

## **Chapter 4. Plankton (David Borkman & Jefferson Turner)**

### **Introduction**

The high fecundity of marine fish and the lack of correlation between size of spawning stock and resultant year-class strength imply a high rate of mortality for each year class of fish (Hjort 1926). Most such mortality occurs during the pelagic larval stage, particularly after yolk absorption, when young fish have to begin feeding on their own. This prompted Hjort (1914) to propose that there is a “critical period” in the survival of first-feeding fish larvae, and that most mortality was due to starvation and transport to unfavorable areas (“larval drift”).

Additional mortality of fish larvae comes from predation by larger fish (Hunter 1981) and invertebrates (Turner et al. 1985). Thus, factors affecting survival of fish larvae are intimately related to fish population dynamics, including stock and recruitment, year-class strength, and population declines (May 1974). Hjort (1914) proposed starvation as the primary cause of larval fish mortality.

Subsequent studies have confirmed the importance of sufficient amounts and types of food to larval fish survival (Lasker 1975, 1981), expanding fishery science to include “fisheries oceanography,” which recognizes that fish, particularly larvae, are subject to biological and oceanographic variations in the food webs that support them.

A review of the feeding habits of 76 species of fish identified from 40 published studies (Turner 1984) revealed that most fish larvae feed on plankton until they are large enough to begin feeding on smaller fish. Thus, attempts to understand the abundance fluctuations of any species of fish in any ecosystem

must include knowledge about the plankton that support the larvae of the fish species of interest. Gut content studies reveal that larvae of the winter flounder (*Pseudopleuronectes americanus*) in New England estuaries feed primarily on small plankton such as nauplius larvae of copepods and ciliate protozoans known as tintinnids (Pearcy 1962), phytoplankton and calanoid copepods (Keller and Klein-MacPhee 2000, Shaheen et al. 2001). Because winter flounder larvae are demersal, living close to the bottom, they also feed upon harpacticoid copepods, which generally inhabit the waters in, or just above the sediments (Pearcy 1962). Young-of-the-year or older juveniles of winter flounder feed upon harpacticoid and calanoid copepods, gastropod larvae, amphipods and polychaetes (Franz and Tanacredi 1992, Stehlik and Meise 2000, Duffy-Anderson and Able 2001, Meng et al. 2001). Because winter flounder larvae feed primarily upon zooplankton and zooplankton feed primarily on phytoplankton, understanding winter flounder requires knowledge of the plankton ecology of their habitat. Thus, a review of Mt. Hope Bay and Narragansett Bay plankton ecology will be presented below.

### **Phytoplankton**

A summary of Narragansett Bay plankton studies may serve as useful background for comparison with Mt. Hope Bay plankton studies. Narragansett Bay is a phytoplankton-based estuary in that the photosynthetic base of the food web is microalgal rather than macrophytic. Phytoplankton in lower Narragansett Bay has been studied intensively for over three decades (Smayda 1957, 1973, 1983, 1984, 1998, Pratt 1959, 1965, 1966, Martin 1965, 1970, Durbin et al. 1975,

Hitchcock and Smayda 1983, Karentz and Smayda 1984, 1998, and references therein). The distinctive phytoplankton feature of the bay is a winter-spring diatom bloom initiating in December-February, and persisting through April. This is in contrast to the typical ephemeral spring bloom observed in other coastal waters. Smayda (1957) attributed the winter-spring bloom in Narragansett Bay to the shallow holomictic water column, which retains phytoplankton in the euphotic zone. Initiation of this bloom in some years in December-January during the annual zooplankton minimum has led to the conclusion that the bloom is prompted by release of copepod grazing pressure (Pratt 1959, Martin 1970). However, Deason (1980) concluded that the effect of grazing on bloom initiation is usually minimal. In other years, bloom initiation appears primarily in response to increasing light after the December-January minimum (Hitchcock and Smayda 1983). The varying explanations for Narragansett Bay winter-spring bloom initiation reflect the multi-factorial and annually variable nature of Narragansett Bay plankton dynamics (Smayda 1998).

Annual variations in the magnitude of the winter-spring bloom have been related to nutrients available prior to bloom initiation, and collapse of the bloom in late spring often co-occurs with reductions in nutrient levels. Inorganic nitrogen appears to be of primary importance, although trace metals may be important for some phytoplankton species (Smayda 1973). There is often a smaller late summer-early fall phytoplankton bloom in some years.

The phytoplankton assemblage may comprise a total of hundreds of species but is typically dominated by only a few at any given time (Karentz and

Smayda 1984). The diatom *Skeletonema costatum* is present and often abundant year-round, and is an important component of both winter-spring and summer-fall blooms. Other winter-spring bloom species include the diatoms *Detonula confervacea* and *Thalassiosira nordenskioldii*, and summer-fall bloom taxa include the diatoms *Leptocylindrus danicus* and *Rhizosolenia fragilissima* (now *Dactyliosolen fragilissima*) and the microflagellate *Olisthodiscus luteus* (= *Heterosigma akashiwo*). Other erratically abundant taxa include the diatoms *Asterionella glacialis* (= *A. japonica*, now *Asterionellopsis glacialis*), *Thalassionema nitzschoides*, various species of the genus *Chaetoceros*, and various dinoflagellates such as *Katodinium rotundatum* (now *Heterocapsa rotundata*) and *Prorocentrum redfieldii* (Karentz and Smayda 1984).

The succession of various species is complicated, and highly variable from year to year (Karentz and Smayda 1984). Seasonal occurrence of many species over a 22-year period of weekly samples appeared strongly related to temperature and light intensity, but for other species these relationships were complex and/or obscure.

Due to essentially weekly sampling since 1959 by Smayda and the URI Graduate School of Oceanography, the phytoplankton of Narragansett Bay is almost certainly better known than for any other coastal waters of the world, but there can still be surprises. In summer of 1985 there was a huge, unprecedented bloom in Narragansett Bay and Long Island, New York and New Jersey coastal waters of a previously undescribed picoplankter *Aureococcus anorexefferens* (Sieburth et al. 1988, Cosper et al. 1989, Smayda and Fofonoff 1989, Smayda and

Villareal 1989a, 1989b, and references therein). This organism formed what has become known as the "brown tide," and it had deleterious effects on zooplankton, mussels, scallops, benthic larval abundance, anchovy fecundity, and kelp beds. Despite the fact that phytoplankton had been studied in Narragansett Bay for decades, *Aureococcus* had never been seen there before. The causes of this bloom are subject to debate, but its unprecedented occurrence is apparently not. The implication is that even in intensively sampled coastal waters where it might be thought that the envelope of variability for phytoplankton events is long established, unprecedented and unpredictable blooms are always a possibility.

