-	-	-
13-Jul	268	325	280	291	38.3	250	400
20-Jul	383	495	498	459	67.0	325	600
31-Jul	794	785	813	797	95.6	400	950
7-Aug	993	989	1020	1000	81.9	875	1200
14-Aug	1117	1109	1086	1102	81.7	900	1250
21-Aug	1109	1090	1113	1104	85.1	1000	1250
28-Aug	1200	1240	1250	1230	35.9	1200	1300
4-Sep	-	1450	1400	1425	57.7	1400	1500
11-Sep	-	1500	2000	1750	28.7	1500	2000
22-Sep	-	-	-	-	-	-	-
7-Oct	-	-	-	-	-	-	-
23-Oct	-	-	-	-	-	-	-
13-Nov	-	-	-	-	-	-	-

Total sample days = 17

2.3a. Summary of average shell length (μm) of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 3, Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (μm) Mussel larvae			Avg. Size (μm) Mussel larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
27-May	-	-	-	-	-	-	-
10-Jun	152	154	152	153	17.8	125	190
26-Jun	168	168	167	168	19.6	125	230
6-Jul	185	188	188	187	19.1	125	250
13-Jul	208	216	213	213	24.4	150	280
20-Jul	228	235	238	233	21.3	175	290
31-Jul	234	232	228	231	22.8	175	290
7-Aug	241	246	230	239	18.9	175	290
14-Aug	295	296	304	299	16.1	250	340
21-Aug	304	302	297	301	16.8	240	340
28-Aug	306	300	305	304	16.2	230	340
4-Sep	297	309	299	302	12.5	280	340
11-Sep	313	302	301	305	12.0	280	340
22-Sep	312	305	312	310	12.3	280	325
7-Oct	310	325	325	320	6.1	310	325
23-Oct	-	325	325	325	-	325	325
13-Nov	-	-	-	-	-	-	-

Total sample days = 17

2.3b. Summary of average length (μm) of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 3, Shellbird Bight. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (μm) Starfish larvae			Avg. Size (μm) Starfish larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
27-May	-	-	-	-	-	-	-
10-Jun	-	-	-	-	-	-	-
26-Jun	-	-	-	-	-	-	-
6-Jul	263	258	-	260	10.8	250	275
13-Jul	300	350	275	308	55.4	275	400
20-Jul	290	375	617	427	140.1	280	650
31-Jul	800	860	850	837	43.3	800	900
7-Aug	970	998	960	976	77.4	875	1200
14-Aug	1103	1083	1109	1098	84.4	900	1250
21-Aug	1088	1042	1076	1068	88.3	900	1250
28-Aug	1120	1108	1095	1108	88.5	900	1250
4-Sep	1180	1230	1288	1233	75.1	1000	1300
11-Sep	1400	1280	1100	1260	130.9	1100	1400
22-Sep	-	1500	2000	1750	353.6	1500	2000
7-Oct	-	-	-	-	-	-	-
23-Oct	-	-	-	-	-	-	-
13-Nov	-	-	-	-	-	-	-

Total sample days = 17

2.4a. Summary of average shell length (μm) of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the sampling season of 1998 for site 4, Jersey Harbour. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (μm) Mussel larvae			Avg. Size (μm) Mussel larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
6-Jun	-	-	-	-	-	-	-
12-Jun	-	-	-	-	-	-	-
23-Jun	-	-	-	-	-	-	-
29-Jun	162	160	224	182	38.9	150	175
8-Jul	263	269	300	277	27.5	230	315
14-Jul	253	278	301	278	48.6	145	330
22-Jul	207	233	255	231	45.8	190	325
29-Jul	273	288	288	283	37.1	170	315
4-Aug	196	219	176	197	68.1	130	425
12-Aug	221	245	260	242	50.9	120	280
20-Aug	257	280	268	268	37.1	200	350
26-Aug	256	258	265	260	42.3	200	450
3-Sep	278	246	291	272	62.2	165	425
9-Sep	286	275	276	279	60.9	175	395
15-Sep	280	287	323	297	58.6	250	425
29-Sep	246	234	280	253	50.1	140	410
6-Oct	277	229	278	261	58.0	130	425
26-Oct	295	325	350	323	52.0	295	425

