REPRODUCTION, POPULATION STRUCTURE, AND RECRUITMENT LIMITATION IN A BAY SCALLOP (ARGOPECTEN IRRADIANS LAMARCK) POPULATION FROM NEW JERSEY, USA

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ABSTRACT A bay scallop, Argopecten irradians irradians (Lamarck 1819), population was studied in Little Egg Harbor, New Jersey, USA to investigate the distribution, reproduction and genetic structure of the population because virtually nothing is known about this species in this region. Argopecten irradians irradians densities varied among eelgrass (Zostera marina Lamark) beds in 1993 (range 0.12-1.0 individuals per 10m transect, but were virtually absent from the region in 1999. The absence of adults in 1999 may have been due to limited spatial recruitment and survival in the fall of 1998, which may be attributed to a reduction in above ground biomass of Z. marina habitat. Genetic analysis using mtDNA indicated that this New Jersey population was intermediate between New York and North Carolina populations. Based on these data and the historical findings of bay scallops in New Jersey, it is probable that a small self-seeding population exists. Assessment of reproductive cycles during 1998 showed two potential peaks in reproductive condition one occurred during June when a maximum Caudal-Somatic Index was recorded (24.7%) and the second was during October when a visual gonadal condition index indicated a majority of scallops in post-spawn conditions. Few adult bay scallops were encountered in 1998 (n = 8) to assess reproductive cycles, but two large individuals collected during July showed a post-spawn gonadal condition. However, during both 1998 and 1999 setting juveniles (15 mm shell height) were only recorded in October, suggesting that recruitment to the population during these years resulted from the late summer-early fall spawn. Given the variability observed over the two years, future studies should concentrate on factors influencing inter-annual variation in abundance of this New Jersey population.

KEY WORDS: bay scallop, Argopecten irradians, reproduction, genetic structure, recruitment

INTRODUCTION

The bay scallop (Argopecten irradians) was once a common and often abundant member of shallow marine communities along the Atlantic and Gulf coasts of the United States and a prized commercial and recreational shellfish. Clarke (1965) identified three distinct sub-species of A. irradians based on morphological characteristics, but recent morphological and genetic studies have suggested a fourth (Blake and Graves 1995, Marelli et al. 1997, Wilbur and Gaffney 1997). The northern sub-species, A. i. irradians ranges from Massachusetts to New Jersey where it is thought to intergrade with the southern sub-species A. i. concentricus. Argopecten irradians concentricus was originally described to range along the mid-Atlantic coast and into the Gulf of Mexico (Clarke 1965, Weller 1989). Recent studies, however, have shown that bay scallops from the Florida gulf coast and from North Carolina are as different from one another as are the northern and southern sub-species on the Atlantic coast, indicating that these populations should be considered distinct subspecies (Blake and Graves 1995, Marelli et al. 1997, Wilbur and Gaffney 1997). The fourth sub-species, A. i. amplificatus, is occasionally reported from the gulf coast of Texas and extends to an undefined southern limit south of the Yucatan Peninsula. This sub-species has been described solely on the basis of morphological analysis and the scarcity of animals in recent years has constrained the incorporation of representatives in the aforementioned genetic surveys. A preliminary analysis of the mitochondrial DNA variation does not support the separation of A. i. amplificatus from other Gulf populations despite the clear demonstration of genetically determined differences in morphology (Wilbur 1993, Wilbur and Gaffney 1997). As such, the taxonomic status of the western gulf form of A. irradians is unclear.

Bay scallops are intimately tied to seagrass beds, which they use as a primary settlement site (Gutzeit 1930, Eckman 1987). Specifically, scallops settle and cling to blades via byssal threads until they are too large to remain suspended (Thayer and Stuart 1974). During this life stage, the seagrass canopy provides protection from hermit predators (Pohle et al. 1991). However, reduced growth rates of juvenile scallops climbing higher on blades (Ambrose and Iraldi 1992), suggests that this behavior may represent a trade-off between growth and mortality. Ultimately, recruitment to the adult population may be determined by predation at this juvenile stage (Streib et al. 1995). Because bay scallops recruit to seagrasses and use them as attachment sites (Thayer and Stuart 1974), the loss of habitat during the eelgrass (Zostera marina) wasting disease in the 1950s (see den Hartog 1987) is thought to have severely limited populations in many regions, while eliminating them from others. Although eelgrass has made recoveries in the subsequent decades (den Hartog 1987), bay scallops have not returned in significant numbers to many areas where they once were abundant. In coastal New Jersey, eelgrass has returned and is relatively abundant in shallow water, yet in the last several decades bay scallop densities remain below a fishable population size (Ford 1997).