### **Mt. Hope Bay Phytoplankton**

Mt. Hope Bay phytoplankton abundance has been assessed as part of BPPS's monitoring program since 1972. Sampling at a minimum of three stations (near BPPS intake, mouth of Lee River and south of Spar Island) was carried out at least once monthly (but at up to a weekly frequency) from February of 1972 to December 1985. Samples were collected at surface and near-bottom depths (or, from 1972 to 1980, at 100%, 50%, 25%, 10% and 1% light level depths) for phytoplankton species identification and enumeration as well as for chlorophyll and nutrient concentration determinations. The results of the February 1972 to February 1979 phytoplankton monitoring effort (along with the results of zooplankton and nutrient studies) have been summarized by Toner (1981). Following 1985, phytoplankton abundance (and the proxy measure of chlorophyll concentration), zooplankton abundance, and dissolved inorganic nutrient

concentration were not routinely monitored. A one-year resumption of the monitoring effort occurred from March 1997 to February 1998. This one-year period of sampling was undertaken to “determine if any gross changes in [plankton] population, chlorophyll-a, nutrients or productivity have occurred since the earlier [pre-1985] studies” (MRI 1999).

Toner (1981) presented results of plankton sampling at two stations in Mt. Hope Bay (near Brayton Point intake and south of Spar Island) where phytoplankton and zooplankton were sampled monthly from 1972-1979. Phytoplankton were preserved in 0.5% gluteraldehyde. Zooplankton were collected via pump sampling ca. 250 L through approximately 50- and 64-mm-mesh nets. In addition, nutrients and hydrographic and meteorological parameters were sampled. Toner found that the phytoplankton consisted of some 230 taxa, primarily dominated by diatoms. Warm-water ( $>18^{\circ}\text{C}$ ) taxa included the diatoms *Rhizosolenia delicatula* and *R. setigera*, and the flagellates *Calycomonas ovalis* and *Olisthodiscus luteus*. Cold-water taxa ( $<10^{\circ}\text{C}$ ) included the diatoms *Skeletonema costatum*, *Thalassionema nitzschooides*, *Thalassiosira nordenskioldii*, *Asterionella formosa*, *Coethron criophilum*, *Detonula confervacea*, and the dinoflagellates *Heterocapsa triquetra* and *Peridinium trochoideum*. Increased winds appeared correlated with increases of phytoplankton abundance, presumably by resuspension of benthic nutrients into the shallow water column. Nutrient levels were significantly inversely correlated with phytoplankton abundance, presumably due to utilization. The zooplankton was dominated by copepods and copepod nauplii, with dominance by *Acartia clausi* (= *A.*

*hudsonica*) in winter and spring, and *A. tonsa* in summer and fall. Gastropod veligers were also abundant from May through November.

A total of 73 phytoplankton species or other taxonomic categories were identified in a more recent (1997–1998) survey of Mt. Hope Bay phytoplankton conducted by MRI (1999). The identified phytoplankton (see Table 4.1) are typical of north temperate estuarine phytoplankton assemblages, with an increased epiphyton component (i.e., epiphytic and ptychopelagic pennate diatoms), as expected in a shallow estuary like Mt. Hope Bay. The diversity of Mt. Hope Bay phytoplankton as identified by the MRI (1999) surveys is lower than that of the west passage of lower Narragansett Bay, where ca. 300 species of phytoplankton have been identified (Hargraves 1988). This difference likely reflects the different lengths of the study periods and different levels of taxonomic expertise applied in the two studies rather than an actual difference in phytoplankton diversity in the two regions. Earlier work (1972 to 1979) in Mt. Hope Bay identified 230 species and categories of phytoplankton (Toner 1981), which is similar to the phytoplankton species diversity of lower Narragansett Bay as listed by Hargraves (1988), suggesting that either 1997–1998 was a year of lowered Mt. Hope Bay phytoplankton diversity or there was a lesser degree of taxonomic refinement applied to the 1997–1998 MRI phytoplankton analyses.

The Mt. Hope Bay phytoplankton community is diatom-dominated (Toner 1981, MRI 1999) but has a greater proportion of euglenoids, chlorophytes and cryptophytes than has been observed in lower Narragansett Bay (Smayda 1957, Pratt 1959). As might be expected, the proportion of freshwater forms

(*Asterionella formosa*, *Tabellaria fenestrata*, etc.) in Mt. Hope Bay is greater than in lower Narragansett Bay. Dominant Mt. Hope Bay phytoplankton observed by MRI (1999) are listed in Table 4.1. The four stations (I – at the BPPS intake, C –

**Table 4.1. Mt. Hope Bay phytoplankton identified in MRI 1997-1998 surveys (MRI 1999). Note Toner (1981) refers to 230 species or categories of phytoplankton in Mt. Hope Bay in 1972-1979.**

**Bacillariophyceae-planktonic**

*Asterionella formosa*  
*Biddulphia* spp.  
*Chaetoceros* spp.  
*Coscinodiscus* spp.  
*Cyclotella glomerata*  
*Cyclotella meneghiniana*  
*Cyclotella* spp.  
*Ditylum brightwellii*  
*Eucampia zodiacus*  
*Hemiaulus sinensis*  
*Leptocylindrus danicus*  
*Rhizosolenia* spp.  
*Skeletonema costatum*  
*Thalassiosira* spp.  
 Unidentified diatom

**Chlorophyceae**

*Pyramimonas* spp.  
*Tetraselmis* spp.

**Dinophyceae**

*Amphidinium* spp.  
*Ceratium* spp.  
*Dinophysis lachmanni*  
*Dinophysis* spp.  
*Glenodinium lenticula*  
*Gymnodinium nelsoni*  
*Gymnodinium* spp.

**Bacillariophyceae (epiphytic, marine)**

*Acnantes* spp.  
*Amphiprora* spp.  
*Amphora* spp.  
*Cylindrotheca closterium*  
*Cylindrotheca* spp.  
*Diploneis* spp.  
*Licmophora* spp.

**Bacillariophyceae (epiphytic, brackish)**

*Brebessonia boeckii*  
*Cocconeis* spp.  
*Melosira* spp.  
*Navicula* spp.  
*Nitzschia* spp.  
*Pleurosigma* spp.  
*Surirella* spp.

