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# REVIEW OF TAUTOG EGG ABUNDANCE STUDIES CONDUCTED FOR MILLSTONE NUCLEAR POWER STATION

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## Introduction

Tautog support one of the principal sport and commercial fisheries of Long Island Sound (LIS), but abundance of juveniles and adults has declined since the mid 1980s (Simpson et. al 1995). Because of this and similar declines along the east coast, likely from overfishing on this slow-growing and long-lived fish, an interstate management plan is currently under development by the Atlantic States Marine Fisheries Commission (ASMFC 1996) to provide for the conservation, restoration, and enhancement of the tautog resource.

Tautog range from New Brunswick to South Carolina, but are most common from Cape Cod to the Delaware Capes (Cooper 1965). Tautog are long-lived with maximum age reported of 34 years for males and 22 years for females (Chenoweth 1963; Cooper 1965). Adult tautog prefer rocky areas and similar reef-like habitats near shore from spring through fall and move to deeper (25-55 m) water during the winter (Cooper 1965; Olla et al. 1974). Adults return to near-shore waters in the spring prior to spawning and Cooper (1965) found that a high percentage return to the same spawning area annually. Tautog eggs can be differentiated from the other common wrasse in LIS, the cunner, which has a similar embryonic development (Kuntz and Radcliffe 1917), by bimodal size-diameter distribution (Williams 1967). Olla and Samet (1977) reported from laboratory observations that spawning occurs at the surface primarily during the evening. Tautog eggs are pelagic and hatch in 42 to 45 h at 22°C (Williams 1967; Fritzsche 1978). The pelagic larval stage lasts about 3 weeks and individuals settle on the bottom when they reach a size of about 17 mm (Sogard et al. 1992; Dorf 1994). Estimated growth rate during pre-settlement is about 0.75 mm per day and during post-settlement about 0.5 mm per day (Sogard et al. 1992; Dorf 1994). Size at the end of the first growth season in

Narragansett Bay (about 50 mm total length; Dorf 1994) was less than found in a southern New Jersey estuary (75 mm standard length; Sogard et al. 1992) and this was attributed to a longer growing season in southern waters. Adult growth rates have been estimated for several regions ranging from Narragansett Bay to Virginia (Cooper 1965; Simpson 1989; Hostetter and Munroe 1993) and fecundity at size and age was reported by Chenoweth (1963).

Tautog eggs are the second-most abundant fish egg collected in entrainment samples at Millstone Nuclear Power Station (MNPS). Annual entrainment estimates of tautog eggs from 1979 through 1994 ranged from 0.7 to 3.9 billion, and during three-unit operation generally exceeded 2.0 billion (NUSCO 1996). These large entrainment estimates have been of concern to the CT DEP since the late 1980s. Although no studies were required prior to 1996, CT DEP concerns have been addressed in recent years with several special short-term studies on tautog eggs and additional studies were conducted in 1996.

The purpose of this report is to review the results of previous tautog egg abundance studies and provide the preliminary findings of studies conducted during 1996. This information is provided as the basis for the proposed 1997 tautog studies.

## Potential Source Area of Entrained Tautog Eggs

Tautog eggs are pelagic and their dispersal from spawning sites in LIS is primarily by tidal transport The numbers of eggs entrained by MNPS is related to their abundance in Niantic Bay, the source of condenser cooling water. Results from drogue studies in 1991 (see NUSCO 1992 for details) indicated that during ebb tide water from LIS enters Niantic Bay from the west, and conversely, during flood tide water enters from the east (Figs. 1 and 2). The distance a tautog egg is transported during a tidal stage should be directly related to tidal current velocity. Average current velocities for ebb and flood tidal stages in the area from the Connecticut River to the Thames River were estimated from information provided in tidal current tables (NOAA 1993) at five locations west of Niantic Bay and five locations to the east (Fig. 3). For simplicity, the duration of both

ebb and flood stages was assumed to be 6 hours. The estimated average tidal velocity was 0.94 knots during an ebb tide and 0.88 knots during a flood. Based on these velocities, a tautog egg can be transported 5.7 nautical miles (n mi) during an ebb tide and 5.3 n mi during a flood tide. Therefore, the potential source area for a tautog eggs entering Niantic Bay during a full tidal cycle is within a radius of about 5 n mi, with a center at a mid-point between Black Point and Millstone Point. This would encompass a shoreline extending from about 2 n mi east of the Connecticut River to the Thames River. Based on this information, farfield studies of tautog egg abundance, conducted during 1996 and proposed for 1997, extend about 5 n mi from the mouth of Niantic Bay.

## Annual Temporal Occurrence of Tautog Eggs

Based on MNPS monitoring data collected from 1979 through 1994, the annual temporal occurrence of tautog eggs in eastern LIS is generally from about early May through mid to late September. This seasonal occurrence of tautog eggs is similar to that reported by Monteleone (1992) for Great South Bay, NY. The annual timing of peak spawning, as indicated by egg abundance, can be estimated from the inflection point of the Gompertz function (see NUSCO 1996 for a discussion of the Gompertz function). From 1979 through 1994, peak spawning occurred during mid to late June and appeared to be related to annual spring water temperatures. There was a significant ($p = 0.002$) negative relationship between May water temperatures and the estimated date of peak spawning (Fig. 4). The 1996 spring water temperatures were abnormally cool, with an average May water temperature at the MNPS intakes of 9.4°C, resulting in an estimated peak egg abundance during the latter portion of June to mid July. This information was used as the basis for the timing of tautog egg studies conducted during 1996.

## Changes in the Abundance of Tautog Eggs Over 24 Hours

Comparison of results from routine day and night entrainment collections at MNPS indicated that tautog eggs were more abundant at night. Therefore, 24-hour entrainment studies were conducted during 1993 to examine the diel change in abundance (NUSCO 1994). Three 24-hour periods (June 8-9, June 15-16, and July 19-20) were sampled at 2-hour intervals. Samples were collected from the condenser-cooling water discharge with a 1.0 x 3.6-m conical plankton net with 333-µm mesh deployed with a gantry system (for details see NUSCO 1996)

The 24-hour pattern of change in tautog egg abundance every 2 hours for a 24- hour period showed very consistent results in the three studies (Fig. 5). In general, egg abundance peaked at about 1800-h, decreased through the night, remained reasonably constant until late afternoon and increased rapidly during the evening. This pattern indicated a short daily spawning period. This evening spawning period is consistent with the laboratory observations of Olla and Samet (1977). The timing of peak abundance was not related to tidal stage because sampling for the June 8-9 and June 15-16 studies occurred during opposing tidal stages. Examination of the geometric mean for each 2-hour sampling period for the three sampling dates combined showed that, on average, daily peak spawning for tautog occurred at about 1800 h (Fig. 5). The rapid decline in abundance from 1800 to 2200 h cannot be attributed to hatching as egg incubation takes longer than a day. Therefore, this decline was probably due to high natural egg mortality, such as from predation, as was suggested for cunner eggs, a sympatric species also found in LIS (Williams et al. 1973). Natural egg mortality, which likely accounts for the rapid decline in tautog egg abundance, from peak spawning (1800 h) through 0200 h was about 70% and through 0600 h was 80%. This information, supporting high natural egg mortality during the first 12 hours after spawning and followed by a reasonably stable abundance, was used in the sampling design for studies conducted during 1996 and for proposed studies for 1997.

## Vertical Distribution of Tautog Eggs and Egg Mortality Estimates

The Draft Fisheries Management Plan for Tautog (ASMFC 1996) states that tautog eggs are primarily found near the surface and this was apparently based on results of a study conducted in Narragansett Bay (Bourne and Govoni 1988). A portion of that bay is a two-layered estuary and the pelagic tautog eggs may concentrate near the halocline. By contrast, the water column in eastern LIS is relatively homogenous with no evident halocline. However, even under these conditions, if eggs tend to concentrate near the surface, the effect of winds on their transport would need to be considered along with tidal currents. Therefore, paired surface and near-bottom tows were taken during the occurrence of tautog eggs in 1996. Simultaneous sampling with two 60-cm bongo samplers with 333-µm mesh nets and 22.7 kg depressors was conducted with one sampler deployed just below the surface and the other near the bottom. Three replicate paired tows were taken during the evenings of July 10 and 16 (during peak spawning) and during the mornings of July 11 and 16 (approximately 12 hours after peak spawning) for at total of 12 paired surface-bottom collections. Sampling was conducted near the time of slack tidal currents on July 10 and 11 and maximum tidal currents for both July 16 collections. The sampling was conducted at a point midway between Millstone Point and Black Point having a water depth of about 10 m. This location was near station ORI discussed below in the farfield spatial distribution study.