Historically, bay scallops were abundant and commercially fished in New Jersey, USA. The first available landing records were collected in 1956, when 52,300 bushels were harvested at an estimated value of $287,000. Continued success of scallop populations for the next 12 years yielded 317,000 bushels valued at over $1 million (Ford 1997). Subsequently, commercial bay scallop harvests were only recorded for 1973 and 1974. Despite its
local importance, little information exists on the ecology and population structure of New Jersey bay scallops, particularly since the collapse of the commercial fishery. In recent years it was generally felt that bay scallops no longer occurred in New Jersey waters. The observation of numerous scallops in 1998 in Little Egg Harbor, New Jersey prompted questions regarding the density and reproductive periodicity of this population, as well as its origin. New Jersey is thought to be the point of contact between the A. i. irradians and A. i. concentricus sub-species, and the return of scallops suggests recruitment of larvae from extant populations north or south of New Jersey, or from a small, remnant local population. It was the goal of this research to investigate the distribution, reproduction and genetic structure of New Jersey bay scallops.

STUDY SITE

Investigations were conducted during 1998 and 1999 in Little Egg Harbor, New Jersey, U.S.A. (39°35'N, 74°14'W; Fig. 1), which is located in the central portion of the Mid-Atlantic Bight. Little Egg Harbor is a relatively unimpacted region of coastal New Jersey and is part of the Jacques Cousteau National Estuarine Research Reserve (Psuty et al. 1993). It is a polyhaline estuary protected by a barrier island. It is relatively shallow (average depth at MLW = 1.7 m, Durand 1984) and submerged aquatic vegetation covers approximately 1.305 hectares of the bottom (Bologna et al. 2000). Seasonal water temperatures range from -2° C to 28° C (Able et al. 1992) with an average tidal range of about 0.7 m (Chizmadia et al. 1984).

MATERIALS AND METHODS

Population Assessment

Argopecten irradians densities were assessed at four sites in Little Egg Harbor, New Jersey during May 1998 and 1999. Density was determined using 10-m x 1-m transects haphazardly lain out in shallow (<1.5 m depth) Zostera marina beds (Table 1,
Fig. 1: (1) West Ham Island (n = 16 transects, 1998; n = 10, 1999), (2) North Ham Island (n = 17, n = 10), (3) Northeast Ham Island (n = 14, n = 10), and (4) Marsh Elder Island (n = 8, n = 10). They were sampled by snorkeling the length of the transect and collecting all scallops within 50 cm of the transect line (1-m width). Scallop abundance was compared among sites and between years using a two-way ANOVA with site and year as independent variables and scallop abundance as the dependent variable. The size structure of the population was assessed monthly from visually located field-collected individuals during 1998. Size frequency distributions were generated for months in which at least 16 individuals were collected to assess the potential age structure of the population.

Reproduction

Visual inspection of the gonad condition and calculation of a Gonadal-Somatic Index (GSI) assessed scallop reproduction from collections on 10 dates from April 1998 to August 1999. Scallops were frozen and returned to the laboratory where shell height was measured to 0.05 mm and gonadal and somatic tissues were then dissected out. Visual condition of gonadal material for scallops was determined for each individual and assessed as undeveloped, ripe, very ripe, or post-spawn following the protocol of Bologn (1998). Reproductive and somatic tissues were then dried at 60°C for 72 hours and weighed (g dry weight). The GSI was calculated for each scallop using the following equation: GSI = (gonadal dry weight/total dry weight) x 100. Evidence of reproductive success was assessed by collection of small juveniles (<15 mm shell height).

