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SPATIO-TEMPORAL DISTRIBUTION OF LARVAL *GOBIOSOMA BOSCA* IN WATERS ADJACENT TO NATURAL AND ALTERED MARSH-EDGE HABITATS OF MISSISSIPPI COASTAL WATERS

J. Read Hendon, Mark S. Peterson and Bruce H. Comyns

ABSTRACT

Larval naked gobies, *Gobiosoma bosc*, were collected monthly from October 1995 to September 1997 by beam plankton trawl from waters adjacent to natural *Juncus/Spartina* marsh-edge, natural sandy beach, and altered *Juncus/Spartina* marsh-edge habitats in Mississippi coastal waters. Altered marsh habitats consisted of two bulkheaded stations and one stretch of riprap. Abundances were significantly higher in waters adjacent to natural marsh-edge habitats than in those adjacent to altered habitats in year one ($P = 0.011$), suggesting that the physical nature of alteration may have caused reduced habitat suitability. Abundances also varied seasonally, with summer conditions of high water temperature, increasing tide height, intermediate depth, low dissolved oxygen, and clear skies being significantly related to high abundance of postflexion *G. bosc* in each year ($r^2 = 0.481$ and 0.276 , respectively). Year two abundances were lower than those of year one and not significantly different among habitats. There was also a noticeable shift in the reproductive strategy of *G. bosc* from a bimodal pattern in year one to a single reproductive peak in year two. This study illustrates the importance of natural *Juncus/Spartina* marsh-edge habitat to *G. bosc* reproduction/recruitment and by extension to the community structure of the Back Bay/Davis Bayou estuarine ecosystem.

Estuarine marsh-edge habitats, the ecotone between intertidal marsh grass and adjacent open water within 3 m of the water/shore edge (Baltz et al., 1993; Peterson and Turner, 1994), are highly productive, variable environments essential for both resident and transient fishes. Residents, such as *Gobiosoma bosc* and *Gobionellus boleosoma*, are abundant in these habitats despite large fluctuations in environmental and meteorological conditions (Baltz et al., 1993; Peterson and Turner, 1994). Many transients, such as sciaenids and penaeids, utilize marsh habitats seasonally as nursery areas for completion of early life-history stages (Rozas and Minello, 1997). Despite the ecological importance of these areas, marsh-edge habitats are highly vulnerable to anthropogenic influence, namely development, because of their value as waterfront property (Thomas, 1995). Development along the marsh-edge continues to substantially alter the physical nature of these habitats, presumably diminishing their suitability as permanent environments for residents and seasonal nursery grounds for transients (Hoss and Thayer, 1993; Waste, 1996).

Gobiids are common benthic fishes, inhabiting mud, sand, and reef habitats of shallow, estuarine waters in temperate and tropical regions (Dawson, 1969; Iglesias, 1981; Peterson and Turner, 1994). Recent studies of marsh-edge fishes along the Louisiana coast have shown that gobiids, including *G. bosc*, account for two of the three most abundant species of fish (Rakocinski et al., 1992; Baltz et al., 1993) and can contribute the second- and third-highest estimates of biomass relative to other fish species in that area (Miller and Guillory, 1980). Distribution of these abundant fishes is controlled mainly by habitat attributes (Weiderholm, 1987; Wilkins and Myers, 1992), as evident by the partitioning of gobiid species across different salinity regimes (Gill and Potter, 1993), varying densities of vegetation (Humphries and Potter, 1993), different depths (Baltz et al., 1993), and

even various sizes of openings of oyster shells (Crabtree and Middaugh, 1982). Although demersal and secretive as adults, *G. bosc* larvae are pelagic and are readily taken by plankton sampling gear (Shenker et al., 1983). After hatching, larvae (~2–3 mm) move up into the water column and remain pelagic before settlement on the substratum at ~12–15 mm. Shenker et al. (1983) found this pelagic behavior enabled *G. bosc* larvae in Maryland to move as far as 28 km upstream over a 1-mo period by ascending or descending within the water column depending upon the direction of tidal flow.

The importance of gobies to estuarine systems is exemplified by the roles they play within these systems. Gobies are abundant predators on polychaetes and small crustaceans, and, consequently, they play an important role in the structuring of benthic communities within estuaries (Fitzhugh and Fleeger, 1985). Gobies are also an important forage fish for several commercial and recreational fishes (Nelson, 1992). For example, gobiids constitute a portion of the diet of many sciaenids, including *Cynoscion nebulosus*, *Cynoscion regalis*, *Micropogonias undulatus*, *Pogonias cromis*, and *Sciaenops ocellatus* (Pearson, 1929; Gunter, 1945; Darnell, 1958; Dawson, 1966; Carr and Adams, 1973), as well as comprising about 50% of the diet of juvenile striped bass *Morone saxatilis* (Wass and Wright, 1969).