Total sample days = 18

2.4b. Summary of average length (µm) of starfish (*Asterias vulgaris)* larvae found over the sampling season of 1998 for site 4, Jersey Harbour. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow. Larvae sized using an ocular micrometer).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	Average Size (µm) Starfish larvae			Avg. Size (µm) Starfish larvae per sampling date	S.D.	MIN	MAX
	Inside	Middle	Outside				
6-Jun	-	-	-	-	-	-	-
12-Jun	-	-	-	-	-	-	-
23-Jun	-	-	-	-	-	-	-
29-Jun	-	-	-	-	-	-	-
8-Jul	-	-	-	-	-	-	-
14-Jul	-	-	-	-	-	-	-
22-Jul	-	850	-	850	-	850	850
29-Jul	-	-	-	-	-	-	-
4-Aug	-	-	-	-	-	-	-
12-Aug	-	-	-	-	-	-	-
20-Aug	-	-	-	-	-	-	-
26-Aug	-	-	-	-	-	-	-
3-Sep	-	-	-	-	-	-	-
9-Sep	-	-	-	-	-	-	-
15-Sep	-	-	-	-	-	-	-
29-Sep	-	-	-	-	-	-	-
6-Oct	-	-	-	-	-	-	-
26-Oct	-	-	-	-	-	-	-

Total sample days = 18

Appendix 3.0

3.1. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* spat settlement during 1998 for site 1, Reach Run. (Note: Each rope collector was made of 13 mm diameter green poly rope, measuring 2 m in length and deployed for two week periods. The dates listed in this table represent retrieval dates.)

Date	# Mussel spat per collector					Avg. # spat per collector	S.D.	S.E.	Avg. spat size (µm) per collector
	Coll.1	Coll. 2	Coll. 3	Coll. 4	Coll. 5				
30-Jun	6056	6496	4156	5987	6124	5763.8	920.1	411.5	450
9-Jul	5423	5681	7220	4986	5988	5859.6	844.5	377.7	390
16-Jul	574	6019	5732	5460	6232	5837.4	296.2	132.5	475
23-Jul	7472	7536	7815	7226	7613	7532.4	214.4	95.9	460
1-Aug	12954	13067	12855	12400	13149	12885.0	293.1	131.1	450
5-Aug	10684	11743	11689	11383	9018	10903.4	1135.2	507.7	470
13-Aug	9851	9320	9465	8076	9117	9165.0	665.7	297.7	390
19-Aug	8642	8729	9887	6054	8713	8405.0	1412.4	631.6	430
2-Sep	7960	8230	7617	7520	6093	7484.0	827.2	369.9	450
8-Sep	5678	7981	7254	6079	7133	6825.0	933.7	417.6	500
16-Sep	6458	7329	6048	6451	7012	6659.6	507.6	227.0	480
23-Sep	11645	16830	12534	12764	13480	13450.6	1999.6	894.2	415
30-Sep	15208	17648	15768	16459	15633	16143.2	953.9	426.6	470
9-Oct	9865	8223	9764	8251	9073	9035.2	789.9	353.3	460
21-Oct	1548	1320	1679	1420	1611	1515.6	145.1	64.9	480
4-Nov	856	791	1152	1097	988	976.8	153.6	68.7	390

Total sample days = 16

3.2a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* spat settlement during 1998 for site 2, Little Shellbird Bight. (Note: Each rope collector was made of 13 mm diameter green poly rope, measuring 2 m in length and deployed for two week periods. The dates listed in this table represent retrieval dates.)