Recruitment Habitat Assessment

Characterization of bay scallop habitat was assessed by collections of benthic cores in *Zostera marina* beds during March, April, May, June, July, and October 1998 to determine shoot density and plant biomass (n = 6 cores/month). The coring device (15.24 cm diameter x 0.1824 m²) was pushed into the substrate to a depth of 25 cm, capped, and removed from the sediment. Samples were frozen and returned to the laboratory. Shoot abundance was determined and samples were separated into *Z. marina* above ground (shoots) and below ground (rhizomes and roots) portions, and an algal-detritus fraction. Above ground *Z. marina* and algal-detritus were dried to constant weight at 80°C, then ashed at 500°C for eight hours to determine ash free dry weight (AFDW). Shoot abun-

**TABLE 1.**

*Argopecten irradians* density comparisons among sites in Little Egg Harbor, New Jersey (see Fig. 1) for 1998 and 1999.

<table>
<thead>
<tr>
<th>Site</th>
<th>Density</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
<td>1999</td>
</tr>
<tr>
<td>West Ham Island (WH)</td>
<td>16</td>
<td>0.12 ± 0.34</td>
</tr>
<tr>
<td>North Ham Island (NH)</td>
<td>17</td>
<td>1.69 ± 0.79</td>
</tr>
<tr>
<td>Northeast Ham Island (NEH)</td>
<td>14</td>
<td>0.21 ± 0.42</td>
</tr>
<tr>
<td>Marsh Elder Islands</td>
<td>8</td>
<td>0.25 ± 0.46</td>
</tr>
</tbody>
</table>

N indicates the number of transects conducted at each site during each year. Density values represent mean number of scallops encountered per 10-m transect ± one standard error.

* Represents significantly greater scallop density for North Ham Island site compared to others (P < 0.0001).

Figure 2. Bay Scallop Size Frequency Distribution. Size distributions for 1998 collections based on scallop shell height measurements (mm). Sample size (N) and average shell height (x) given for each month. Note y-axis scale change for October and the identified year classes for scallops represented in the sample.
TABLE 2.
Scallop reproductive potential: Visual gonad condition index.

<table>
<thead>
<tr>
<th></th>
<th>Mean shell height (mm)</th>
<th>Undeveloped</th>
<th>Ripe</th>
<th>Very ripe</th>
<th>Post-spawn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>43.0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>June</td>
<td>52.3</td>
<td>0</td>
<td>3</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>July</td>
<td>50.0</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>August</td>
<td>55.6</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>September</td>
<td>55.7</td>
<td>1</td>
<td>13</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>October</td>
<td>58.6</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>November</td>
<td>64.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>50.0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

*indicates the number of *Argopecten irradians* collected on each date for reproductive assessment. Values in the table represent the number of individuals exhibiting each condition for a sample.

Genetic Stock Assessment

Total DNA was extracted from 20 scallops collected in Little Egg Harbor during 1998 (PureGene extraction Kit, Gentra Systems, Inc.) and amplified using primers specific for an 833bp fragment of the 12s ribosomal and NADH dehydrogenase 1 subunit regions of the mtDNA genome. Polymerase chain reaction (PCR) amplifications were carried out in 50μl reaction volumes and were subjected to an initial denaturation step of 3 min at 94°C, followed by 40 cycles consisting of 30 sec at 94°C, 30 sec at 53°C and 1 min at 72°C. Each product was digested with 9 restriction endonucleases (Alu I, Ban I, Bgl I, BstHII A, Rsa I, Hinf I, SspF I, αTaq I and Tspl 09 I) following manufacturer's protocols (New England Biolabs, Beverly, MA). Digestion products were electrophoresed on 2% agarose gels and visualized using ethidium bromide.

Restriction fragment patterns were analyzed using the REAP (McElroy et al. 1992) and compared with data previously collected on scallop samples from New York (East Hampton), North Carolina (Core Sound, Bogue Sound), and Florida (Florida Bay, Mosessass, St. Joseph’s Bay). For each of the seven populations sampled, nucleotide divergences were estimated and corrected for within population variation (Nei 1987). Sample haplotype frequency distributions were tested for heterogeneity using contingency tables and a randomized chi-square test of independence (Roff and Bentzen 1989). Population structure among scallop samples was analyzed using a hierarchical analysis of molecular variance (AMOVA, Excoffier et al. 1992).