Due to their ubiquitous nature, their importance in estuarine food webs, and their high tolerance of physical conditions (Dawson, 1969), distribution patterns of gobies in waters adjacent to a variety of habitat edges can offer insight into certain anthropogenic effects on habitat quality. The objective of this study was to quantify the spatial and temporal distribution and relative abundance of larval *G. bosc* in waters adjacent to natural *Juncus*/*Spartina* marsh, natural sandy beach, and altered *Juncus*/*Spartina* marsh habitats over a 2-yr period.

MATERIALS AND METHODS

FIELD COLLECTIONS.—Larval *G. bosc* were collected monthly at 13 sites from Back Bay (Biloxi, MS) to Davis Bayou (Ocean Springs, MS) between 6 October 1995, and 10 September 1997 (Fig. 1). Sites were classified as waters adjacent to natural *Juncus*/*Spartina* marsh-edge (“natural marsh”, 7 sites), waters adjacent to natural sandy beach (“natural beach”, 3 sites), or waters adjacent to altered *Juncus*/*Spartina* marsh-edge (“altered marsh”, 3 sites). Altered marsh habitats included one stretch of riprap (Site 5) and two bulkheaded shoreline areas that previously contained *Juncus*/*Spartina* marsh grass (Sites 9 and 12). Sediments associated with natural and altered marsh habitats were composed of a relatively high percentage of fine-grain sand and mud, but sediments in natural marsh habitats had over four times the percentage of total organic carbon (%TOC) than those in altered marsh (Peterson et al., 2000). Sediments in natural beach habitats were primarily medium- to coarse-grain sand with a relatively high %TOC.

Collections were taken during daylight with a Renfro (1963) beam plankton trawl (BPL) fitted with 0.794 mm mesh outer netting and a 505 μm sleeve and cod end. Sampling involved pulling the net by hand for 46 m along a transect adjacent to the marsh edge unless low water levels caused by seasonal atmospheric forcing required sampling further from the edge. Samples were fixed in 10% formalin in the field and later transferred to 70% ethanol for storage.

Physical parameters including water temperature ($^{\circ}\text{C}$), salinity ($^{\circ}/_{\text{oo}}$), dissolved oxygen (DO, mg L^{-1}), turbidity (NTU), and water depth (cm) were measured at each site on each date. Shade was categorically ranked as full sun (1), partial sun (2), temporary full shade (3), or overcast (4). Wind speed (mph, converted to m s^{-1}) was measured at each site with a hand-held anemometer. Rainfall amount (cm) was obtained from the NOAA National Climate Data Center, Asheville, North Carolina, and tide height (cm) above mean low water was obtained in 30-min intervals for each sampling

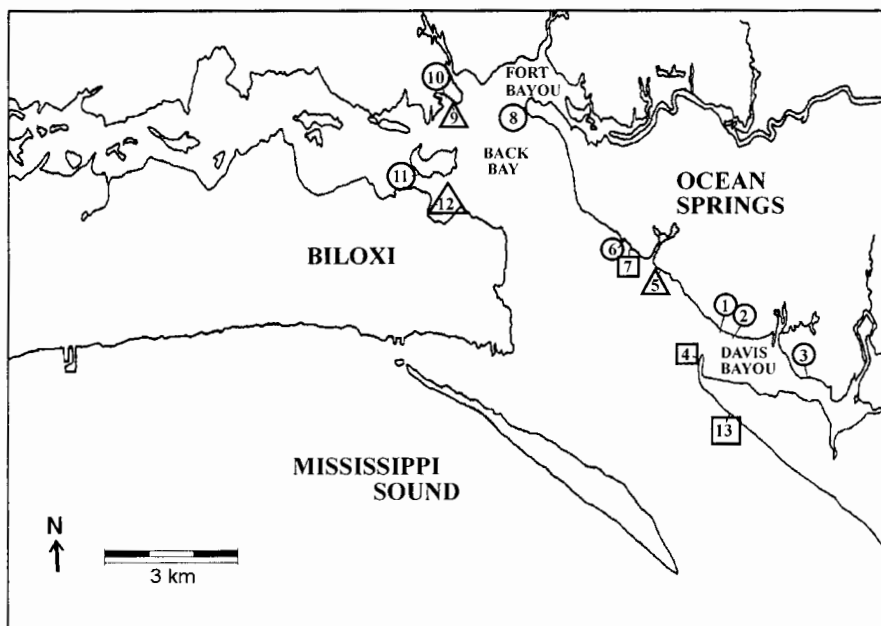


Figure 1. Sampling locations in Back Bay, Biloxi, and Davis Bayou, Ocean Springs, MS. ○ = natural *Juncus/Spartina* marsh site; □ = natural sandy beach site; Δ = altered *Juncus/Spartina* marsh site (sites 9 and 12 are bulkheads and site 5 consists of riprap).

date using MicroNautics, Inc., Tide.1 Program for the Back Bay area. This tide height calculation did not take wind direction or speed into account.