Date	# Mussel spat per collector					Avg. # spat per collector	S.D.	S.E.	Avg. spat size (µm) per collector
	Coll.1	Coll. 2	Coll. 3	Coll. 4	Coll. 5				
13-Jul	109	246	764	238	316	334.6	251.4	112.4	390
20-Jul	1758	1692	1723	1784	1631	1717.6	59.6	26.7	415
31-Jul	9680	9433	9726	9715	9428	9596.4	152.4	68.2	385
7-Aug	10657	10891	9964	10571	10132	10443.0	383.7	171.6	400
14-Aug	10093	10781	10477	10729	10636	10543.2	276.9	123.8	460
21-Aug	4621	4350	6087	4219	4387	4732.8	770.8	344.7	610
28-Aug	6085	5923	5770	5961	6118	5971.4	139.1	62.2	420
4-Sep	4720	4933	4382	4610	3976	4524.2	365.2	163.3	395
11-Sep	2864	2370	4610	3861	2995	3340.0	890.3	398.2	540
22-Sep	1106	1058	1116	961	834	1015.0	118.3	52.9	610
7-Oct	960	945	802	873	916	899.2	63.7	28.5	630
23-Oct	137	160	179	224	238	187.6	42.6	19.1	610
13-Nov	31	65	71	28	44	47.8	19.5	8.7	600

Total sample days = 13

3.2b. Summary of starfish (*Asterias vulgaris)* juvenile settlement during 1998 for site 2, Little Shellbird Bight. Note: Each rope collector was made of 13 mm diameter green poly rope, measuring 2 m in length and deployed for two week periods. The dates listed in this table represent retrieval dates.)

Date	# Starfish per collector					Avg. # starfish per collector	S.D.	S.E.	Avg. starfish size (µm) per collector
	Coll.1	Coll. 2	Coll. 3	Coll. 4	Coll. 5				
13-Jul	0	0	0	0	0	0	0	0	0
20-Jul	0	0	0	0	0	0	0	0	0
31-Jul	0	0	0	0	0	0	0	0	0
7-Aug	0	0	0	0	0	0	0	0	0
14-Aug	2	1	1	2	0	1.2	0.84	0.37	1200
21-Aug	4	4	3	2	4	3.4	0.89	0.40	1300
28-Aug	3	1	1	0	2	1.4	1.14	0.51	1500
4-Sep	1	0	1	1	2	1.0	0.71	0.32	1400
11-Sep	0	2	1	1	0	0.8	0.84	0.37	1400
22-Sep	0	0	0	0	0	0	0	0	0
7-Oct	0	0	0	0	0	0	0	0	0
23-Oct	0	0	0	0	0	0	0	0	0
13-Nov	0	0	0	0	0	0	0	0	0

Total sample days = 13

3.3a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* spat settlement during 1998 for site 3, Shellbird Bight. (Note: Each rope collector was made of 13 mm diameter green poly rope, measuring 2 m in length and deployed for two week periods. The dates listed in this table represent retrieval dates.)

Date	# Mussel spat per collector					Avg. # spat per collector	S.D.	S.E.	Avg. spat size (µm) per collector
	Coll.1	Coll. 2	Coll. 3	Coll. 4	Coll. 5				
13-Jul	216	279	345	280	330	290.0	50.8	22.7	360
20-Jul	1657	1823	1628	1702	1691	1700.2	74.6	33.4	340
31-Jul	12680	14962	13872	14351	13995	13972.0	837.2	374.4	420
7-Aug	15678	16089	15328	15977	15846	15783.6	297.2	132.9	460
14-Aug	14052	14348	13906	13734	16081	14424.2	953.2	426.3	415
21-Aug	10829	11647	11320	10985	10668	11089.8	393.8	176.1	390
28-Aug	8753	10746	8644	8943	9094	9236.0	861.7	385.3	500
4-Sep	3281	4519	4677	3384	3263	3824.8	709.5	317.3	475
11-Sep	1120	1019	1169	1008	984	1060.0	80.1	35.8	615
22-Sep	865	802	971	840	899	875.4	64.1	28.7	620
7-Oct	134	273	228	196	242	214.6	52.9	23.6	700
23-Oct	68	64	95	82	80	77.8	12.3	5.5	680
13-Nov	41	25	67	30	34	39.4	16.5	7.4	600

Total sample days = 13

3.3b. Summary of starfish (*Asterias vulgaris)* juvenile settlement during 1998 for site 3, Shellbird Bight. (Note: Each rope collector was made of 13 mm diameter green poly rope, measuring 2 m in length and deployed for two week periods. The dates listed in this table represent retrieval dates.)