RESULTS

Population Assessment

During 1998, bay scallop densities were significantly greater from all Little Egg Harbor study sites compared to 1999 (F \(_{1,97} = 24.6; P < 0.0001\)), because no scallops were collected during 1999 transacts (Table 1). As such, a significant interaction occurred between year and site in the two-way ANOVA (F \(_{3,97} = 5.6; P < 0.001\)). Therefore, we conducted a post-hoc ANOVA comparing scallop abundance among sites for 1998. Results indicated significant among site differences in scallop density (F \(_{5,91} = 8.8; P < 0.0001\)), with density significantly greater for the North Hamm Island site (1.0 individual 10 m\(^2\)) compared to the other sites (Table 1). Sufficient population samples were collected during April, June, September, October, and November 1998 to assess the size structure of the population (Fig. 2). Based on these data, a single year class (45–75 mm shell height) was identified but a few individuals of a second year class (60–120 mm shell height) occurred in October.

Reproduction

Visual assessment of gonad condition in 1998 suggested that spawning occurred during September and early October, as evi-
enced by the prevalence of post-spawn individuals in October (Table 2). However, this result differs with the assessment of GSI, which showed maximum values in June (Fig. 3), corresponding with 75% of the individuals showing a very ripe gonad condition (Table 2). Despite these very high GSI values, the presence of settling individuals (<15 mm shell height n = 3) was noted only for October. This was true for both 1998 (6 and 12 mm shell height, Fig. 2) and in 1999 (9 mm). Based on these preliminary data, the peak recruitment period for New Jersey Argopecten irradians may be early fall.

Recruitment Habitat Assessment

During 1998 significant losses of recruitment habitat, Zostera marina, occurred in Little Egg Harbor. Macroalgae (e.g., Ulva, Gracilaria, Codium) increased in abundance in eelgrass beds, blanketing the bottom. This led to significant increases in algal biomass by June, with significant loading of algal and detrital material by July and continuing through to October (F = 11.3, P < 0.0001, Fig. 4). These changes to the system resulted in significant declines in eelgrass shoot density and biomass by July 1998 (F = 11.4, P < 0.0001, F = 8.9, P < 0.0001), with complete elimination of above ground Z. marina biomass in the study area by October 1998 (Fig. 4).

Genetic Stock Analysis

A total of 22 haplotypes were resolved in the analysis of 120 Argopecten irradians from the six populations between New York and Florida (Table 3). Haplotype diversity (the probability that a pair of individuals sampled from a population were different in mDNA haplotype) was moderate, averaging 0.53 (range from 0.1 in Rabbit Key, Florida to 0.82 in New York). Between-population nucleotide divergence estimates averaged 0.46% but did not show a clear correlation with geography. Curiously, the most northern populations (NY and NJ) exhibited lower divergence relative to Florida populations (Florida Bay, Homosassa and St. Joseph’s Bay) than when compared to the geographically closer North Carolina (Core and Bogue Sound) populations (Table 3). The New Jersey sample was equally distant from its adjacent population: 0.066% relative to North Carolina, 0.068% relative to New York. Haplotype frequency distributions were significantly different among surveyed populations (χ² = 250.53, P < 0.0001). Pair-wise comparisons revealed a lack of significant difference between the New Jersey and North Carolina samples (χ² = 29.78, P = 0.168) but highly significant differences between New Jersey and New York (χ² = 23.01, P < 0.0001).

Three working hypothesis regarding population structure in bay scallop were tested using AMOVA. The greatest amount of variation was accounted for with the New Jersey sample grouped with the North Carolina samples (alternate hypotheses grouped New Jersey with New York, or as a distinct New Jersey entity), supporting the result of the analysis of the haplotype frequency distributions. The majority of the variation (39.4%) was attributed to differences among regions (defined as North Atlantic (NY), South Atlantic (N, NC) and Gulf (FL)) while only a small fraction (1.8%) of the variation was accounted for by genetic differences among samples within defined regions (Table 4).