**Bacillariophyceae (epiphytic, fresh water)**

*Cymbella* spp.  
*Diatoma* spp.  
*Eunotia* spp.  
*Fragillaria* spp.  
*Gomphonema* spp.  
*Meridion circulare*  
*Synedra* spp.  
*Tabellaria fenestrata*  
*Tabellaria* spp.

Gyrodinium spp.  
Heterocapsa triquetra  
Katodinium spp.  
Peridinium spp.  
Polykrikos kofoidi  
Prorocentrum micans  
Prorocentrum spp.  
Unid. naked dinophyceae

**Desmidaceae**

Crucigenia quadrata  
Scenedesmus spp.

**Chrysophyceae**

Dinobryon sertularia  
Dinobryon spp.  
Pseudopedinella pyriforme  
Unid. flagellate

**Cryptophyceae**

Chilomonas spp.  
Chroomonas spp.  
Chroomonas/Hemiselmis sp.  
Cryptomonas pseudobaltica  
Cryptomonas spp.  
Cryptomonas testacea

**Euglenophyceae**

Euglena spp.  
Eutreptia viridis

**Cyanophyceae**

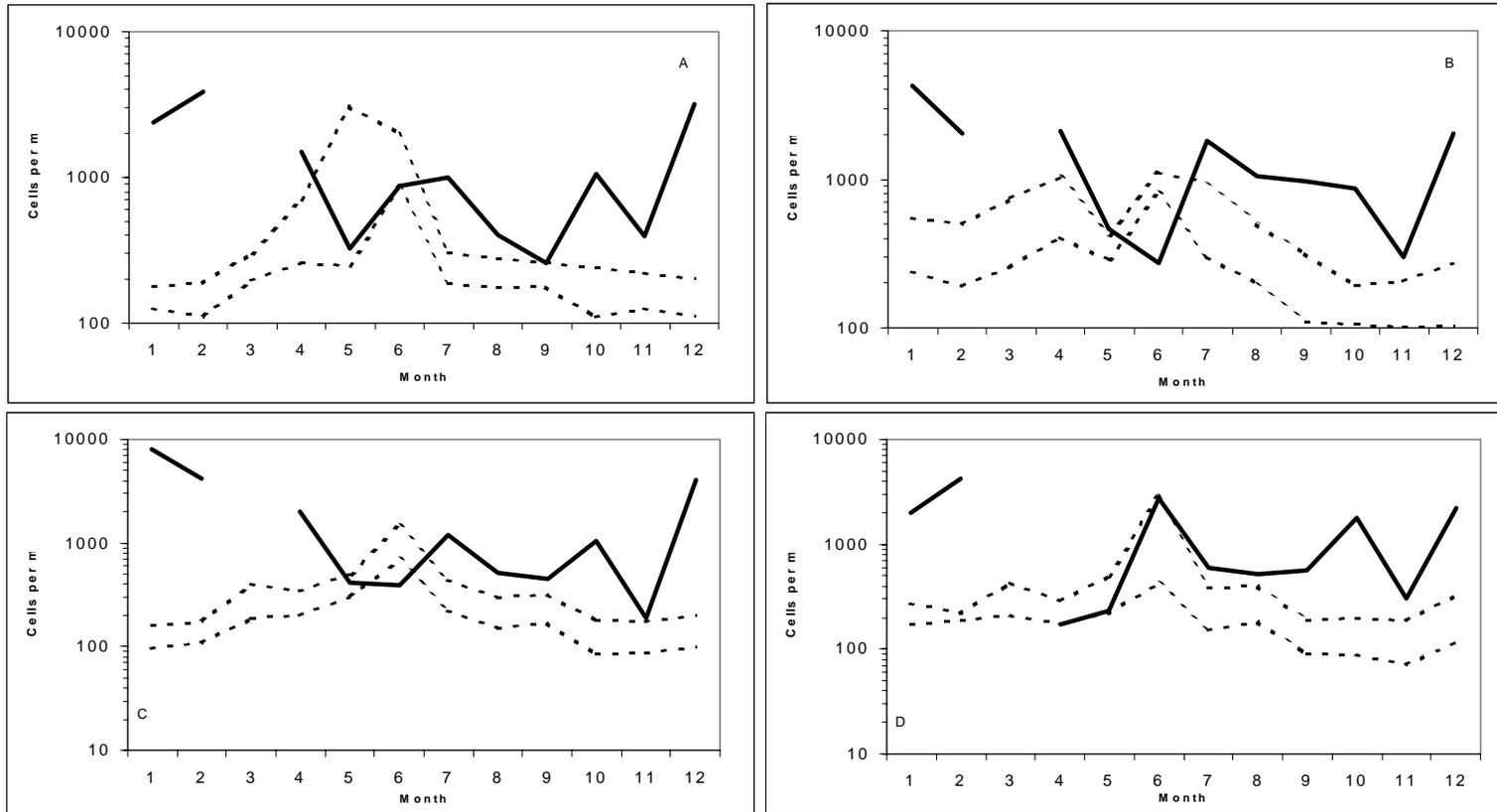
Anacystis spp.  
Oscillatoria spp.  
Spirulina spp.

**Other Categories**

Closterium spp.  
Pediastrum spp.  
Unknown pigmented cell

mouth of Lee River, F – south of Spar Island, A' – south of Brayton Point) surveyed by MRI in 1997–1998 were similar in phytoplankton abundance and community composition. No significant difference in total phytoplankton abundance (as tested by fixed-effects ANOVA of log transformed data;  $p < 0.05$ ) was found among the four stations, indicating no gross differences in the spatial distribution of Mt. Hope Bay phytoplankton.