Date	# Starfish per collector					Avg. # starfish per collector	S.D.	S.E.	Avg. starfish size (µm) per collector
	Coll.1	Coll. 2	Coll. 3	Coll. 4	Coll. 5				
13-Jul	0	0	0	0	0	0	0	0	0
20-Jul	0	0	0	0	0	0	0	0	0
31-Jul	0	0	0	0	0	0	0	0	0
7-Aug	0	0	0	0	0	0	0	0	0
14-Aug	0	0	0	0	0	0	0	0	0
21-Aug	1	2	0	1	1	1.0	0.71	0.32	1200
28-Aug	4	3	4	4	1	3.2	1.30	0.58	1000
4-Sep	8	10	6	9	9	8.4	1.52	0.68	1300
11-Sep	3	8	3	4	4	4.4	2.07	0.93	1300
22-Sep	2	0	1	2	1	1.2	0.84	0.37	1200
7-Oct	0	1	1	0	0	0.4	0.55	0.24	1500
23-Oct	0	0	0	0	0	0	0	0	0
13-Nov	0	0	0	0	0	0	0	0	0

Total sample days = 13

3.4. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* spat settlement during 1998 for site 4, Jersey Harbour. (Note: Each rope collector was made of 13 mm diameter green poly rope, measuring 2 m in length and deployed for two week periods. The dates listed in this table represent retrieval dates.)

Date	# Mussel spat per collector					Avg. # spat per collector	S.D.	S.E.	Avg. spat size (µm) per collector
	Coll.1	Coll. 2	Coll. 3	Coll. 4	Coll. 5				
8-Jul	43	31	38	50	42	40.8	7.0	3.1	450
14-Jul	176	254	189	130	149	179.6	47.5	21.3	620
22-Jul	1154	1982	1678	1311	1620	1549.0	324.7	145.2	700
29-Jul	2564	3401	2875	2644	2150	2726.8	459.0	205.3	740
4-Aug	985	1128	1496	1067	2019	1339.0	427.5	191.2	680
12-Aug	3110	2362	2875	1165	1678	2238.0	813.4	363.8	710
20-Aug	1660	1495	1320	1589	1121	1437.0	217.8	97.4	765
26-Aug	1108	2811	2013	2760	2614	2261.2	718.9	321.5	730
3-Sep	3623	3215	3094	2981	2876	3157.8	289.1	129.3	640
9-Sep	1192	1204	1153	1670	1400	1323.8	216.0	96.6	720
15-Sep	6720	5884	5642	4837	5381	5692.8	693.5	310.2	740
29-Sep	7016	7584	6980	7132	7198	7182.0	241.2	107.9	680
6-Oct	1354	2018	1450	2119	1871	1762.4	342.3	153.1	670
26-Oct	1960	876	1462	1321	1540	1431.8	391.4	175.0	700

Total sample days = 14

Appendix 4.0

4.1a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the 12-hour tidal cycle for site 1, Reach Run, on July 2, 1999. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater** Station 1							# Mussel larvae/L original seawater Station 2						
	SS1*	SS2	SS3	Avg. # Mussel larvae/L	S.D.	S.E.	Avg. Size (µm)	SS1	SS2	SS3	Avg. # Mussel larvae/L	S.D.	S.E.	Avg. Size (µm)
9:00	3.54	8.49	5.66	5.89	2.48	1.43	222	2.83	4.24	4.95	4.01	1.08	0.62	226
10:3(	6.37	3.54	3.54	4.48	1.63	0.94	236	10.61	28.29	11.32	16.74	10.01	5.78	238
12:0(	3.54	9.20	7.78	6.84	2.94	1.70	252	3.54	26.17	12.73	14.15	11.38	6.57	241
13:3(	3.54	7.78	5.66	5.66	2.12	1.23	243	1.41	2.12	0.71	1.41	0.71	0.41	265
15:0!	2.83	7.78	4.95	5.19	2.48	1.43	255	0.71	15.56	4.95	7.07	7.65	4.42	275
16:3(	4.24	7.78	6.37	6.13	1.78	1.03	277	6.37	7.07	6.37	6.6	0.41	0.24	286
18:0(	0	6.37	2.12	2.83	3.24	1.87	298	0	2.83	2.12	1.65	1.47	0.85	265
19:3(	0	1.41	0.71	0.71	0.71	0.41	275	1.41	0.71	1.41	1.18	0.41	0.24	280
20:3!	1.41	0.71	1.41	1.18	0.41	0.24	295	3.54	12.73	7.78	8.02	4.60	2.66	262