LABORATORY PROCEDURES.—Identification.—All gobies were identified to the lowest possible taxonomic level, counted, and standard length (SL) was measured with dial calipers or an ocular micrometer. Because fin rays and other meristic features can be difficult to count in small specimens, gobiids <15 mm SL were cleared and stained according to a revised protocol from Potthoff (1984). Specimens were categorized as preflexion, flexion, or postflexion larvae, following the definitions in Leis and Rennis (1983). Postflexion larvae ranged in length from 4.7 to 9.9 mm SL. *Gobiosoma bosc* were distinguished from other gobiid species by having seven dorsal spines, 13 second dorsal rays, and 11 anal rays (Dawson, 1969). Ray counts of small larvae were facilitated by counting pterygiophores that were evident after clearing and staining. *G. bosc* was further distinguished by the presence of a prominent postanal melanophore (D. Ruple, Nature Conservancy, Grand Bay, Alabama, pers. comm.). For unusually large collections, splits (3.9% of total collections) were taken for species enumeration and were later proportionally adjusted to the total number of individuals. Additionally, postflexion stage abundance within species was determined by measuring a subsample of up to 100 fish (11.7% of total collections) and then proportionally adjusting the subsample to the total numbers of fish. These final data were used in all statistical analyses.

STATISTICAL ANALYSES.—Collections were generally taken monthly, but during fall sampling frequency was increased to quantify larval sciaenids. For this study, these extra collections were not used, and one collection date was randomly selected from months in which multiple days were sampled ($n = 8$), yielding 23 collection dates.

Relative abundance of *G. bosc* (by habitat and date) and physical data both violated the homogeneity of variance and normality assumptions on both raw and transformed data, so nonparametric statistics were implemented for these analyses (Hendon, 1998). The Kruskal-Wallis (K-W) test was used to examine differences in larval *G. bosc* rank abundance among habitats ($n = 3$) within years. Months were grouped into four seasons with winter including December, January, February; spring

including March, April, May; summer including June, July, August; and fall including September, October, November. In reporting results, seasons were distinguished between years with a "-1" following seasons in the first year and a "-2" following seasons in the second year. Temporal abundance patterns of *G. bosc* were examined among seasons ($n = 4$) across years ($n = 2$) with a Friedman's test, the nonparametric equivalent of a one-way repeated measures ANOVA (SPSS, 1996). If significant differences were detected with the K-W or Friedman's test, the Mann-Whitney U-test (M-W) was used to separate the mean ranks of abundance among habitats and/or seasons, and then the sequential Bonferroni adjustment (Rice, 1989) was applied to obtain appropriately-adjusted P values. Note that while statistics were based on ranked abundance, actual abundances were plotted for clarity.

To examine the relationship between habitat variables and larval *G. bosc* abundance, a two-step multivariate procedure (Peterson and Vanderkooy, 1997) was used. First, principal components analysis (PCA) computed a correlation matrix based on mysid abundance (obtained from the same samples as the gobiids) and nine physical variables and then used varimax rotation to produce orthogonal and more interpretable factor loadings. Eigenvalues ≥ 1.00 were used to determine the number of meaningful principal components. Any variable that loaded onto a component at a value $\geq |0.50|$ was considered to make a significant contribution to interpreting that component (Peterson and Vanderkooy, 1997). In short, the PCA took the ten habitat variables and compressed them into four components that represent correlated habitat variables. The PCA factor scores were then compared to transformed $[\log_{10}(x+1)]$ abundances of larval *G. bosc* for each year with a stepwise multiple linear regression. Factor scores based on the habitat variables were also compared with a K-W test among habitats ($n = 3$) to determine habitat-specific patterns in these composite environmental variables. If a significant difference was detected ($P < 0.05$), the M-W test was used to separate the means. All descriptive data presented are means \pm SE unless otherwise noted.