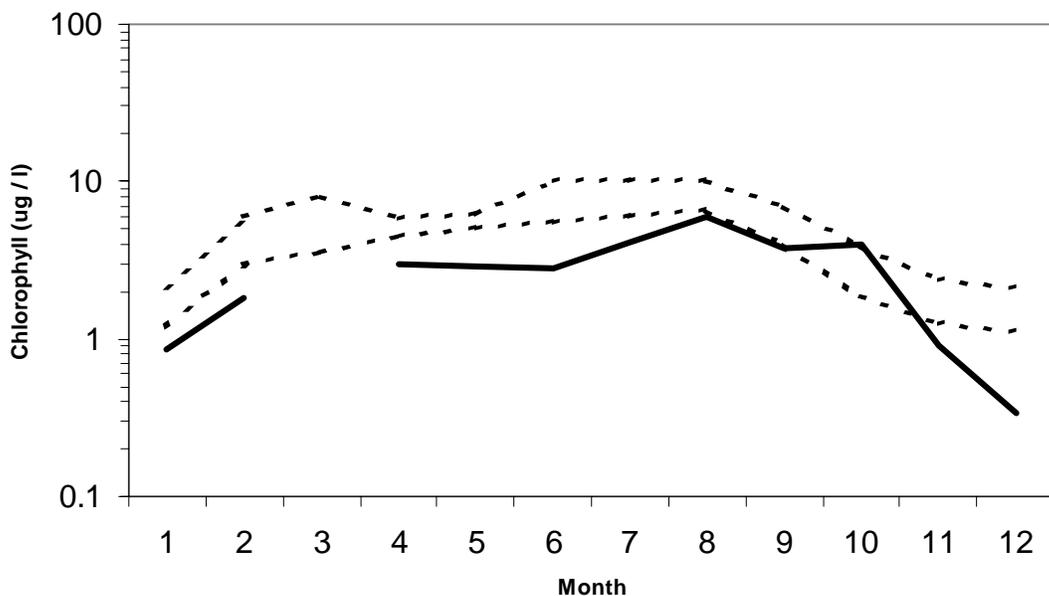
Total phytoplankton abundance (as cells  $\text{ml}^{-1}$ ) appears to have shown no change between 1972-1985 and 1997-98. However, long-term changes in Mt. Hope Bay community composition still may have occurred, but the 1986 to 1996 gap in available phytoplankton data complicates analysis. Preliminary analyses indicate that Mt. Hope Bay dinoflagellate abundance may be on the increase (see MRI 1999). Comparison of 1972-1985 versus 1997-1998 dinoflagellate annual abundance patterns shows elevated dinoflagellate abundance, relative to the 1972-1985 pattern, that lasted from mid-summer (July) through the winter months and into spring (April) (Figure 4.1). Much of the 1997-98 elevated dinoflagellate abundance appears to be due to a bloom of the potentially inimical dinoflagellate *Prorocentrum* spp. that reached ca. 7,400 cells  $\text{ml}^{-1}$  at station F (south of Spar Island) in January 1998 (MRI 1999). This *Prorocentrum* bloom was ca. 37-fold greater than the 1972 to 1985 January total dinoflagellate abundance of near 150 to 250 cells  $\text{ml}^{-1}$ . The dinoflagellate *Prorocentrum minimum*, common in Narragansett Bay and presumably in Mt. Hope Bay, has been found to form blooms in response to high nitrogen loading in Japanese and southeastern U.S.



**Figure 4.1. 1997-1998 dinoflagellate abundance (heavy line) compared to 1972-1985 mean  $\pm$  1 standard error dinoflagellate abundance (dashed line) at four Mt. Hope Bay monitoring stations. Panel A shows pattern at Mt. Hope Bay station 'I', panel B shows station 'C', panel C shows station 'F' and panel D shows station 'A' 1997-1998 and 1972-1985 mean dinoflagellate abundance annual cycles. (From data in MRI 1999.)**

coastal waters (Burkholder 1998). Given the potential food- web-altering consequences of dinoflagellates (Turner and Tester 1997, Turner et al. 1998), discerning whether elevated dinoflagellate abundance, especially *Prorocentrum* abundance, is a regularly recurring feature of recent (post-1985) Mt. Hope Bay phytoplankton successional cycles, or was an anomalous feature of the 1997-1998 phytoplankton cycle, may be an important task of future Mt. Hope Bay research.

Chlorophyll concentration in 1997-1998 appears to be decreased relative to that seen in 1972-1983 (Figure 4.2, MRI 1999). This late-1990's decline in Mt. Hope Bay chlorophyll concentration is consistent with declines in lower