Total sample times = 9
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered $= \pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

4.1b. Summary of starfish (*Asterias vulgaris)* larvae found over the 12-hour tidal cycle for site 1, Reach Run, on July 2, 1999. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Starfish larvae/L original seawater** Station 1							# Starfish larvae/L original seawater Station 2						
	SS1*	SS2	SS3	Avg. # Starfish larvae/L	S.D.	S.E.	Avg. Size (µm)	SS1	SS2	SS3	Avg. # Starfish larvae/L	S.D.	S.E.	Avg. Size (µm)
9:00	2.83	2.12	1.41	2.12	0.71	0.41	936	6.37	4.24	4.24	4.95	1.23	0.71	811
10:3(	2.12	0.71	2.12	1.65	0.82	0.47	994	5.66	9.90	6.37	7.31	2.27	1.31	831
12:0(	2.12	1.41	2.12	1.89	0.41	0.24	1105	1.41	3.54	2.12	2.36	1.08	0.62	974
13:3(	2.83	1.41	2.83	2.36	0.82	0.47	1120	1.41	0.71	0.71	0.94	0.41	0.24	1000
15:0:	0.71	0.71	2.12	1.18	0.82	0.47	1017	9.20	11.32	3.54	8.02	4.02	2.32	903
16:3(	0	0.71	0.71	0.47	0.41	0.24	1150	7.07	3.54	3.54	4.72	2.04	1.18	720
18:0(	0	0	0	0	0	0	-	2.83	2.12	1.41	2.12	0.71	0.41	867
19:3(	1.41	0.71	1.41	1.18	0.41	0.24	1040	3.54	5.66	1.41	3.54	2.12	1.23	890
20:3:	0	0	0	0	0	0	-	4.95	3.54	5.66	4.72	1.08	0.62	1134

Total sample times = 9
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

4.2a. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the 12-hour tidal cycle for site 2, Jersey Harbour, July 5, 1999. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater** Station 1							# Mussel larvae/L original seawater Station 2						
	SS1*	SS2	SS3	Avg. # Mussel larvae/L	S.D.	S.E.	Avg. Size (µm)	SS1	SS2	SS3	Avg. # Mussel larvae/L	S.D.	S.E.	Avg. Size (µm)
9:00	0	0	0	0	0	0	-	0	0	0	0	0	0	-
10:3(	1.41	2.12	0.71	1.41	0.71	0.41	235	0	0	0	0	0	0	-
11:5(	0	0.71	0.71	0.47	0.41	0.24	200	0	0	0	0	0	0	-
13:3:	5.66	1.41	4.24	3.77	2.16	1.25	245	2.12	0.71	0.71	1.18	0.82	0.47	163
15:0(	4.24	7.78	4.95	5.66	1.87	1.08	240	2.12	0.71	1.41	1.41	0.71	0.41	288
16:2:	12.73	11.32	15.56	13.20	2.16	1.25	245	0.71	0.71	0.71	0.71	0	0	260
18:2:	11.32	8.49	10.61	10.14	1.47	0.85	275	0.71	1.41	1.41	1.18	0.41	0.24	223
19:3(	3.54	4.95	1.41	3.30	1.78	1.03	210	0	0	0	0	0	0	-
20:4(	1.41	0.71	1.41	1.18	0.41	0.24	233	0.71	0.71	1.41	0.94	0.41	0.24	150

Total sample times = 9
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered $= \pi(0.15)^2 (10\ m) = 0.70685\ m^3 \times 1000 = 706.85$ litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