The densities of tautog eggs were greater at the surface than near-bottom for all 12 paired comparisons, but based on vertical temperature and salinity measurements no water column stratification was apparent (Table 1). Examination of the geometric mean densities of the three replicate pairs indicated that differences between surface and near-bottom were much greater for collections made in the evening just after spawning than for collections during the morning, approximately 12 hour after spawning (Fig. 6). Tidal current did not appear to affect this relationship. Relatively similar egg densities were collected during the evening near-bottom and during morning collections at both surface

and near-bottom compared to surface densities during the evening. This, in addition to the large difference in tautog egg abundance between surface and near-bottom collections during evening and the reduction in density at the surface from evening to morning, suggests selectively higher mortality for eggs near the surface during the 12-hour period following spawning.

Tautog egg mortality during about the first 12 hours after spawning may be estimated if the combination of surface and bottom densities (geometric mean of 6 samples) is assumed to be representative of abundance at the time of collections. Under this assumption there was about 65% mortality (68.9% for slack current collections and 64.4 % for maximum current collections) during the 12-hour period. This mortality estimate, although large for a 12-hour period, was less than the about 80% mortality estimated from the 24-hour studies discussed above.

## Nearfield Spatial Distribution of Tautog Eggs

The nearfield spatial distribution of tautog eggs was examined from Black Point to Twotree Island Channel and in Niantic Bay in 1994 (NUSCO 1995) with five stations sampled (Fig. 7). The offshore stations (BP, LI, NB, and SS) were sampled with the 60-cm bongo system with 333-μm mesh nets using a stepwise oblique tow pattern for a 6-minute duration with equal sampling time at surface, mid, and near-bottom depths. Station EN was sampled using the previously described entrainment gantry system. The water depth at all offshore stations ranged from about 6 to 10 m. Station BP was sampled during an ebb tide and station SS during a flood tide, so that collection densities of tautog eggs would represent those potentially imported into Niantic Bay from the west and east, respectively. The remaining three stations (EN, NB, and LI) were sampled during both tidal stages. Samples were collected during the period of 0500 to 1100. This time period was selected because 24-hour studies conducted in 1993 showed that tautog egg densities remain relatively stable at this time of day (Fig. 5). Stations EN and NB were sampled at

approximately at the same time. The collection sequence of stations sampled was LI, NB, and SS during a flood tide and LI, NB, and BP during an ebb tide. These sequences facilitated paired comparisons of stations BP, LI, and SS with EN. By sampling NB second in the sequence (with EN sampled almost simultaneously), the sampling interval between EN and the other three stations was minimized. Sampling dates were June 23 and 24 during a flood tide and June 29 and 30 during an ebb tide. These dates occurred during peak density of tautog eggs. On each sampling date, three sequences of samples were taken (LI, NB, EN, BP during an ebb and LI, NB, EN, SS during a flood), with the first sequence starting about 1 hour before maximum tidal current, the second starting at near maximum current, and the third immediately after the second was completed.

The results of this nearfield study of tautog egg abundance indicated that the geometric mean densities of tautog eggs at each station were similar and had overlapping 95% confidence intervals (Fig. 8). The lack of localized egg concentrations was confirmed by the results of paired comparisons between station EN and the other stations (NB, LI, SS, and BP) when tested with the Wilcoxon's signed-rank test (Sokal and Rohlf 1969). Although the number of paired comparisons was rather low (12 pairs for NB and LI and 6 for SS and BP), no significant ($p < 0.05$) differences were detected between station EN and the other four stations. These nearfield data indicated that eggs were not concentrated near MNPS and entrainment densities of tautog eggs were representative of a more homogenous distribution, including nearfield areas outside of Niantic Bay.

## Farfield Spatial Distribution of Tautog Eggs

No information was available for tautog egg abundance further offshore of Niantic Bay. In 1996 sampling was extended to the 5 n mi boundary mentioned above as a potential source area of tautog eggs entrained by MNPS (see Potential Source Area of Entrained Tautog Eggs section). Sampling sites were at 1 n mi intervals along three separate transects (Fig. 9). The point of origin (station ORI) of each transect was at the mid-point between Millstone Point and Black Point. The approximate directions from the origin of

the transects were southeast (SE), south (S), and southwest (SW). Vertical tows were taken with a 60-cm bongo sampler fitted with nets of 333-μm mesh and a 22.7-kg depressor. Volume filtered was determined using a single GO flowmeter mounted in the center of each bongo opening. The sampler was lowered from the surface to the bottom and immediately retrieved to the surface while the boat remained at idle. Therefore, sampling was conducted during both descent and ascent. Replicate tows were taken at shallower sampling sites until approximately 30 $m^3$ of seawater had been filtered (both nets combined). Material retained by both nets was combined as one sample for each site. Sampling was conducted in the morning after sunrise on July 2 and July 9. This sampling time was selected because the results of 24-h studies conducted in 1993 showed that tautog egg densities remain relatively stable during this time of day (Fig. 5). Sampling simultaneously with two boats required about 3 hours. Sampling started about 2 hours prior to slack current and was conducted during the period encompassing slack after ebb (July 2) and slack after flood (July 9). On both dates each site was sampled once, except for station ORI which was sampled at the beginning, near the middle, and at the end of each sampling period.

Abundances of tautog eggs, expressed as density per 500 $m^3$, for both sampling dates at station ORI (0 n mi) were generally similar (geometric mean of 3 replicates), although no consistent trends were evident between dates or along transects (Fig. 10). On July 2, the greatest abundances of eggs were collected along transect SE at n mi 2 through 4, but the remaining two transects had relatively similar densities. On July [illegible] abundances were more similar among transects with slightly higher densities at n [illegible] and 2 for transects SE and SW. For both dates there was no clear nearshore to offshore gradient of tautog egg densities.

The depths of the sampling sites varied greatly, ranging from 8 to 58 m (Tables 2 and 3). Water temperature and salinity measurements at surface, mid-depth, and bottom were similar at each site, indicating a relatively well-mixed water column throughout the 5 n mi radius from Niantic Bay. Due to the large variation in water depths among sampling sites, tautog abundance indices were recomputed based on number of eggs per $m^2$ of the entire water column at the sampling site (Fig. 11). These indices suggested greater

similarity in abundance among transects than density estimates, but still no obvious nearshore to farshore trends were evident. This lack of trends and of any indication of preferred spawning area may be due to the time of sampling. Results of previous 24-hour studies showed that tautog adults spawn primarily during the evening (Fig. 5). The time period of sampling for farfield spatial distribution was during the morning, which followed a full tidal cycle after spawning and allowed for mixing and distribution of eggs by tidal currents.

An instantaneous standing stock within the 5 n mi radius of Niantic Bay was computed in an attempt to estimate the number of tautog eggs that could be potentially entrained by MNPS due to tidal transport. The geometric mean density of all 16 stations combined was calculated and extrapolated to a total number of eggs based on the average depth of the stations sampled. The estimated number of tautog eggs within a 5 n mi radius of Niantic Bay during the time period of sampling was $4.9 \times 10^9$ on July 2 and $3.1 \times 10^9$ on July 9. These daily egg standing stock estimates equaled or exceed the total number of tautog eggs entrained by MNPS during a complete year since 1979 of 0.7 to $3.9 \times 10^9$ (NUSCO 1996). In addition, these standing egg stock estimates represent the number of eggs approximately 12 hours after peak spawning and based on the results from 24-hour studies and evening-morning abundance comparisons from vertical distribution studies, only account for about 20 to 35% of the previous evenings spawn due to natural mortality.