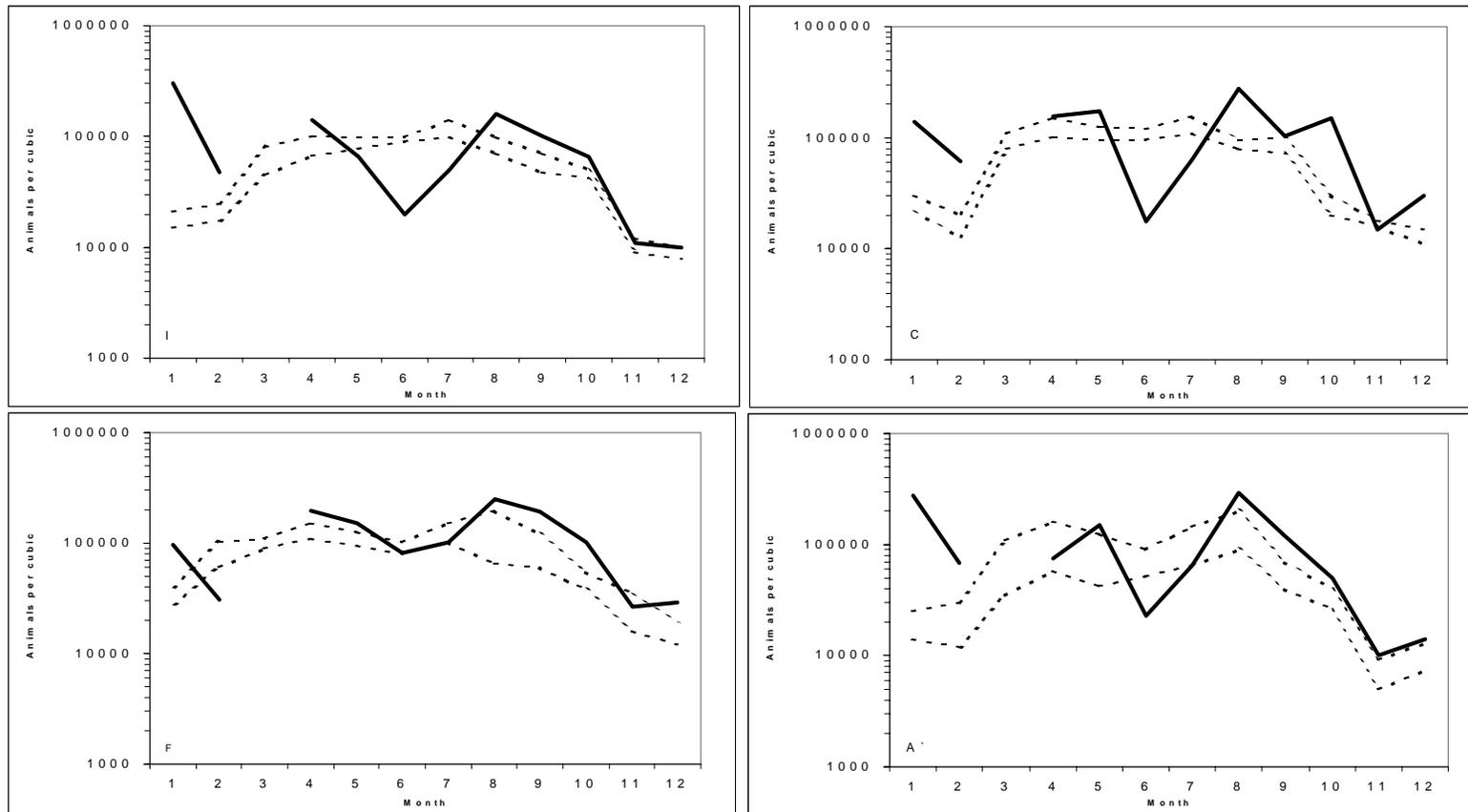


**Figure 4.2. Monthly change in Mt. Hope Bay chlorophyll concentration compared between 1972-1985 (dashed line is mean  $\pm$ 1 SE) and the 1997-1998 sample year (solid line). (Adapted from Figure P-23, MRI 1999.)**

Narragansett Bay chlorophyll concentration (Li and Smayda 1998). A main feature of the recent decline in lower Narragansett Bay chlorophyll has been a decrease in the size and relative contribution of the winter-spring bloom to the annual chlorophyll cycle (Keller et al. 1999). Mt. Hope Bay chlorophyll in 1997-

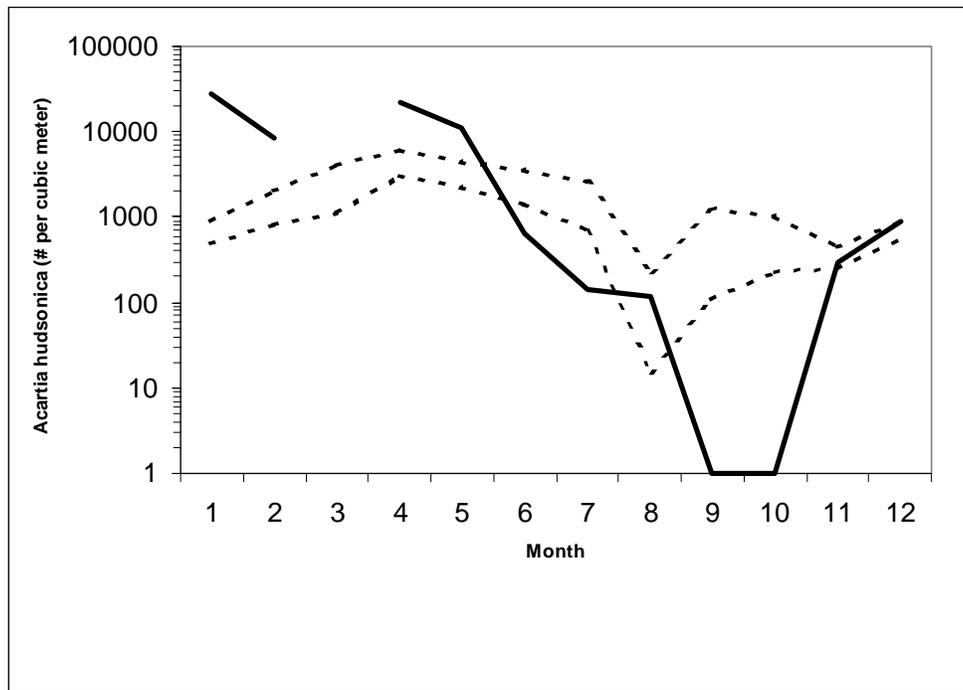
98 showed declines in the winter-spring as well as in the summer months relative to the pattern seen in 1972-1983. For example, the 4-station (stations I, C, F, A', all depths) mean chlorophyll concentration in February 1998 was ca. 2.4 ug l<sup>-1</sup> compared to a 1973 to 1983 mean February chlorophyll value of near 4 ug l<sup>-1</sup>; while December 1997 chlorophyll (4 station mean) was ca. 0.4 ug l<sup>-1</sup> compared to a 1972-83 mean December value of near 1.75 ug l<sup>-1</sup> (MRI 1999). Summer 1997 declines in chlorophyll, relative to the mean 1972 to 1983 levels, were of similar magnitude, with a June 1997 mean (4 stations, all depths) chlorophyll level of near 4 ug l<sup>-1</sup> compared to a 1972 to 1983 mean June level of near 7 ug l<sup>-1</sup> (MRI 1999; see their Figure P-23). As with phytoplankton abundance and community composition, identification of any trends in Mt. Hope Bay chlorophyll concentration, and identification of mechanisms causing such trends remain unknown.

In lower Narragansett Bay recent increases in winter zooplankton abundance and feeding activity, partially in response to warming winter water temperature, have been linked to declines in winter-spring chlorophyll concentration (Keller et al. 1999). It is worth noting that early winter 1997-1998 Mt. Hope Bay zooplankton abundance was elevated relative to the 1972-1985 mean winter levels (Figure 4.3, MRI 1999). For example, January 1998 total zooplankton abundance at station I (BPPS Intake) was near 300,000 animals m<sup>-3</sup> compared to a 1972-985 mean January level of near 20,000 animals m<sup>-3</sup> (Figure 4.3). Most of this increase appears to be due to elevated abundance of *Acartia*



**Figure 4.3. 1997-1998 zooplankton abundance (heavy line) compared to 1972-1985 mean  $\pm 1$  standard error zooplankton abundance (dashed line) at four Mt. Hope Bay monitoring stations. Panel A shows pattern at Mt. Hope Bay station 'I', panel B shows station 'C', panel C shows station 'F' and panel D shows station 'A' 1997-1998 and 1972-1985 mean zooplankton abundance annual cycles. (Adapted from data in MRI 1999.)**

*hudsonica*, the dominant winter copepod in Mt. Hope Bay, which had a January 1998 abundance of 25,830 animals m<sup>-3</sup> at Station I compared to a 1972 to 1985 mean abundance of ca. 700 animals m<sup>-3</sup> at Station I (Figure 4.4, MRI 1999). The Mt. Hope Bay observation of 1997-98 increased winter-spring zooplankton abundance and concomitant declines in winter-spring chlorophyll concentration are consistent with observations, and inferred mechanisms, of Keller et al. (1999) in lower Narragansett Bay. A secondary effect of increased winter-spring zooplankton abundance and grazing pressure may be selection, via differential grazing, of dinoflagellates (such as *Prorocentrum* spp. as seen in Mt. Hope Bay in January 1998) rather than the typical winter diatom-dominated flora.