4.2b. Summary of clam (*Hiatella* sp.) larvae found over the 12-hour tidal cycle for site 2, Jersey Harbour, July 5, 1999. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Clam larvae/L original seawater** Station 1							# Clam larvae/L original seawater Station 2						
	SS1*	SS2	SS3	Avg. # Clam larvae/L	S.D.	S.E.	Avg. Size (µm)	SS1	SS2	SS3	Avg. # Clam larvae/L	S.D.	S.E.	Avg. Size (µm)
9:00	5.66	3.54	7.78	5.66	2.12	1.23	257	7.78	5.66	4.95	6.13	1.47	0.85	275
10:3(	20.51	14.85	19.81	18.39	3.08	1.78	281	1.41	2.83	1.41	1.89	0.82	0.47	227
11:5(	29.00	19.98	33.25	27.35	6.87	3.97	293	11.32	6.37	8.49	8.72	2.48	1.43	303
13:3!	71.44	43.86	63.66	59.65	14.22	8.21	299	5.66	12.73	4.95	7.78	4.30	2.48	294
15:0(	41.73	69.32	58.71	56.59	13.92	8.03	292	11.32	8.49	4.24	8.02	3.56	2.06	310
16:2!	290.73	211.50	244.04	248.76	39.82	22.99	291	15.56	19.81	9.90	15.09	4.97	2.87	310
18:2!	226.36	188.87	215.75	210.32	19.32	11.16	289	48.10	29.71	35.37	37.73	9.42	5.44	300
19:3(	125.91	85.59	130.86	114.12	24.83	14.34	300	17.68	8.49	14.15	13.44	4.64	2.68	300
20:4(	63.66	46.69	55.17	55.17	8.49	4.90	294	11.32	13.44	15.56	13.44	2.12	1.23	298

Total sample times = 9
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered = $\pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.

4.3. Summary of blue mussel (*Mytilus edulis/Mytilus trossulus)* larvae found over the 12-hour tidal cycle for site 1, Reach Run, October 5, 1999. (Note: 10 m vertical plankton tow, at the inside, middle and outside of each site, with three 1 mL subsamples counted per tow).

Depth of each tow = 10 m
Haul Time = 45 s
Haul Speed = 0.25 m/s

Date	# Mussel larvae/L original seawater** Station 1							# Mussel larvae/L original seawater Station 2						
	SS1*	SS2	SS3	Avg. # Mussel larvae/L	S.D.	S.E.	Avg. Size (µm)	SS1	SS2	SS3	Avg. # Mussel larvae/L	S.D.	S.E.	Avg. Size (µm)
7:50	0.71	1.41	0	0.71	0.71	0.41	175	1.41	0.71	1.41	1.18	0.41	0.24	189
9:30	1.41	0.71	1.41	1.18	0.41	0.24	215	10.61	3.54	7.78	7.31	3.56	2.06	272
11:0(	3.54	0.71	2.83	2.36	1.47	0.85	237	0	0.71	0.71	0.47	0.41	0.24	325
12:2(	31.12	12.73	26.88	23.58	9.63	5.56	250	5.66	7.78	1.41	4.95	3.24	1.87	249
14:0(	1.41	0.71	0.71	0.94	0.41	0.24	200	4.95	3.54	3.54	4.01	0.82	0.47	282
15:3(	12.03	7.78	10.61	10.14	2.16	1.25	263	5.66	1.41	2.12	3.07	2.27	1.31	203
17:0(	5.66	4.95	6.37	5.66	0.71	0.41	228	2.12	1.41	3.54	2.36	1.08	0.62	255
18:3(	9.20	8.49	5.66	7.78	1.87	1.08	251	6.37	3.54	4.24	4.72	1.47	0.85	176

Total sample times = 8
*SS = Subsample
**Calculation for # of larvae per L original seawater: Volume filtered $= \pi(0.15)^2$ (10 m) = 0.70685 m^3 x 1000 = 706.85 litres. Then, (# larvae/mL x 500 mL) / 706.85 L = # larvae/L original seawater.