These daily standing stock estimates were also compared to an average lifetime fecundity estimate for female tautog (Table 4). Parameters used to estimate average lifetime fecundity under 1996 conditions were length at age for LIS (Simpson 1989), fecundity at age (Chenoweth 1963), fraction of mature females at age (Chenoweth 1963), and natural (M=0.15) and fishing (F=0.54) mortality rates from ASMFC (1996). In addition, present fishing regulations were used, including a 14 in (356 mm) legal size limit with a natural mortality of M=0.15 and a discard mortality of F=0.04 (D. Simpson, CT DEP, pers. comm.) for fish less than the legal size limit. The lifetime fecundity was estimated to be 142,655 eggs per female. The daily egg standing stock was adjusted for mortality during the previous 12 hours after spawning by using 65% from the vertical

distribution study and 80% from the 24-hour study. Equivalent lifetime spawners for the July 2 study ranged from 98,139 to 171,743 and for the July 9 study ranged from 62,388 to 108,654 female spawners. These numbers of equivalent spawners in the 5 n mi radius are conservative (low) because tautog are serial spawners and may spawn over an extended number of days (Olla and Samet 1977).

## Tautog Study Plan for 1997

The objective of the proposed 1997 tautog study is to identify preferred tautog spawning locations within an approximate 5 n mi radius of Niantic Bay, which will be determined on the basis of egg densities. All sampling will be conducted during the evening when peak spawning occurs, as determined from the results of 24-h and vertical distribution studies (Figs. 5 and 6). Samples will be taken with a 60-cm bongo sampler fitted with 333-μm mesh nets. At each sampling site the sampler will be towed just below the water surface, where newly spawned eggs are concentrated (Fig. 6), and tow distance will be sufficient to filter at least 50 $m^3$ of water. Sampling sites will be the same as those sampled during the 1996 farfield spatial study (Fig. 9) and at 10 additional sites (5 west and 5 east of Niantic Bay). These 10 additional sites will be located near the shoreline at approximately 1 nautical mile intervals. Exact station locations will be determined based on bottom topography. Sampling will be conducted twice (different days) at each site during the estimated peak spawning season, which will be determined from May 1997 water temperature (Fig. 4).

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Table 1. Time of sampling, tidal current stage, water temperature, and salinity when paired surface and near-bottom collections were taken to compare the vertical distribution of tautog eggs at a site midway between Millstone and Black Points during July 1996.

| Sampling time (h) | Tidal current | Temperature (°C) | | | Salinity (ppt) | | |
|---|---|---|---|---|---|---|---|
| | | Surface | Mid | Bottom | Surface | Mid | Bottom |
| 2005-2105 | Slack | 17.6 | 17.6 | 17.6 | 29.2 | 29.3 | 29.3 |
| 0832-0939 | Slack | 17.6 | 17.3 | 16.9 | 29.5 | 29.5 | 29.6 |
| 2005-2046 | Maximum | 19.1 | 17.5 | 17.0 | 28.0 | 29.0 | 29.4 |
| 0822-0914 | Maximum | 18.2 | 17.5 | 17.1 | 27.7 | 28.8 | 29.2 |

Table 2. Station depth, water temperature and salinity for the July 2, 1996 collections to examine farfield spatial distribution of tautog eggs.

| Station | Depth (m) | Temperature (°C) | | | Salinity (ppt) | | |
|---|---|---|---|---|---|---|---|
| | | Surface | Mid | Bottom | Surface | Mid | Bottom |
| ORI[a] | 8 | 16.3 | 16.5 | 16.3 | 28.7 | 28.5 | 28.6 |
| SE1 | 11 | 16.1 | 16.0 | 16.0 | 28.7 | 28.7 | 28.7 |
| SE2 | 13 | 16.4 | 16.4 | 16.1 | 28.4 | 28.5 | 28.7 |
| SE3 | 18 | 17.1 | 16.1 | 16.1 | 27.2 | 28.8 | 28.8 |
| SE4 | 22 | 16.5 | 16.1 | 16.0 | 28.3 | 288.8 | 28.8 |
| SE5 | 20 | 16.0 | 15.9 | 15.8 | 28.8 | 28.8 | 29.0 |
| S1 | 20 | 16.3 | 16.2 | 16.1 | 28.4 | 28.5 | 28.7 |
| S2 | 24 | 16.1 | 15.9 | 16.0 | 28.7 | 28.9 | 28.8 |
| S3 | 45 | 16.2 | 15.9 | -[b] | 28.5 | 28.8 | - |
| S4 | 58 | 16.6 | 16.1 | - | 27.6 | 28.3 | - |
| S5 | 52 | 16.7 | 16.4 | - | 27.6 | 27.9 | - |
| SW1 | 28 | 16.5 | 16.3 | 16.4 | 28.6 | 28.6 | 28.6 |
| SW2 | 29 | 16.5 | 16.2 | 16.2 | 27.7 | 28.3 | 28.4 |
| SW3 | 34 | 16.6 | 16.2 | 16.2 | 27.4 | 28.2 | 28.3 |
| SW4 | 37 | 16.6 | 16.2 | 16.1 | 27.4 | 28.3 | 28.5 |
| SW5 | 49 | 16.8 | 16.3 | - | 27.3 | 27.9 | - |

[a] Parameters for station ORI are a mean of three collections during the sampling date.

[b] No temperature and salinity measurements because the bottom depth was greater than the length of the probe cable.

Table 3. Station depth, water temperature and salinity for the July 9, 1996 collections to examine farfield spatial distribution of tautog eggs.

| Station | Depth (m) | Temperature (°C) | | | Salinity (ppt) | | |
|---|---|---|---|---|---|---|---|
| | | Surface | Mid | Bottom | Surface | Mid | Bottom |
| ORI[a] | 8 | 17.5 | 17.4 | 17.4 | 29.4 | 29.5 | 29.5 |
| SE1 | 12 | 17.5 | 17.3 | 16.9 | 29.4 | 29.5 | 29.7 |
| SE2 | 12 | 17.2 | 17.1 | 16.8 | 29.5 | 29.5 | 29.7 |
| SE3 | 17 | 17.2 | 16.4 | 16.5 | 29.0 | 29.9 | 29.9 |
| SE4 | 23 | 17.2 | 16.4 | 16.0 | 29.0 | 29.8 | 30.2 |
| SE5 | 19 | 17.7 | 16.6 | 16.3 | 28.6 | 29.7 | 29.9 |
| S1 | 21 | 17.1 | 16.8 | 16.8 | 29.3 | 29.6 | 29.6 |
| S2 | 24 | 17.2 | 16.8 | 16.4 | 29.2 | 29.6 | 29.9 |
| S3 | [illegible] | 16.8 | 16.1 | -[b] | 29.6 | 30.1 | - |
| S4 | [illegible] | 16.9 | 16.4 | - | 29.4 | 29.8 | - |
| S5 | 5[illegible] | 17.9 | 16.3 | - | 28.2 | 29.9 | - |
| SW1 | 29 | 17.4 | 16.9 | 16.7 | 29.3 | 29.7 | 29.7 |
| SW2 | 30 | 17.1 | 17.0 | 16.9 | 29.3 | 29.6 | 29.7 |
| SW3 | 34 | 17.0 | 16.5 | 16.3 | 29.1 | 29.8 | 30.0 |
| SW4 | 37 | 17.8 | 16.8 | 16.4 | 28.2 | 29.4 | 29.8 |
| SW5 | 50 | 18.0 | 16.3 | - | 28.1 | 30.0 | - |

[a] Parameters for station ORI are a mean of three collections during the sampling date.

[b] No temperature and salinity measurements because the bottom depth was greater than the length of the probe cable.