RESULTS

Of the 26,348 gobiids collected over the 2-yr period, 24,213 (91.9%) were developed enough to be identified to species. Of these fishes, *G. bosc* accounted for 23,780 (98.2%), with 23,667 of these being postflexion individuals (99.5%) (Hendon, 1998). These postflexion larvae occurred in 36.4% of the samples, mainly from May through October in both years (Fig. 2). The greatest numbers of postflexion *G. bosc* were collected in May of year one and June of year two. Interestingly, two peaks in larval abundance were observed in year one, whereas only one peak was apparent in the second year (Fig. 2).

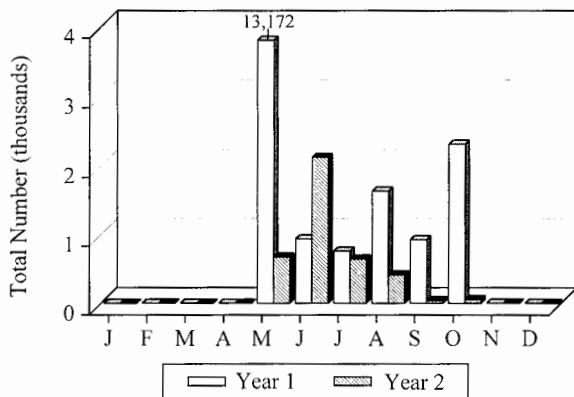


Figure 2. Monthly abundance (total number) of larval *Gobiosoma bosc* for both years of study (pooled among habitats).

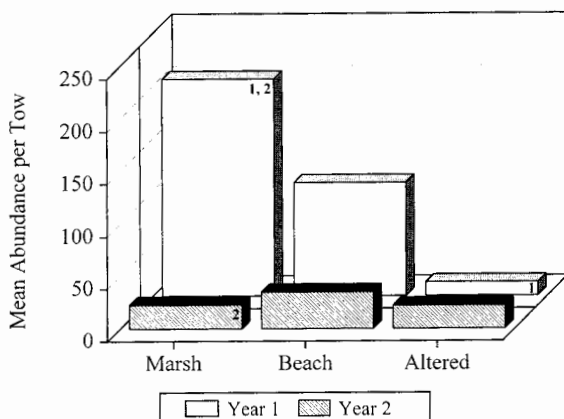


Figure 3. Mean abundance per standardized tow of postflexion *Gobiosoma bosc* among habitats for each year. ¹ denotes significant pairwise difference of mean ranks between habitat types ($P = 0.011$) after Bonferroni adjustment; ² denotes significant pairwise difference of mean ranks between years within habitat ($P = 0.013$). Year 1 = number of collections in natural marsh habitats = 76 and number in both natural beach and altered marsh = 33. Year 2 = number of collections in natural marsh habitats = 84 and number in both natural beach and altered marsh habitats = 36.

Mean abundance per standardized tow of *G. bosc* (both years combined) was highest in natural marsh habitat (110.19 ± 61.82), followed by natural beach (69.91 ± 37.18), and then altered marsh (17.80 ± 8.35 ; Fig. 3). Almost 10,000 postflexion *G. bosc* were found in a single BPL collection in May 1996 in natural marsh habitat (site 6), whereas the largest collection in altered marsh (site 12) contained only 549 larvae. A marginal overall difference in abundance was found for year one among habitats (K-W test, $\chi^2 = 6.00$, $n = 3$, $P = 0.050$), while no significant difference among habitats was detected for year two abundances (K-W test, $\chi^2 = 0.53$, $n = 3$, $P = 0.768$). There was a significant pairwise difference between year one rank abundance in natural marsh habitat (mean_{rank} = 42.09) and rank abundance in altered marsh (Fig. 3; = mean_{rank} = 26.91, M-W test, $Z = -2.54$, $n = 2$, $P = 0.011$). Analysis of these data without the single collection of 9,808 larvae from natural marsh habitat showed only a 0.014 decrease in significance (K-W test, $\chi^2 = 5.48$, $n = 3$, $P = 0.064$), with the pairwise difference still detected between natural marsh (mean_{rank} = 32.50) and altered marsh (mean_{rank} = 20.76, M-W test, $Z = -2.44$, $n = 2$, $P = 0.015$) abundances. Comparisons between natural marsh and natural beach (mean_{rank} = 37.00, $P = 0.483$) and natural beach and altered marsh ($P = 0.260$) showed no difference in mean rank abundance for year one data. No interannual difference in rank abundance was detected for natural beach or altered marsh habitat (M-W test, $Z \geq -1.92$, $n = 2$, $P \geq 0.054$); however, in natural marsh habitats, year two rank abundance was significantly lower (mean_{rank} = 72.46) than that for year one (Fig. 3; mean_{rank} = 89.39, M-W test, $Z = -2.50$, $n = 2$, $P = 0.013$).