DISCUSSION

For species of economic value, assessing population structure and reproduction is essential for both wise management of healthy populations and conservation and enhancement of endangered populations. For bay scallops in New Jersey, some information exists regarding the commercial nature of the fishery and landings from preceding decades (Ford 1997), but virtually nothing is known about the ecology of this species. One feature of bay scallop ecology that is relatively well known for many other populations is reproductive effort. Our results indicate that bay scallops in New Jersey spawn in late summer or early fall (Table 2, Fig. 2), and recruit to eelgrass habitat in October, as evidenced by collection of a few newly recruited individuals in both 1998 and 1999. However, based on the assessment of gonadal condition index (Table 2) and the maximum GSI values (Fig. 3), we believe that scallops may also show a minor late-spring spawn. Although no recruits were collected during the summer, the visual gonadal condition index suggested post-spawn conditioning of bay scallops from July 1999 (Table 3). This pattern of reproduction appears to be opposite of populations from New York, which show maximum reproductive effort during May through August, with only minor contributions during the fall (Tettelbach et al. 1999). However, it is similar to the reproductive pattern of bay scallops from North Carolina, which exists a strong fall spawn and a much less well documented early spring event (Peterson et al. 1989).

Given that bay scallops may suffer high mortality after spawning (Garshelis 1963), significant research has focused on reproduction, reproductive conditioning and changes in biomass associated with gonad development (Bricelj et al. 1987a, Bricelj et al. 1987b). It has been shown that scallops show distinct peaks in spawning activity and these peaks differ temporally based on latitude of the populations (Sastre 1970, Barber & Blake 1983, Chenshaw et al. 1991). Although scallops do show peaks in reproductive activity, recruiting individuals (< 15 mm shell height) have been reported throughout the year, suggesting that trickle spawning may occur in some locations (Gutierrez 1980, Bricelj et al. 1987a, Bologna 1998). Although our data are limited in scope, we surmise that only the
Percent nucleotide divergence (Nel 1987) among populations of *Argopecten irradians* based on RFLP analysis of an 833bp mtDNA fragment (9 restriction enzymes).

<table>
<thead>
<tr>
<th></th>
<th>East Hampton</th>
<th>Little Egg Harbor</th>
<th>Bogue Sound</th>
<th>Core Sound</th>
<th>Rabbit Key</th>
<th>Homosassa</th>
<th>St Joseph Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Hampton, NY</td>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Egg Harbor, NJ</td>
<td>0.1300</td>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bogue Sound, NC</td>
<td>0.2813</td>
<td>0.0911</td>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Sound, NC</td>
<td>0.3370</td>
<td>0.0625</td>
<td></td>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rabbit Key, FL</td>
<td>0.9339</td>
<td>1.0320</td>
<td>1.2570</td>
<td>0.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homosassa, FL</td>
<td>0.4836</td>
<td>0.7250</td>
<td>0.9143</td>
<td>0.9728</td>
<td>0.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St Joseph Bay, FL</td>
<td>0.5290</td>
<td>0.6381</td>
<td>0.8468</td>
<td>0.8811</td>
<td>0.0408</td>
<td>0.0005</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

The recent sporadic occurrence of bay scallops in the inland bays of New Jersey might be attributed to one of two scenarios. First, these pulses of adults could be traced to an occasional successful reproductive event by a small resident population. Alternatively, these ephemeral populations may represent a chance recruitment of allochthonous larvae from more stable populations located north or south of New Jersey. These scenarios have different consequences with respect to genetic composition of the New Jersey scallops. The expectation under the first hypothesis is that the New Jersey scallops would be genetically distinct from scallops collected from adjacent populations. While it is true that the New Jersey population is not likely to have been isolated for sufficient time for major genetic divergence to have occurred, the presumed frequent bottlenecks of the population suggested by the absence of detectable numbers in most years would have resulted in genetic drift. Under the second hypothesis of episodic recruitment from adjacent populations, the expectation is that the New Jersey scallops would genetically resemble either *A. i. irradians* to the north or *A. i. concentricus* to the south.