Table 4. Tautog lifetime average egg production of an Age 3 female spawner.

| Age | Length (mm)[a] | Fecundity[b] | Survival probability[c] | Fraction mature[d] | Egg production |
|---|---|---|---|---|---|
| 3 | 223 | 16,069 | 1.000000 | 0.8 | 12,855 |
| 4 | 273 | 26,476 | 0.826280 | 1.0 | 21,876 |
| 5 | 317 | 39,000 | 0.682738 | 1.0 | 26,627 |
| 6 | 354 | 53,519 | 0.564133 | 1.0 | 30,192 |
| 7 | 386 | 69,938 | 0.282955 | 1.0 | 19,789 |
| 8 | 414 | 88,181 | 0.141924 | 1.0 | 12,515 |
| 9 | 439 | 108,184 | 0.071186 | 1.0 | 7,701 |
| 10 | 460 | 12[illegible],[illegible]94 | 0.035705 | 1.0 | 4,638 |
| 11 | 478 | 153,264 | 0.017909 | 1.0 | 2,745 |
| 12 | 493 | 178,251 | 0.008983 | 1.0 | 1,601 |
| 13 | 507 | 204,820 | 0.004505 | 1.0 | 923 |
| 14 | 519 | 232,937 | 0.002260 | 1.0 | 526 |
| 15 | 529 | 262,571 | 0.001133 | 1.0 | 298 |
| 16 | 538 | 293,697 | 0.000569 | 1.0 | 167 |
| 17 | 545 | 326,288 | 0.000285 | 1.0 | 93 |
| 18 | 552 | 360,321 | 0.000143 | 1.0 | 52 |
| 19 | 558 | 395,774 | 0.000072 | 1.0 | 28 |
| 20 | 562 | 432,628 | 0.000036 | 1.0 | 16 |
| 21 | 567 | 470,864 | 0.000018 | 1.0 | 8 |
| 22 | 570 | 510,463 | 0.000009 | 1.0 | 5 |
| | | | | **Total** | **142,655** |

[a] Length at age from Simpson (1989)
[b] Fecundity at age from Chenoweth (1963)
[c] Instantaneous mortality rates (Z) were:
Natural (M) = 0.15 from ASMFC (1996)
Discard through Age 6 (F) = 0.04 from Simpson (CT DEP, pers. comm.)
Fishing Ages 7 through 22 (F) = 0.54 from ASMFC (1996)
[d] Female Maturity from Chenoweth (1963)

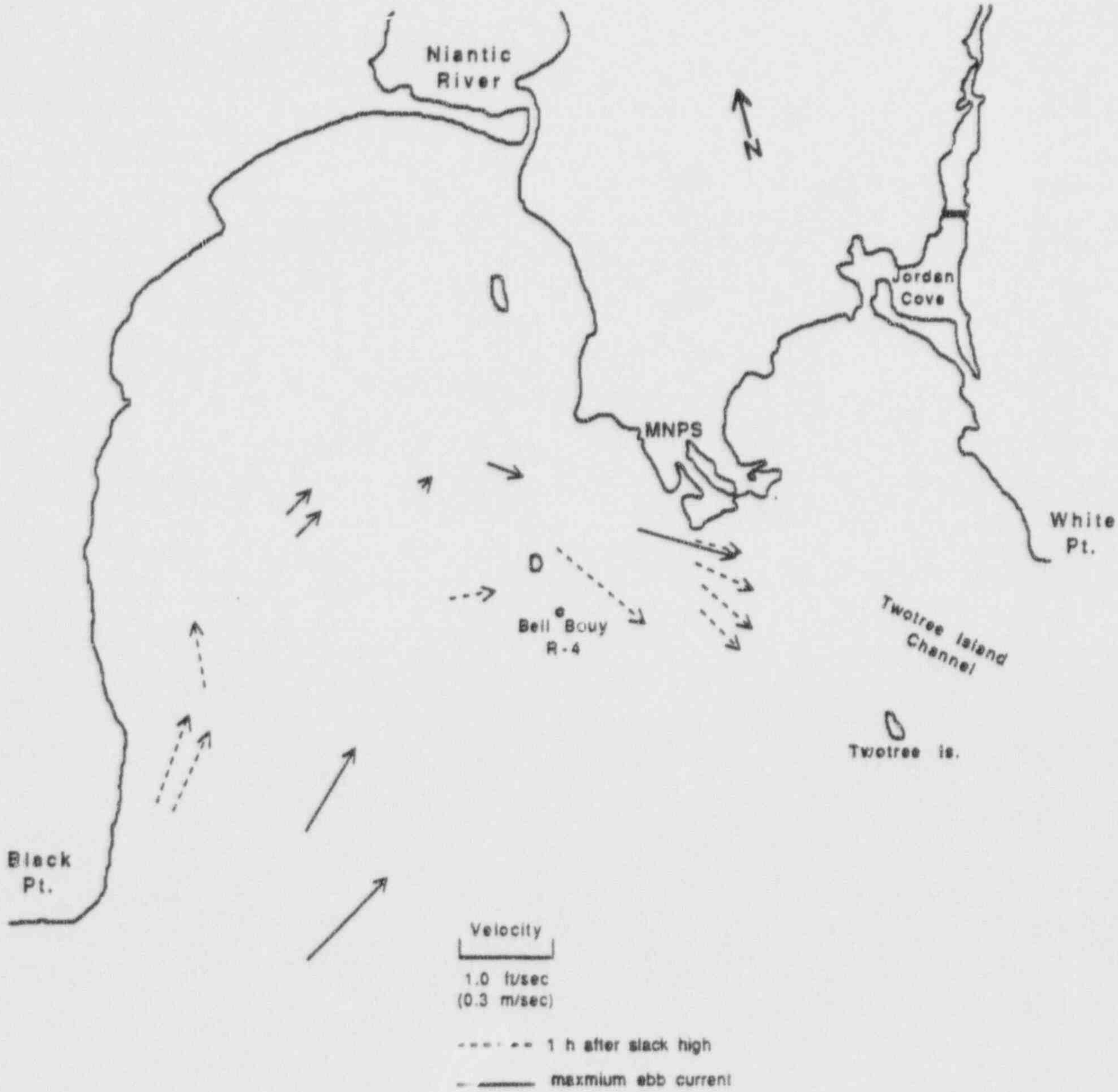



Fig. 1. Estimated tidal current direction and velocity in Niantic Bay for an ebbing tide during first hour after high slack and at the time of maximum ebb current, based on results of drogue studies conducted in 1991. Note that the length of the arrows corresponds to estimated average current velocities.