Unfortunately, not all three habitat types were equally represented along the estuarine gradient. Collections were taken within the lower and middle regions of the estuary, but both bulkheaded sites were located in the mid-estuarine area. A comparison between the two sites located on opposing banks at the mouth of Fort Bayou (Fig. 1; sites 8 and 9) provided the most meaningful comparison between a bulkhead and a natural marsh site. High abundances of naked gobies were found at site 8 (natural marsh), whereas relatively few larvae were collected at site 9 (altered marsh; Fig. 4A). Two other natural marsh sites

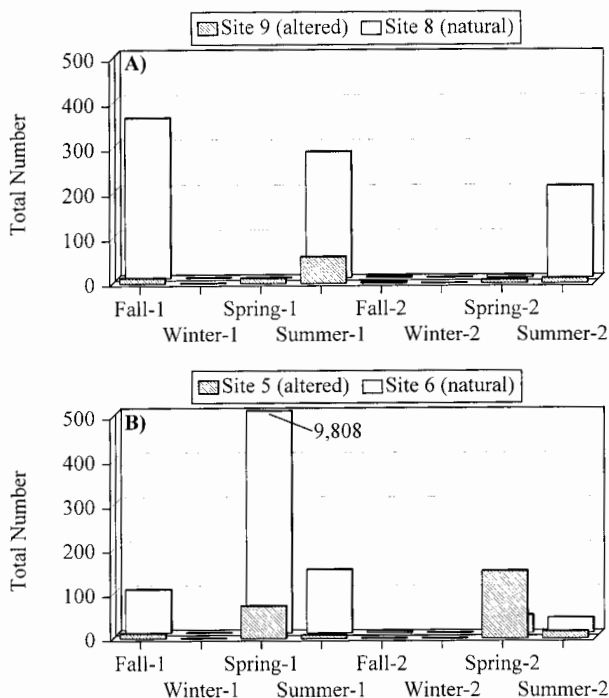


Figure 4. Comparisons of relative abundance of larval *Gobiosoma bosc* between adjacent natural *Juncus/Spartina* marsh and altered *Juncus/Spartina* marsh in middle to upper estuary study sites. Panel A is a comparison of *G. bosc* abundance between adjacent sites 8 and 9; panel B is a comparison of abundance between adjacent sites 5 and 6. Numbers -1 and -2 refer to the first and second years of the study, respectively.

(Fig. 1; sites 10 and 11) were located in the vicinity of the bulkheaded sites, but were associated with relatively low abundances of larvae for several potential reasons. Site 10 was characteristic of an erosional marsh-edge, with relatively deep water continuing to the edge of the marsh grass, which appeared to seldom be inundated by rising tides. Site 11 was located in close proximity to the Back Bay ship channel, a commercial shrimping vessel harbor, and a petroleum terminal, each of which may have had a detrimental effect on the abundance of larval *G. bosc* at this site. A clear distinction was found between abundances of larval *G. bosc* at the ripped shoreline (site 5) and at a nearby stretch of natural *Juncus/Spartina* marsh (site 6; Fig. 4B). When larval gobies were numerous during the first year of study, abundances were on average an order of magnitude greater at the natural marsh site.

Of the ten habitat variables entered into the PCA, four components were extracted which explained 71.65% of the total variance in all habitat data (Table 1). PC-I explained 29.24% of the total variance in the original variables, with temperature and tide height having strong positive loadings, depth having a moderate positive loading, and both DO and shade having strong negative loadings. PC-I illustrates the seasonal trends in environmental variables of late spring through early fall in local marsh habitats, which are characterized by high temperature and tide height, intermediate depth, low DO, and clear skies. Mean rank abundance of *G. bosc* varied among seasons in year one in natural marsh habitat (Friedman's Repeated Measures ANOVA, $\chi^2 = 12.26$, $n = 4$, $P = 0.007$),

Table 1. Factor loadings on principal components I to IV (eigenvalues > 1) after varimax rotation. Cumulative variance (%) explained in parentheses. Factor loadings $\geq |0.500|$ are considered to make a significant contribution to interpreting each component. The Kaiser-Meyer-Olin (KMO) measure of sampling adequacy was acceptable (KMO = 0.665), and Bartlett's test of sphericity ($\chi^2 = 963.57$, $n = 45$, $P = 0.000$) showed that non-zero correlations existed at the 0.05 significance level. Variables in bold loaded onto the various PC axes.