**Figure 4.4. Seasonal pattern of *Acartia hudsonica* abundance in Mt. Hope Bay compared between the 1972-1985 (dashed line is mean  $\pm$ 1 S.E.) and the 1997-1998 sampling year (solid line). (Adapted from Figure Z-25 in MRI 1999.)**

## Zooplankton

The well-studied zooplankton of lower Narragansett Bay provide a basis for the limited number of Mt. Hope Bay zooplankton studies. The metazoan zooplankton of Narragansett Bay are dominated by seasonally alternating, congeneric species of copepods (Jeffries 1962, 1967). *Acartia hudsonica* is abundant from late fall to early summer, and *Acartia tonsa* is dominant in summer and fall (Frolander 1955, Martin 1965, Hulsizer 1976, Durbin and Durbin 1981, 1989). The seasonality of occurrence or absence in the plankton is due to alternating periods of population diapause by resting fertilized eggs of these copepods (Zillioux and Gonzalez 1972, Sullivan and McManus 1986). Other important metazoan zooplankters include pulses of various meroplanktonic larvae of benthic invertebrates, and the ctenophore *Mnemiopsis leidyi*. This ctenophore can become extremely abundant and ecologically important in Narragansett Bay in summer and fall (Kremer 1975a, 1975b, 1976a, 1976b, 1977, 1979, Kremer and Nixon 1976, Deason 1982, Deason and Smayda 1982). *Mnemiopsis* bloom abundance and bloom duration may be increasing in Narragansett Bay in response to warming winter water temperatures (Sullivan et al. 2001).

The potential population production rates of the *Acartia* congeners have been investigated by Ann and Ted Durbin, and their collaborators, using a combination of field and laboratory studies (Durbin and Durbin 1978, 1981, 1989, 1992a, 1992b, Durbin et al. 1983, 1992). Potential production rates were highly temperature-dependent. Even though the summer population of *A. tonsa* had a smaller biomass than that of *A. hudsonica* in winter, temperature effects on

reproductive rates allowed the summer *A. tonsa* population to potentially double in less than a day, whereas this could require over nine days for *A. hudsonica* in winter. From studies to estimate if copepods were growing at maximal rates in the bay, the Durbins found that *Acartia tonsa* fecundity and body weight closely tracked variations in natural phytoplankton food supply, and that fecundity and body weight could always be increased by offering surplus food. This indicated that *A. tonsa* production in the bay was continuously food-limited in summer (Durbin et al. 1983).

This food limitation of maximum growth and production rates appeared due to quality rather than quantity of food. Small-sized cells that may have been inefficiently captured and/or nutritionally inadequate dominated the natural phytoplankton in summer. During the winter-spring period, the Durbins found different results for *Acartia hudsonica* (Durbin et al. 1992, Durbin and Durbin 1992a, 1992b). Egg production rates were correlated with temperature, but not with concentration of natural phytoplankton. When additional cultured phytoplankton was offered as food, egg production rates did not increase. This suggests that food was sufficient in quality and quantity to allow actual copepod production rates to approach maximal potential rates. Mild food limitation of *Acartia hudsonica* developed in May-June, but this was more in terms of body weight than egg production. This was partly due to changing age groups during this period, as autumn-hatched (senescent) over-wintering adults were being replaced by newly hatched, winter-spring-hatched adults.

Higher-trophic-level predators such as ctenophores may impact relations between phytoplankton and zooplankton. Deason and Smayda (1982) investigated ctenophore-zooplankton-phytoplankton interactions during six summer-fall seasons (1972-77) in lower Narragansett Bay. In 4 of these years, summer increases in the ctenophore *Mnemiopsis leidyi* accompanied rapid declines in copepods and other zooplankton, and increases in phytoplankton. The summer phytoplankton blooms were typically dominated by *Skeletonema costatum*, the abundance of which was correlated with that of ctenophores. Termination of such blooms coincided with declining ctenophores and increasing copepods in two years. Thus, it appears that summer phytoplankton dynamics are typically affected by, and possibly regulated by ctenophore predation on the copepods that are major grazers of the phytoplankton.

There have been several major studies of tintinnids (thecate ciliate protozoans) in Narragansett Bay (Hargraves 1981, Verity 1984, 1985, 1986a, 1986b, 1987). These are important since tintinnids and other microzooplanktonic protists have long been suspected to be major grazers of the smaller nanoplankton (see Pierce and Turner 1992 for a review). Hargraves (1981) described seasonal patterns of tintinnid abundance and occurrence from weekly samples in Narragansett Bay from March through November, 1976. There were bimodal peaks in abundance, with a maximum in late May-early June, a precipitous decline in late June, a lesser peak in late summer, and a gradual decline in October. There were 33 tintinnid species recorded from 8 genera, with the genus *Tintinnopsis* accounting for 21 species and 90% of total abundance. Tintinnid

abundance was not obviously correlated with salinity, temperature, or nanoplankton chlorophyll abundance.

Verity (1986a) used tintinnid cultures established from Narragansett Bay to determine that clearance, ingestion, respiration, excretion and growth rates for two species of *Tintinnopsis* increased with increasing temperature. Applying these laboratory-determined values to field estimates of tintinnid and phytoplankton abundance and production, Verity determined that the tintinnid population ingested a carbon equivalent of 16-26% of total annual net phytoplankton primary production, and 32-52% of <10 mm nanoplankton production. Tintinnid nitrogen excretion was sufficient to support 11-18% of net primary production.

Verity (1986a) compared photosynthetic nanoplankton growth rates and total microzooplankton (10-202 mm) grazing rates using in situ incubations over the annual cycle in Narragansett Bay. He found that nanoplankton growth rates were linearly related to temperature, and microzooplankton grazing rates were linearly related to nanoplankton production. Verity estimated that the total microzooplankton assemblage grazed an annual mean of 62% of nanoplankton production. In the same incubations, Verity (1986b) found that maximum tintinnid species growth rates were regulated by temperature, but that net tintinnid community growth rates were influenced primarily by food quality and availability. Tintinnid growth rates were suppressed by blooms of small solitary centric diatoms and the toxic flagellate *Olisthodiscus luteus*. Excluding these blooms, tintinnid growth rates increased asymptotically with nanoplankton

biomass and production rates. Tintinnid species exhibited maximum growth rates that exceeded 1-2 doublings  $d^{-1}$ . thus, high abundance (up to  $10^5$  cells  $l^{-1}$  - Verity 1987) and rapid growth of tintinnids suggests that they are important grazers of nanoplankton in Narragansett Bay, and presumably Mt. Hope Bay as well.