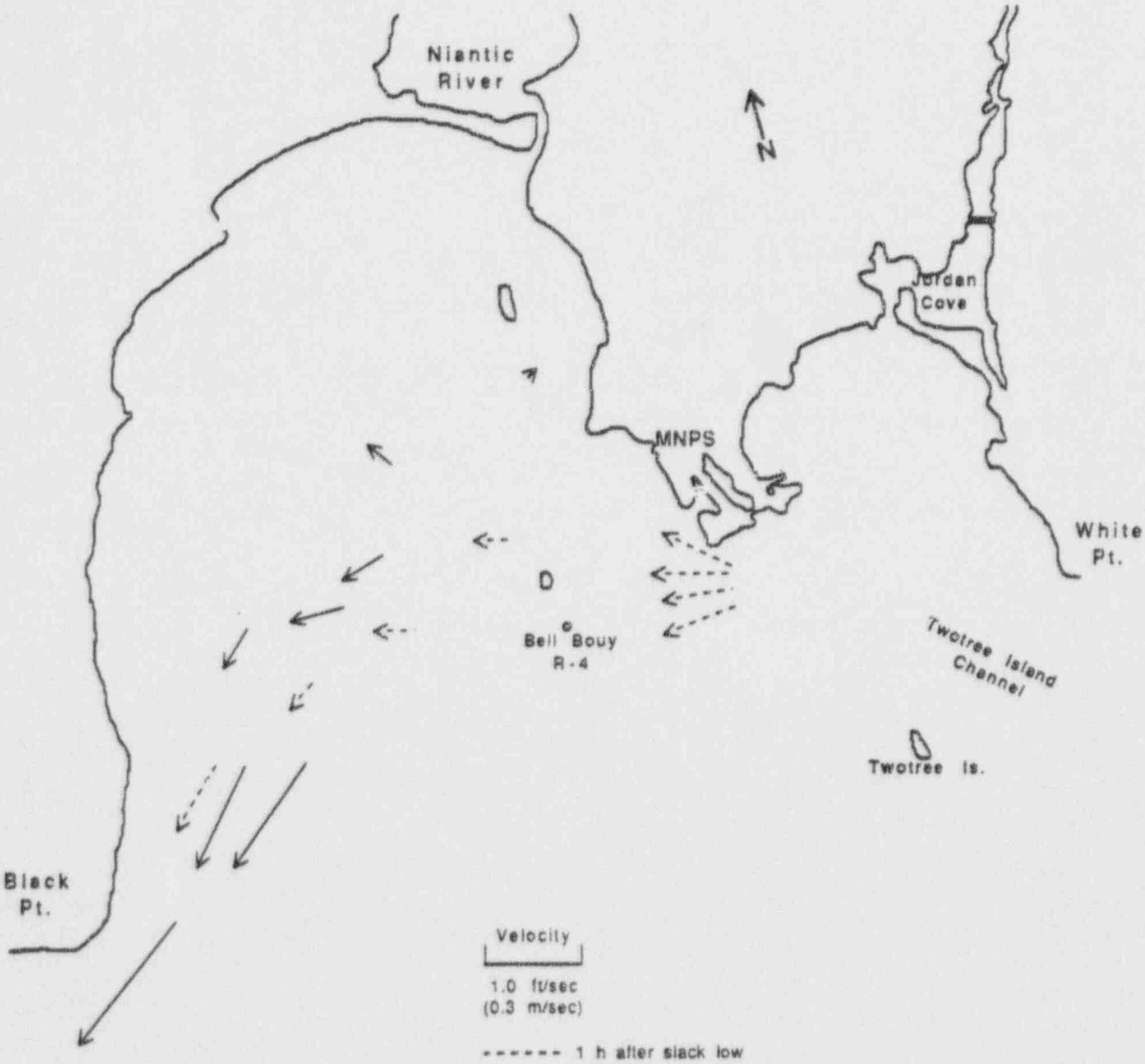



Fig. 2. Estimated tidal current direction and velocity in Niantic Bay for a flooding tide during first hour after low slack and at the time of maximum flood current, based on results of drogue studies conducted in 1991. Note that the length of the arrows corresponds to estimated average current velocities.

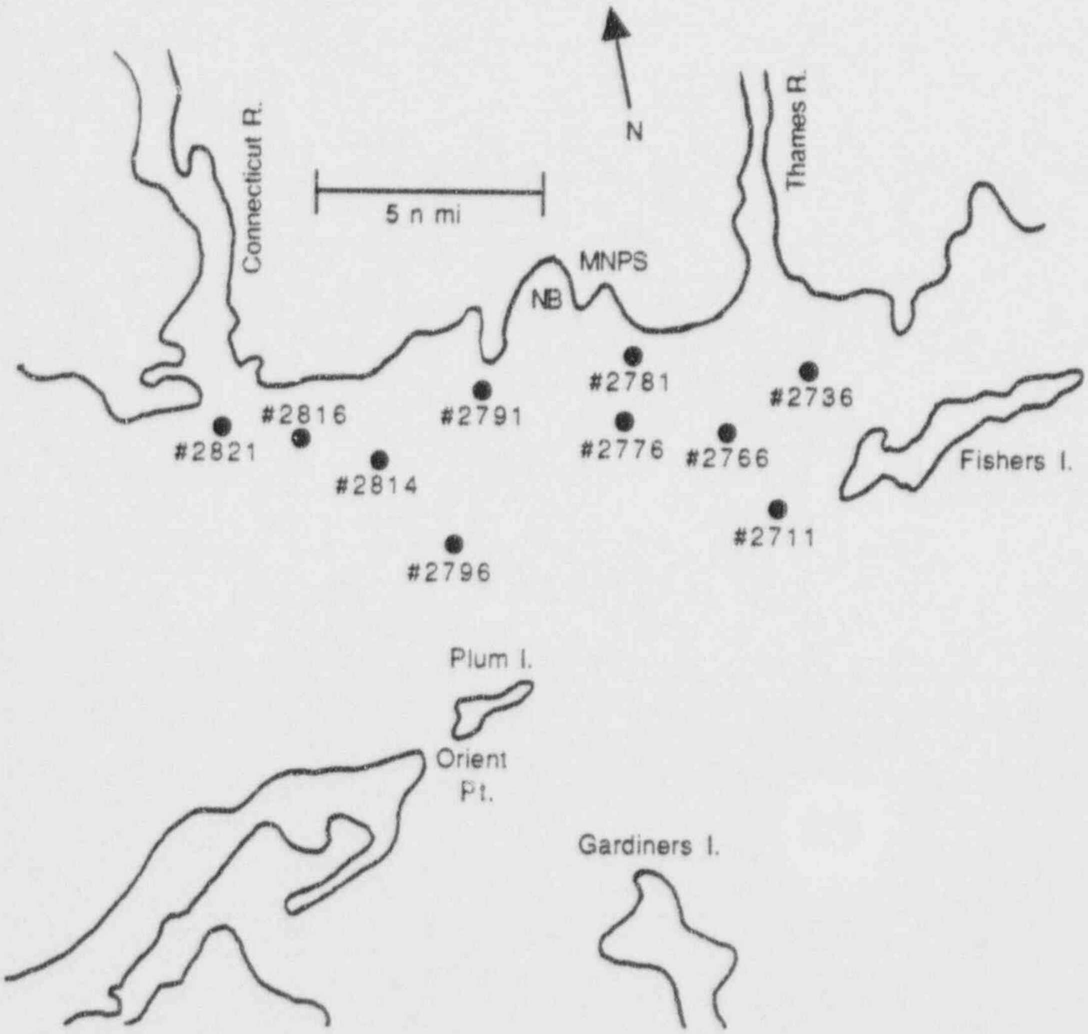



Fig. 3. Approximate location of sites used to estimate average current velocities during ebb and flood tides including the NOAA reference number (NOAA 1993).

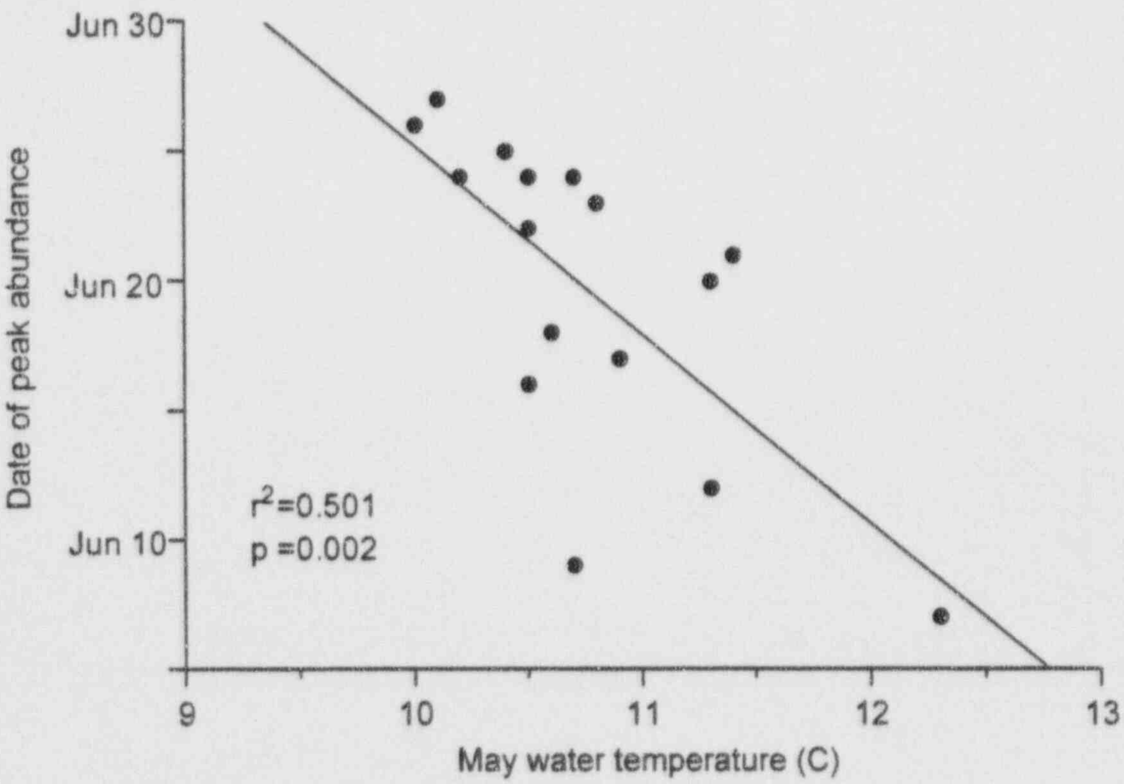



Fig. 4. Relationship between annual mean May water temperature (°C) at the MNPS intakes and date of peak abundance for tautog eggs from 1979 through 1994.