Variable	PC-I (29.24%)	PC-II (45.21%)	PC-III (60.56%)	PC-IV (71.65%)
Temperature	0.888	0.150	-0.044	-0.060
Dissolved Oxygen	-0.805	-0.169	0.142	0.033
Depth	0.514	-0.049	-0.054	0.297
Shade	-0.608	0.461	0.133	-0.142
Tide Height	0.904	-0.184	0.018	-0.076
Salinity	-0.087	0.727	-0.079	0.316
Rainfall	0.120	0.872	0.027	-0.101
Turbidity	-0.045	-0.004	0.863	-0.024
Wind Speed	-0.118	-0.008	0.860	0.008
Mysid Abundance	0.023	0.090	0.005	0.938

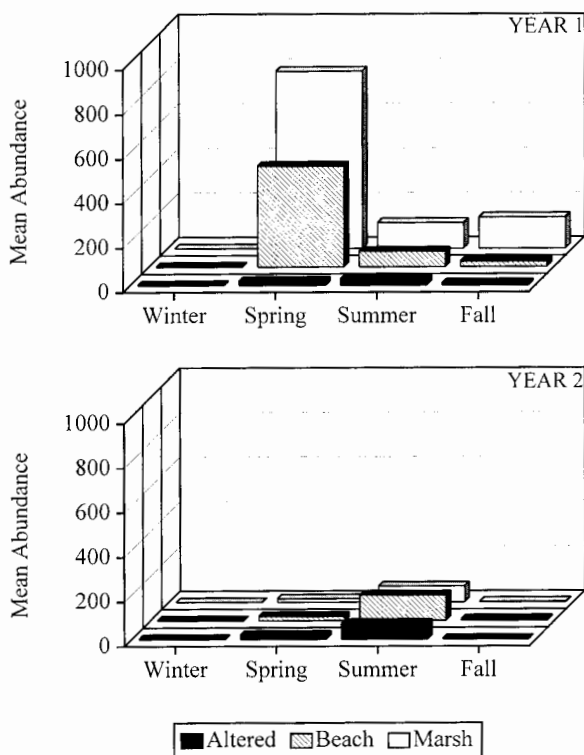


Figure 5. Mean abundance of postflexion *Gobiosoma bosci* among seasons and habitats for each year. Number of collections in natural marsh habitats = 21 for all seasons except spring of year 1 ($n = 13$) and number of collections in natural beach and altered marsh habitats = 9 for all seasons except spring of year 1 ($n = 6$).

Table 2. Statistics for stepwise regression of transformed postflexion naked goby abundance [$\log_{10}(x+1)$] based on raw factor loadings for principal components that loaded into regression model.

Component(s)	Year	y-intercept	slope	r ²	F-value	P-value
PC-I	1	0.697	0.667	0.481	131.94	0.000
PC-I + PC-IV	1	PC-I = 0.689 PC-IV = 0.214	PC-I = 0.660 PC-IV = 0.169	0.524	78.70	0.000
PC-I	2	0.530	0.406	0.276	60.19	0.000

being higher in both fall (mean_{rank} = 2.85) and summer (mean_{rank} = 3.08) compared to winter (mean_{rank} = 1.54) (Fig. 5). Seasonal differences (habitats combined) in abundance in year two were found for every pairwise comparison of summer (mean_{rank} = 3.45), spring (mean_{rank} = 2.45), fall (mean_{rank} = 2.38), and winter (mean_{rank} = 1.72), with the exception of that between spring and fall. Habitats were combined for the year two comparison among seasons because no overall statistical difference existed among habitats in this year. There was a significant relationship between PC-I factor scores and postflexion *G. bosc* abundance in both years (Table 2), in which PC-I explained 48.1% of the variability in abundance in year one and 27.6% of the variability in year two (Fig. 6). However, the mean ranks of PC-I factor scores which represent temperature, tide height, depth, DO, and shade did not differ significantly among habitats (K-W test, $\chi^2 = 2.17$, $n = 3$, $P = 0.339$).

PC-II loaded positively for both salinity and rainfall and explained 15.97% of the total variance in the original variables (Table 1). This component illustrates a different aspect of local seasonal trends, as rainfall was generally greater in the summer months, and salinity was moderate throughout summer, fall, and winter months. PC-II factor scores failed to load into the stepwise linear regression for either year, and the K-W test comparing PC-II factor scores among habitats detected no overall habitat difference ($\chi^2 = 5.272$; $n = 3$; $P = 0.072$).