### **Mt. Hope Bay Zooplankton**

Mt. Hope Bay zooplankton have been sampled by MRI personnel at monthly or greater intervals, at three stations in Mt. Hope Bay (stn. F – south of Spar Island, stn. C – mouth of Lee River, stn. I – BPPS intake) from 1972 to 1985, and from April 1997 to February 1998. The results of the 1972 to 1979 portion of this monitoring were summarized by Toner (1981), who found that Mt. Hope Bay zooplankton were dominated by copepods and copepod nauplii, with dominance by *Acartia clausi* (= *A. hudsonica*) in winter and spring, and *A. tonsa* in summer and fall. Gastropod veligers were also abundant from May through November, reaching 10,000  $m^{-3}$  in August - September. Dominant Mt. Hope Bay zooplankton observed in 1997-98 sampling (MRI 1999) are listed in Table 4.2. Total zooplankton density fluctuated, on average, from a minimum of near 3,000 to 5,000 animals  $m^{-3}$  in winter to peaks near 100,000 animals  $m^{-3}$  in late spring or summer. Fluctuations in zooplankton abundance were closely linked, with a significant positive correlation, leading Toner (1981) to suggest that zooplankton in Mt. Hope Bay are food-limited and under ‘bottom-up’ control. Similar conclusions have been drawn for lower Narragansett Bay zooplankton (Durbin et al. 1983).



Comparison of 1972 to 1985 zooplankton patterns to those of April 1997 through February 98 suggest that in 1997-1998, Mt. Hope Bay zooplankton abundance was increased relative to the long-term (1972-1985) pattern (MRI 1999). Marine Research, Inc.'s 1999 study revealed that 1997/98 *Acartia hudsonica* abundance exceeded the 1972-1985 mean abundance levels in April, May, December 1997 and in January and February of 1998. The elevated winter 1997/1998 *A. hudsonica* abundance was reflected in the December 1997 through February 1998 total zooplankton abundance, which were higher than the corresponding 1972-1985 mean values. Comparison of 1997/98 total zooplankton abundance to that of 1981 to 1985 showed that 1997-98 total zooplankton abundance was greater than that of 1981 through 1983, but not significantly different from that of 1984 and 1985 (MRI 1999). In contrast to the apparent increase in copepod abundance, 1997/98 abundance of polychaetes, nauplii and gastropods displayed no change relative to the 1972 to 1985 period. As mentioned in the phytoplankton section, recent (1997/98) increases in winter zooplankton abundance are consistent with observations made by Keller et al. (1999) in lower Narragansett Bay.

### **Ichthyoplankton**

There have been three major studies of ichthyoplankton in Narragansett and Mt. Hope Bays prior to 1989-90, as summarized by Durbin and Durbin (1990). In 1957-58 Herman collected fish eggs and larvae at 4 stations in the East Passage and West Passage of lower Narragansett Bay, the northern entrance to the

Sakonnet River and in lower Mt. Hope Bay. These data were presented in a Master's thesis from the University of Rhode Island (Herman 1958) and later published (Herman 1963).

From 1972-73 there was an extensive survey of ichthyoplankton at 160 stations throughout Narragansett and Mt. Hope Bays, performed by Marine Research, Inc. of Falmouth, Massachusetts. These data were presented by MRI (1974) and later published by Bourne and Govoni (1988). Additional ichthyoplankton monitoring by Marine Research, Inc. has continued in Mt. Hope Bay since 1972. These data were presented in quarterly progress reports to Narragansett Electric Power Company, and were summarized by Durbin and Durbin (1990). The following summary is abstracted from Durbin and Durbin (1990).

The 1972-73 survey reported 42 species of fish eggs and/or larvae with maximum abundance in June-July and minimum abundance in September-January. The more abundant species were, in order, anchovies, menhaden, winter flounder, tautog, cunner, sand lance, weakfish, windowpane, silversides, mackerel, seaboard goby, and fourbeard rockling. Sand lance and winter flounder were winter-spring spawners with peak larval abundance in April. Fourbeard rockling and mackerel were spring-early summer spawners with peak larval abundance in May-June. Late spring-early summer spawners included bay anchovy, tautog, cunner, silversides, weakfish, windowpane, and seaboard goby. Atlantic menhaden had an extended spawning period with greatest larval numbers in spring and fall. There were three main groups of species in terms of

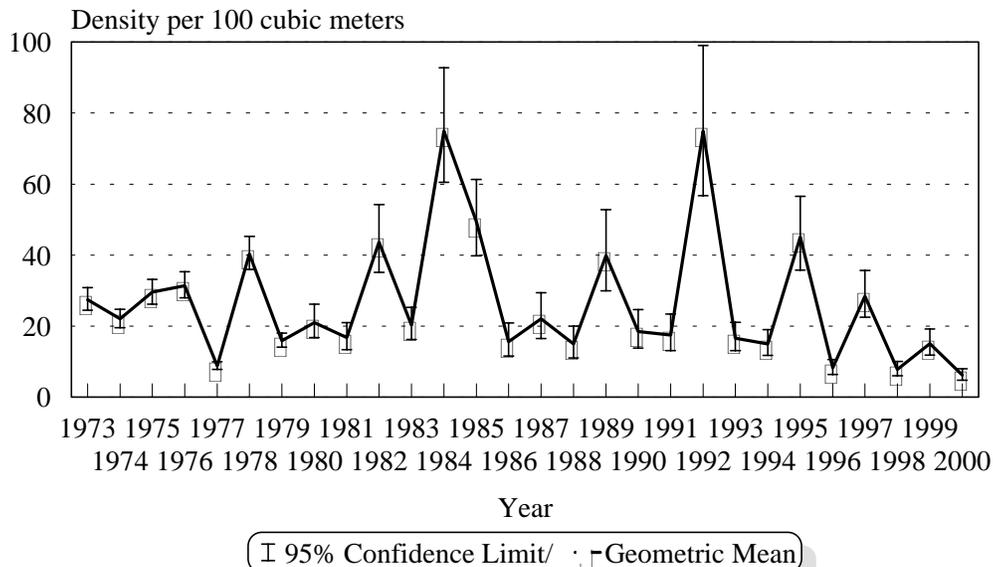
geographic areas of abundance. Of the 12 most abundant species, 8 (menhaden, anchovy, winter flounder, tautog, weakfish, windowpane, silversides, seaboard goby) were most abundant in upper Narragansett/Mt. Hope Bays. Sand lance, rockling and mackerel were most abundant in the lower East Passage, and cunner was abundant in both the upper and lower bay. Thus, the upper and most anthropogenically impacted regions of Narragansett and Mt. Hope Bays were also the major spawning and nursery areas for fish.