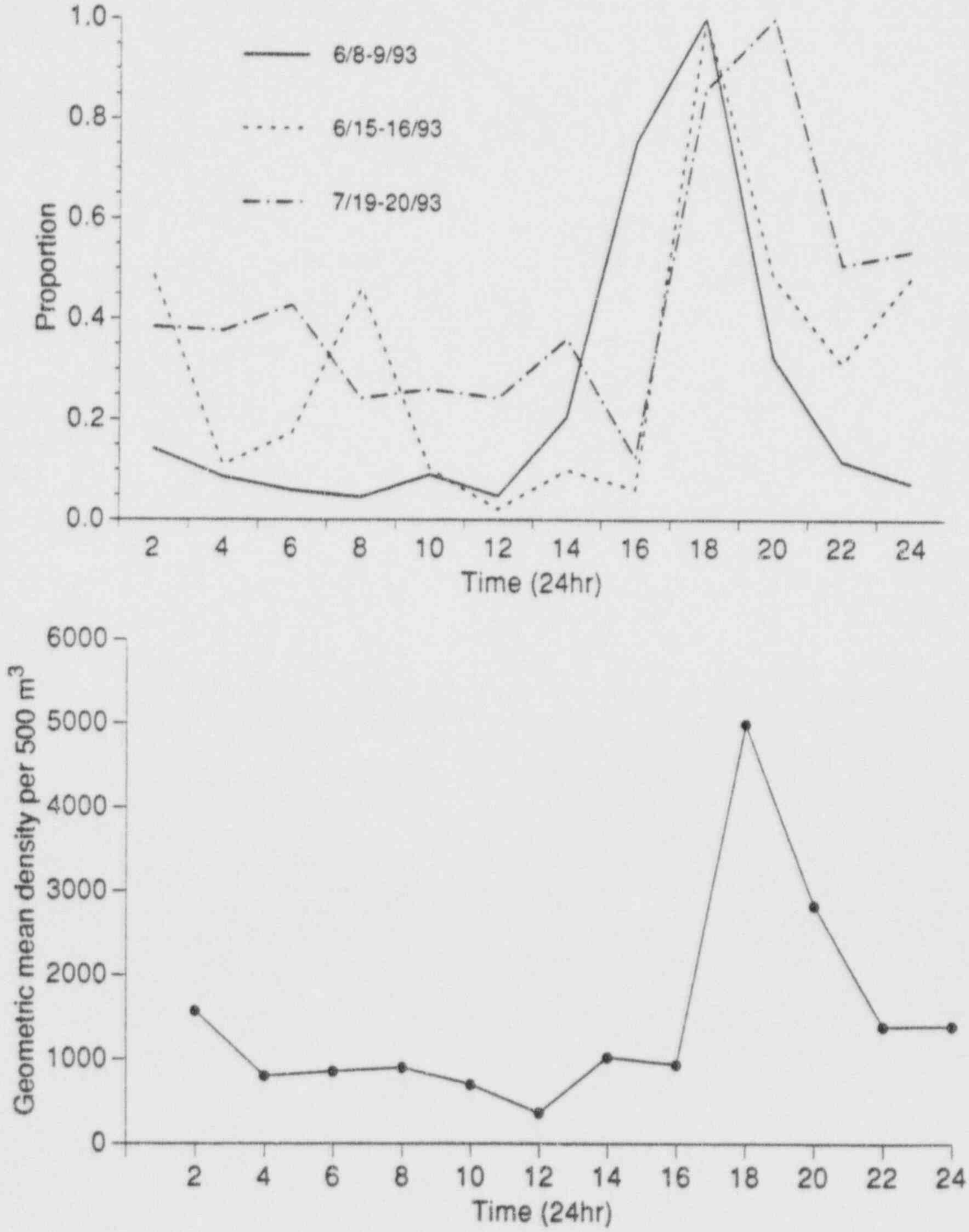



Fig. 5. Daily proportional abundance (top), expressed as sample density/maximum sample density for each study, of tautog eggs for the three 24-hour studies, and the geometric mean density of the three 24-hour studies combined (bottom) conducted in 1993.

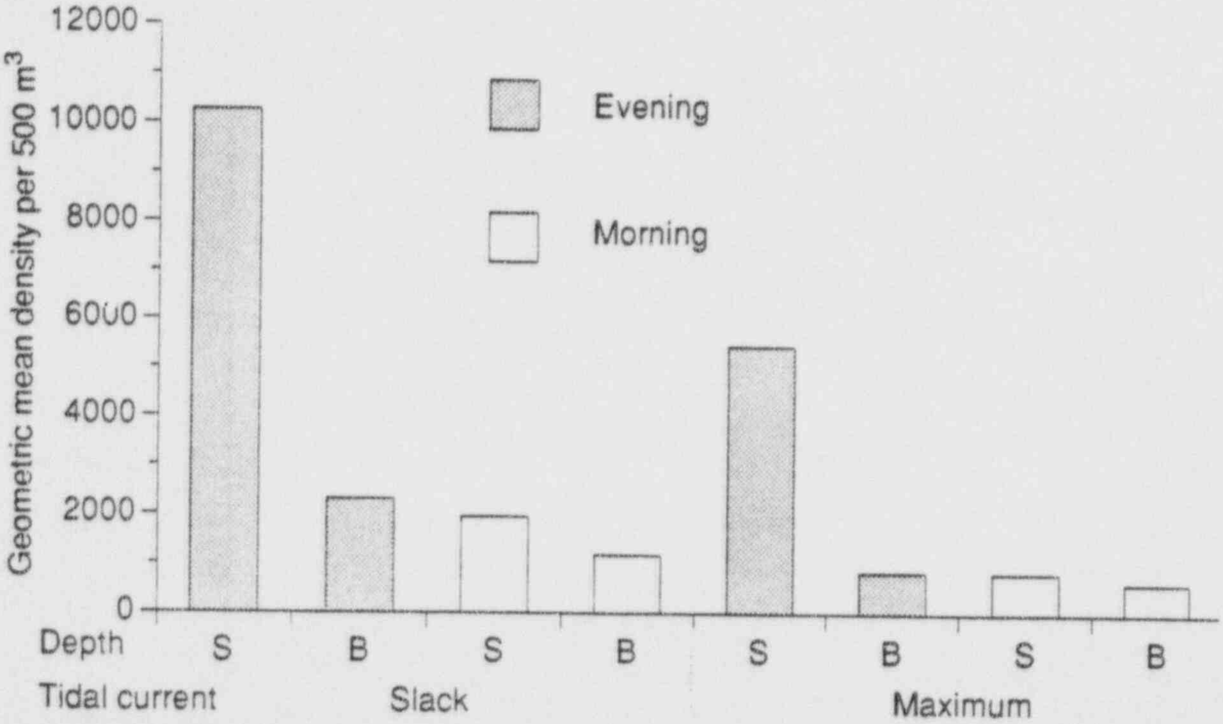



Fig. 6. Comparison of geometric mean densities of tautog eggs from paired surface and near-bottom samples collected during the evening and morning at the time of slack and maximum tidal currents from a site midway between Millstone and Black Points during July 1996.

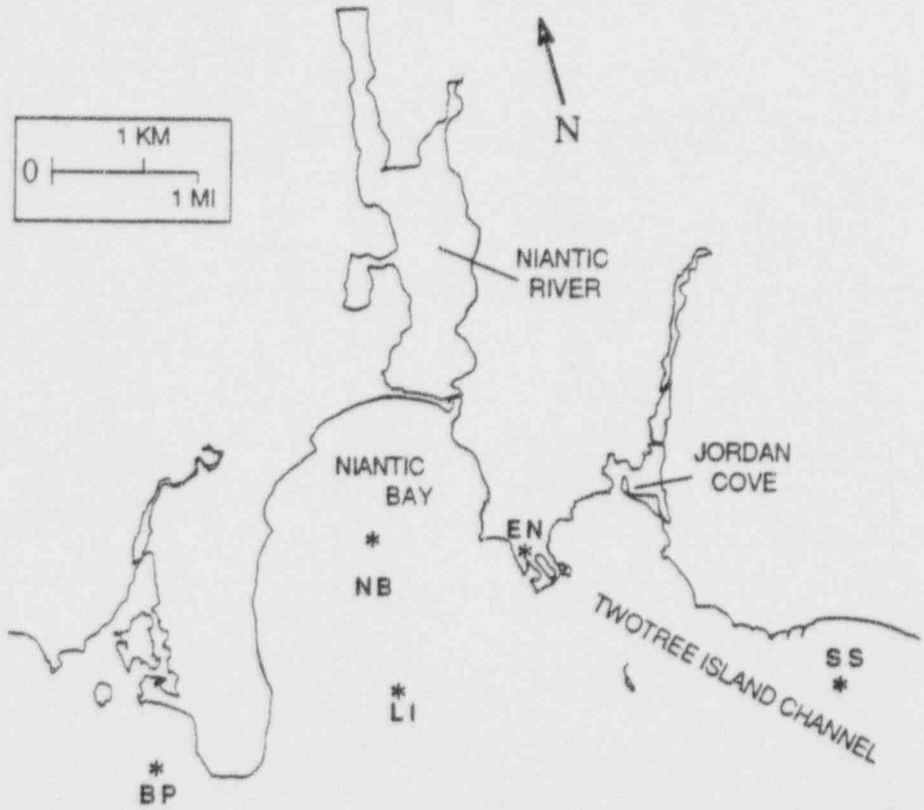



Fig. 7. Location of ichthyoplankton stations sampled for nearfield spatial distribution of tautog eggs during 1994.