PC-III loaded positively for turbidity and wind speed and explained 15.34% of the total variance in the original variables (Table 1). These two variables would be expected to load on the same component as higher wind speeds would tend to cause greater wave action and subsequent increased turbidity. Transformed abundance did not correlate with factor scores of PC-III, although *Gobiosoma bosc* abundances were generally higher during spring when intermediate to high turbidity (~28 NTU) and wind speeds were common. Comparison of PC-III factor scores among habitats by the K-W test yielded an overall difference ($\chi^2 = 13.886$, $n = 3$, $P = 0.001$), with a significant difference in ranks between the more turbid waters adjacent to natural sandy beach (mean_{rank} = 183.14) and those adjacent to natural marsh (mean_{rank} = 143.19, M-W U-test, $Z = -3.20$, $n = 2$, $P = 0.001$), as well as between natural beach and altered marsh (mean_{rank} = 132.75, M-W U-test, $Z = -3.43$, $n = 2$, $P = 0.001$). Natural marsh and altered marsh did not differ in mean rank for PC-III factor scores (M-W U-test, $Z = -0.83$, $n = 2$, $P = 0.407$).

Mysid abundance had a strong positive loading on PC-IV and explained 11.09% of the total variance (Table 1). This was largely due to the relatively low abundance of mysids in spring and summer when highest abundances of *G. bosc* were found. Factor scores of PC-IV were different among habitats (K-W test, $\chi^2 = 15.73$, $n = 3$, $P = 0.000$), with M-W showing a significant difference of mean rank abundance between altered marsh (mean_{rank} = 185.07) and natural marsh (mean_{rank} = 143.14, M-W U-test, $Z = -3.36$, $n = 2$, $P = 0.001$).

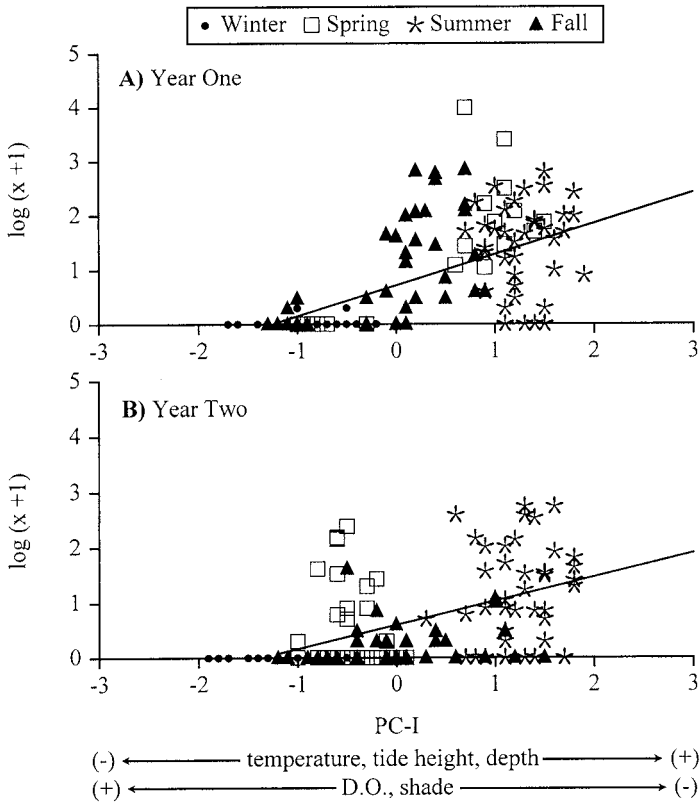


Figure 6. A) Stepwise regression of $\log_{10}(x+1)$ abundance of postflexion *Gobiosoma bosc* compared to PC-I factor loadings for year 1 ($r^2 = 0.481$; $y = 0.697x + 0.667$). B) Stepwise regression of $\log_{10}(x+1)$ abundance of postflexion *G. bosc* compared to PC-I factor loadings for year 2 ($r^2 = 0.276$; $y = 0.530x + 0.406$).

as well as between altered marsh and natural beach (mean_{rank} = 130.93, M-W U-test, $Z = -3.70$, $n = 2$, $P = 0.000$). No difference in PC-IV factor scores was found between natural marsh and natural beach habitats (M-W U-test, $Z = -0.97$, $n = 2$, $P = 0.333$).