Herman (1958, 1963) recorded 34 taxa from his 1957-58 study, all of which were later found by the 1972-73 Marine Research, Inc. study, but the ranking of abundant species was different for the two studies. Herman found that the 12 most abundant species were (in order) sculpin, silversides, cunner, anchovy, scup, sand lance, searobin, butterfish, winter flounder, tautog, northern pipefish, and radiated shanny. Of these, only half were among the most abundant species in the Marine Research study. This was mainly due to relative abundances of 5 species (winter flounder, silversides, goby, sand lance, and sculpin) that hatch from demersal eggs. These discrepancies may be due to differences in sampling gear. Herman's nets for larval collections had a coarse mesh (>1 mm) and a bridle in front that might have contributed to larval avoidance, whereas Marine Research used 505 mm-mesh bongo nets (which do not have a bridle in front). However, Herman also used a Clarke-Bumpus sampler with 366-mm mesh to collect eggs, particularly near-bottom. This may have explained Herman's disproportionate collections of larger and/or demersal-spawning taxa relative to Marine Research, which collected eggs and larvae of primarily pelagic-spawning species.

Continuation of collection by Marine Research from 1972-86 reveals that total numbers of larvae have fluctuated approximately 3-fold over this period. There may have also been major changes in the populations of certain species during this period. Since 1972 there has been a precipitous decline in abundance of larvae of Atlantic menhaden, with replacement by bay anchovy (*Anchoa mitchilli*) as the dominant species in Mt. Hope Bay. Sand lance have also fluctuated in abundance, increasing from low numbers in the early to mid-1970's with a peak in 1979, followed by low abundance in 1985-86. Winter flounder larvae also have varied by 5-6 fold, with apparent 4-5 year periodicity of cycles, but do not exhibit a statistically significant decline (Figure 4.5, Collie and Delong 2001). Thus, although the total abundance of fish larvae of all species may be somewhat stable, larval abundance of certain species is apparently not.

## Larval Winter Flounder

### Geometric Means and 95% Confidence Limits



**Figure 4.1. Abundance of larval winter flounder collected at the BPPS from 1973-2000. (Reprinted from USGen 2001).**

The most recent survey of ichthyoplankton in Narragansett Bay (Keller et al. 1999) was done in 1989-1990, partly to examine changes in the bay since the last bay wide survey of 1972-73. It used similar sampling protocols to the previous study. The taxonomic composition of eggs and larvae and patterns of seasonal occurrence in 1989-90 were similar to 1972-73. However, abundances of eggs and larvae were lower in 1990 than in 1972-73. Bay anchovy, tautog, and cunner accounted for 86% of the eggs and 87% of the larvae in 1990, compared to only 55% of the eggs and 51% of the larvae in 1972-73. Much of this difference was due to a precipitous decline in abundances of larval menhaden. Winter flounder larvae were significantly less abundant in 1990 than 1973, particularly in the upper bay in Greenwich Bay and the Providence River. Keller et al. (1999) concluded that there had been a general down-bay shift between the surveys in labrid, anchovy, fourbeard rockling and menhaden eggs, and in anchovy, tautog, cunner, winter flounder and menhaden larvae. This shift was thought to be due to degradation of the pelagic habitat in the upper bay, and the overall decline of ichthyoplankton in Narragansett Bay may have resulted from a combination of habitat loss, overfishing and pollution.

In addition to the adult fish data outlined above, ichthyoplankton abundance has been monitored in Mt. Hope Bay to assess the potential impact of BPPS operations on ichthyoplankton. Fish may be affected by Brayton Point operations in at least three ways: entrainment, impingement, and indirect effects (habitat loss, migration blockage,  $Q_{10}$  effects, etc.). Entrainment is the inadvertent capture and passage of fish eggs and larval fish through the plant cooling water

system while impingement is the trapping of fish on the screened water intake. Impingement effects are limited to fish larger than the intake screen mesh (need size?), and are not expected to affect ichthyoplankton. Entrainment and impingement are quantified as part of BPPS monitoring program, with field estimates of numbers of fish entrained and impinged being made by MRI personnel. Impingement was quantified three times per week from 1972 to 1996, and has been monitored daily from 1997 to the present. Entrainment has been estimated under various levels of effort from 1972 to 1985, and 1993 to 2001. MRI has estimated larval fish abundance in Mt. Hope Bay through monthly (or more frequent) surveys in the Bay from June 1972 to 1992. Since 1993, these larval fish surveys have been done only in February to mid-May (coincident with peak winter flounder larvae abundance). Abundance and species composition of larval fish entrained (drawn in with cooling water) by BPPS have been monitored by MRI personnel from June 1972 through the end of 1985, and from 1993 to the present (2001). Bourne and Govoni (1988) have reported on the abundance and distribution of larval fish in Narragansett and Mt. Hope Bays in 1972-1973. A comparison of 1989-90 Narragansett Bay larval fish abundance, distribution and seasonal abundance to the 1972-73 observations of Bourne and Govoni (1988) has been made by Keller et al. (1999).

## Summary

Extensive plankton work in Narragansett Bay provides sound basis for expected plankton processes in Mt. Hope Bay, but site-specific factors affecting

Mt. Hope Bay spatial and temporal plankton distribution need to be identified. MRI phytoplankton, zooplankton and ichthyoplankton data will allow Mt. Hope Bay plankton abundance patterns to be examined for 1972 to 1985. The unfortunate data gap from 1986 to 1996 will prevent more recent analyses. Resumption of phytoplankton and zooplankton sampling (for one year, 1997/1998) in the 1990's revealed several provocative results that may be indicative of recent changes in Mt. Hope. Namely:

1. Apparent increase (ca. 2-fold) in mean ammonia concentration in 1997/98 relative to 1972-85 mean levels.
2. Apparent increase in winter dinoflagellates (especially *Prorocentrum*) in 1997/98 compared to 1972 to 1985 mean pattern.
3. Apparent increase in 1997/98 winter zooplankton relative to 1972-85 mean pattern.
4. Apparent decline in fish egg and larval fish abundance in 1990 survey relative to 1972/73 survey.