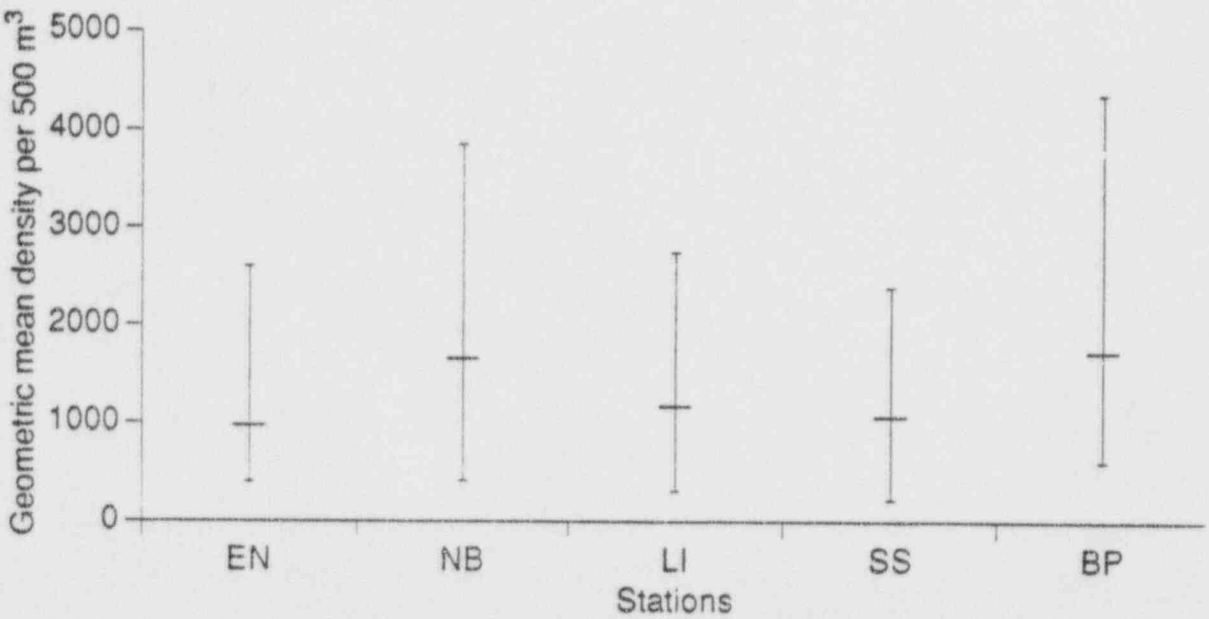



Fig. 8. Comparison of nearfield spatial distribution of tautog eggs in the Millstone area, based on geometric mean densities with 95% confidence intervals for each station sampled during 1994.

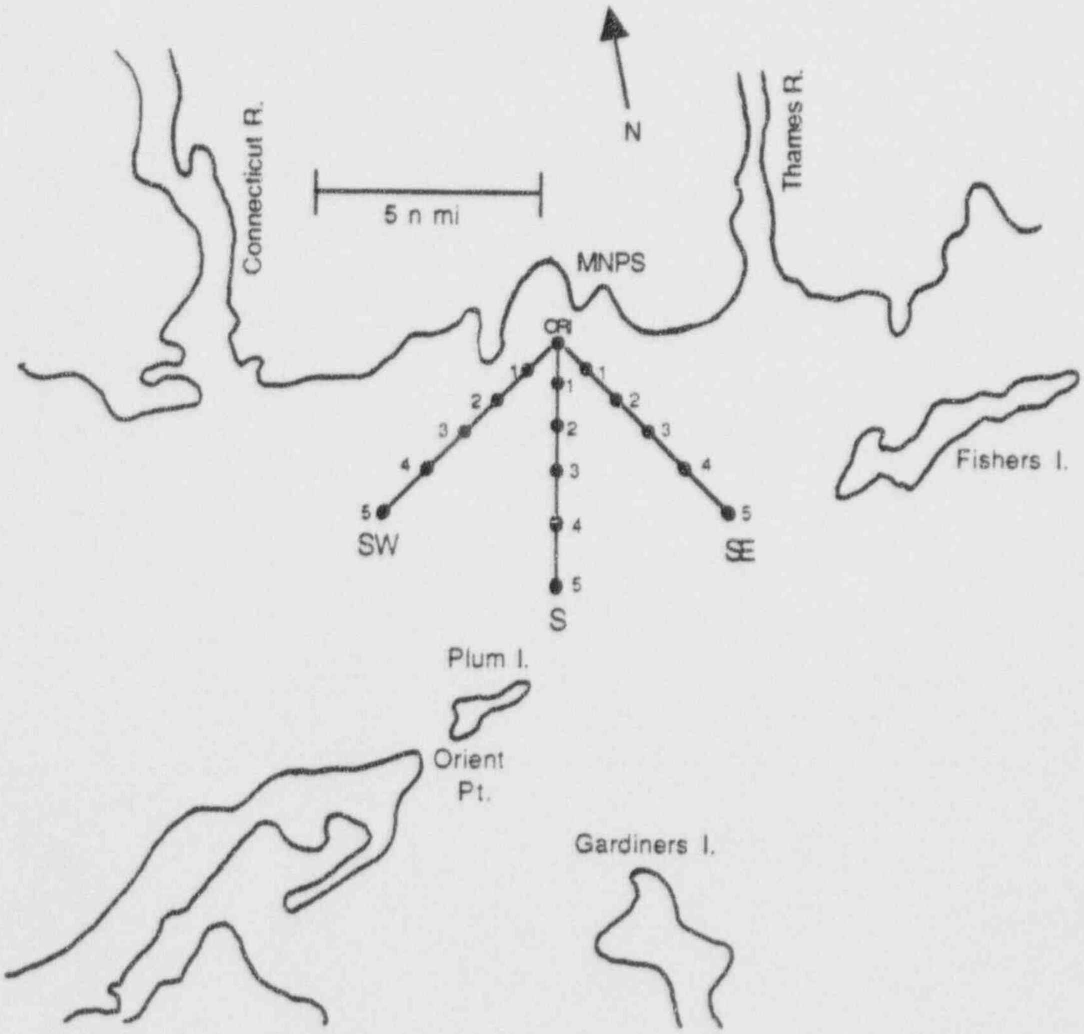
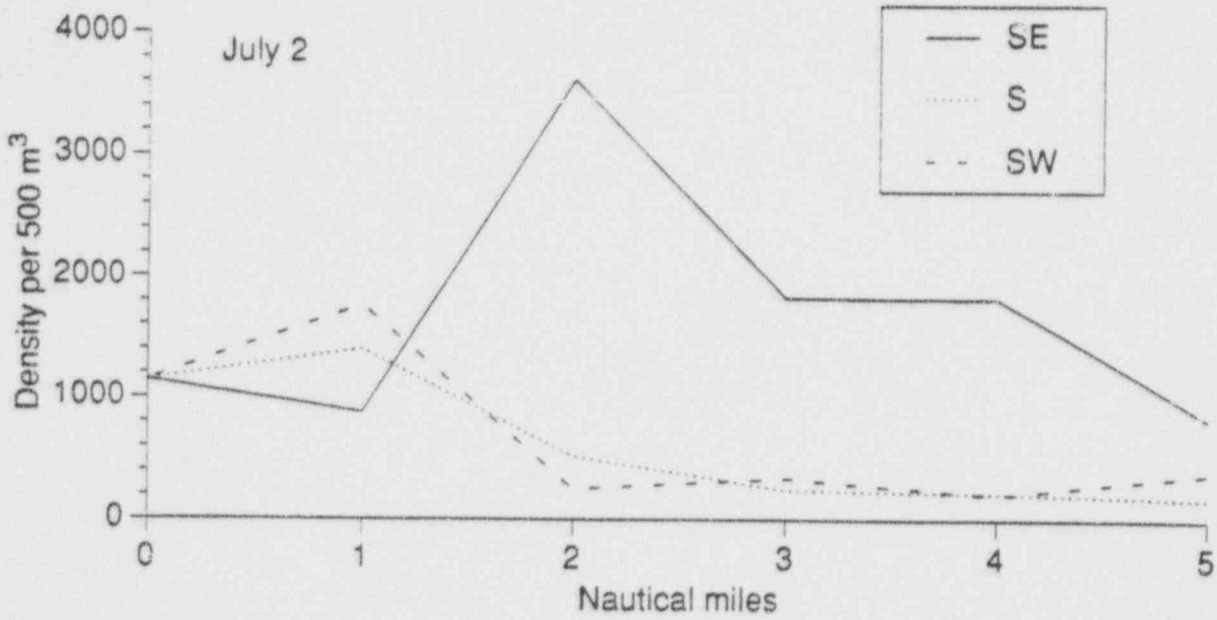