The results of the statistical analysis clearly support a closer relationship of the New Jersey scallops with the populations sampled in North Carolina, despite the notable genetic distance between these samples (Table 3). This association is supported by the conventional interpretation of morphological data, which originally described the southern subspecies from type specimens collected from New Jersey. The genetic differentiation between New Jersey and North Carolina may be indicative of some restriction of genetic exchange, although the data presented here are insufficient to conclude that these populations are isolated from one another. The short larval duration of *A. irradians* (10–14 days) makes the probability of direct transport of larvae from North Carolina unlikely. While scallops are occasionally found in the inland bays of Maryland and Virginia, the ephemeral nature and low densities of these populations make them poor candidates as a source for larval export. The absence of evidence to support long distance larval transport in bay scallops is not uncommon. Arnold et al. (1998) found little evidence to support significant larval transport from “high” density populations (St. Joseph’s Bay and Steinshatchee) in northwest Florida to “low” density populations further to the south (Crystal River and Anclote). Other studies in the sounds of North Carolina and the Peconic Bay system in New York show a similar lack of recruitment in areas decimated by toxic algal events from adjacent unaffected areas over much smaller spatial scales (Peterson and Summerson 1992, Wenzel et al. 1993). As such, it is likely that the New Jersey population of bay scallops is a resident, albeit cryptic one.

Assessment of recruitment habitat provided novel insight into the ecology of New Jersey bay scallops. During 1998, juvenile bay scallops were observed in the field during October. While this event alone was not unexpected, the fact that the two recruiting juveniles (shell height 6 and 12 mm) were both attached to adults via byssal threads is intriguing. This behavior was most likely their response to the lack of above ground eelgrass biomass (Fig. 4). This behavior has been observed for Antarctic scallops, *Adamas- sum colbecki* (Berkman 1988), but observations of this occurring for *A. irradians* have not been recorded. Clearly, for an organism that is so intimately tied to seagrass as primary habitat, the loss of eelgrass signaled a significant loss of recruitment habitat. The loss of eelgrass also may have played a significant role in over-winter mortality. Field collections during November 1998 indicated that substantial passive burial of adults was occurring. Specifically, adults were frequently located within a recceded pit approximately 5–8 cm deep or adjacent to one with sediment funneling apparent on the dorsal shell. Although these observations were not quantified during this period, they suggest that sediment burial was occurring and may have had significant impacts on winter survival. Tettelbach et al. (1990) showed significant winter mortality due to burial for bay scallops in New York, and our observations of burial in 1998 and lack of adults in 1999 correspond to this trend.

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**TABLE 4.**

Hierarchical analysis of variance on the matrix of distances between scallop mtDNA haplotypes.

<table>
<thead>
<tr>
<th>Variance component</th>
<th>Variance</th>
<th>% Total</th>
<th>p</th>
<th>( \phi ) statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Among regions</td>
<td>0.00553</td>
<td>59.42</td>
<td>&lt;0.001</td>
<td>( \phi_1 = 0.549 )</td>
</tr>
<tr>
<td>Among populations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>within regions</td>
<td>0.00017</td>
<td>1.79</td>
<td>0.022</td>
<td>( \phi_1 = 0.044 )</td>
</tr>
<tr>
<td>Within populations</td>
<td>0.00361</td>
<td>38.79</td>
<td>&lt;0.001</td>
<td>( \phi_0 = 0.612 )</td>
</tr>
</tbody>
</table>

Population samples were grouped into three regions (New York; New Jersey and North Carolina; Florida). \( \phi \) statistics measure haplotype correlations and are analogous to the hierarchical F-statistics of Cockerham (1969, 1973). P values indicate the probability of finding a more extreme variance component and \( \phi \)-statistic than that observed by chance alone.
Eelgrass not only serves as a primary recruitment habitat for bay scallops, but the beds also alter water velocity, dampen wave energy, and stabilize sediments (Ponsseca et al. 1982, Fonseca & Fisher 1986). Consequently, the loss of eelgrass during the summer and fall of 1998 (Fig. 4) may have had direct effects on the abundance of settling bay scallops and also indirect effects on the population, in that the lack of sediment stability may have led to increased winter mortality through burial. These losses in eelgrass biomass correspond to the reduction in bay scallop population density during 1999 (Table 1), but not their elimination from the system.

Since the turn of the century, seagrasses have undergone dramatic declines worldwide due to both natural and anthropogenic sources (Phillips 1982, Cambridge et al. 1986, Robblee et al. 1991). Over the last 25 years, several studies have investigated the distribution of seagrass from coastal New Jersey and have shown significant declines in total coverage (R. Lathrop pers. comm., Bologaun unpubl. data). These declines parallel the loss of the commercial and recreational fishery for bay scallops in New Jersey as well (Ford 1997). If continued loss of Zostera marina habitat occurs, it may severely limit this population in the future.

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LITERATURE CITED