Fig. 9. Sampling sites for farfield spatial distribution study of tautog egg abundance conducted in 1996.



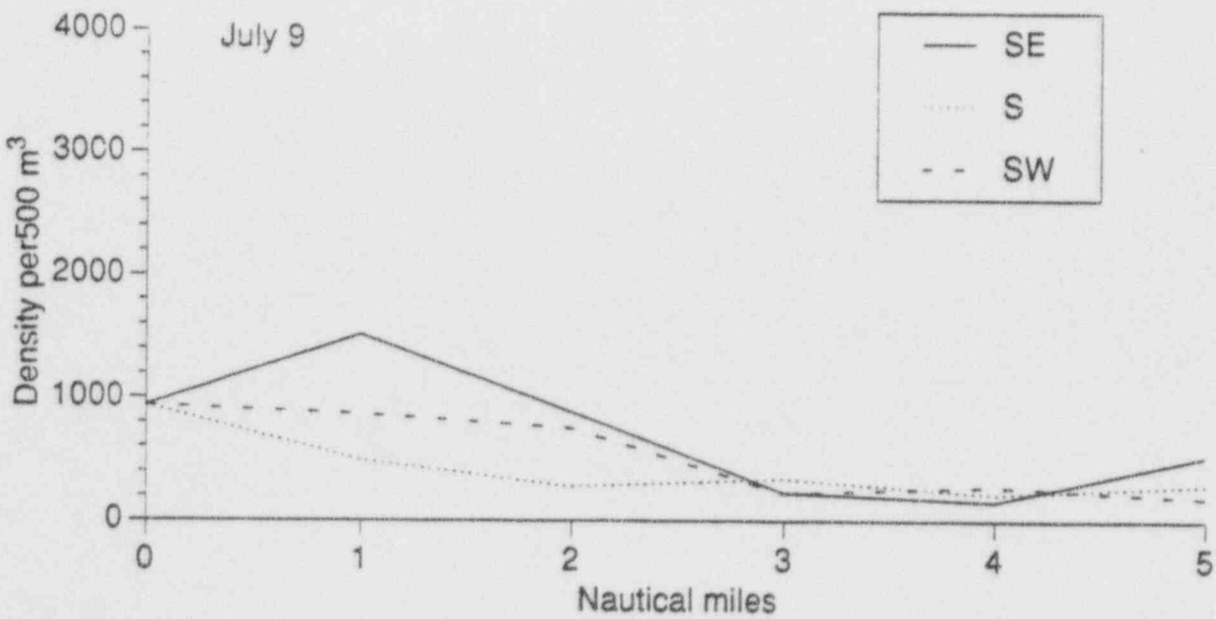




Fig. 10. Comparison of tautog egg densities along three transects sampled at 1 n mi intervals on two dates in 1996. Nautical mile 0 is station ORI (the origin of the three transects).

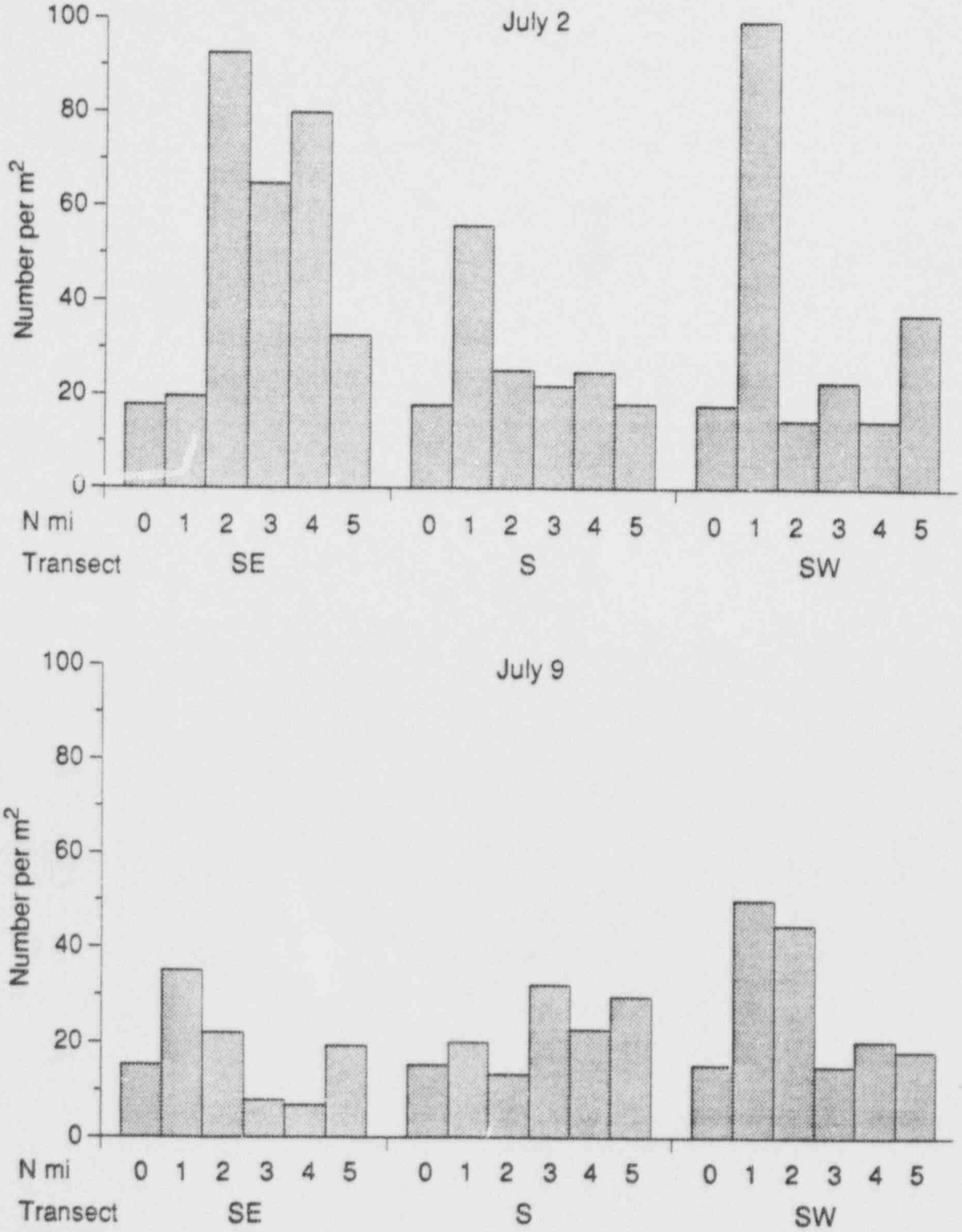



Fig 11. Comparison of tautog egg abundance based on number per $m^2$ along three transects sampled at 1 n mi intervals on two dates in 1996. Nautical mile 0 is station ORI the origin of the three transects.