DISCUSSION

Larval *G. bosc* were an abundant component of the fish assemblage within waters adjacent to marsh-edge habitat in Mississippi, accounting for 47% of the abundance of all fishes collected (Peterson et al., 2000). Larval *G. bosc* were abundant from May through October, corroborating published accounts of the breeding season for *G. bosc* (Dawson, 1966; Dahlberg and Conyers, 1973; Nero, 1976). Abundances of *G. bosc* larvae collected during the first year of the study were an order of magnitude greater than larval abundances found during the second year. Also, during year one, larval abundance peaked in May and again in October, while larval abundance in year two was much lower and peaked only once in June. This single peak in year two deviates from the bimodal spawning strategy reported by Conn and Bechler (1996) for *G. bosc* in Texas. Dahlberg and Conyers

(1973) found that reproductive strategies of this species are linked to water temperatures, so it is likely that spawning of *G. bosc* was affected by the 3°C reduction in water temperature in spring of year two compared to the previous spring. This may have caused a delay in spawning until near June of the second year, and the energetic requirements for two large reproductive outputs may not have been possible during the shorter spawning period. The lower spring-2 water temperatures may have been caused by the El Niño-Southern Oscillation event (i.e., Childers et al., 1990) of 1997. The shift in reproductive strategy between years illustrates the plasticity in life history strategies of *G. bosc* and also emphasizes the importance of multi-year sampling in determining certain biological and ecological phenomena.

The annual fluctuation in abundance of larval *G. bosc* was likely due to the variable nature of the local estuarine ecosystem between years. The lower seasonal water temperatures at the beginning of the spawning season in year two not only modified the spawning strategy of *G. bosc* but also significantly reduced abundances of larvae at natural marsh habitats. In addition to an overall decrease in year two abundance, the distribution of larval *G. bosc* among sites was increasingly patchy compared to the previous year, with no evidence of an association between abundance and habitat. On average, year two abundances were fairly equal among habitats, with natural beach replacing natural marsh as the most abundant habitat (based on annual mean abundance). Distribution and abundance patterns of larval *G. bosc* are thus probably influenced not only by habitat but also by annual variation in physical-chemical components within the local estuary.

The importance of *G. bosc* to the marsh-edge community has been typically underestimated, as only 10 of 40 studies reviewed (Hendon, 1998) showed a relatively high abundance of gobiids (>13% of total species abundance) within estuarine/marsh communities. For example, Peterson and Ross (1991) found juvenile/adult *G. boleosoma* to be the dominant gobiid in shallow habitats along a Mississippi riverine-estuarine gradient using seines, whereas larval *G. bosc* were dominant in abundance in both years of the present study using a BPL. The underestimation of gobiid abundance in estuarine habitats may be a function of interannual variability, but the most parsimonious explanation is the inadequacy of traditional gear types such as seines, trawls, etc., in collecting larval and post-larval fishes (Hendon, 1998). The importance of *G. bosc* to estuarine and marsh-edge production is apparent by the abundance of larvae (de Sylva, 1978; Allen and Barker, 1990) which are an abundant food source for young piscivorous fishes maturing within the estuarine environment, such as spotted seatrout, red drum, and Atlantic croaker (Pearson, 1929; Peterson and Ross, 1991).

During year one, when the greatest numbers of larval *G. bosc* were collected, larvae were an order of magnitude more abundant in waters adjacent to natural marsh-edge than in waters adjacent to altered marsh-edge. In interpreting these results, it is important to recall that there was a lack of a significant difference in PC-I, PC-II, and PC-III factor scores between natural marsh and altered marsh habitats. Because these components represent a number of known meaningful non-biological variables of the habitats surveyed and did not differ between these habitat types, we infer that something related to the physical landscape at each of the habitat types was likely a controlling factor in determining *G. bosc* abundance.

It is not possible from our data to determine whether the relatively low abundance of *G. bosc* larvae in waters adjacent to altered marsh-edge was due to decreased reproduction and survivorship, to emigration of larvae to more preferable habitat, or to the apparently

patchy distribution of the spawning adults (in year two). For example, the larvae of several species of gobies, including *G. bosc*, have the ability to use selective tidal transport to migrate along an estuarine gradient (Shenker et al., 1983; Bell and Brown, 1995). The ability to descend or ascend through the water column to take advantage of tidal flow demonstrates that postflexion *G. bosc* have the ability to actively move into favorable habitats or depart unfavorable habitats. Tidal flow in estuaries of the northern Gulf of Mexico is relatively small (tidal height <1 m), but there is ample water movement to transport larvae between the different habitat types described in this study. In addition, during spring when larval gobies were abundant, water movement is often increased by atmospheric forcing caused by the passage of cold fronts. Whatever the reason, our data indicate that the alteration of natural *Juncus/Spartina* marsh reduces habitat quality by removing access to the marsh surface, which is likely detrimental to the production or maintenance of the demersal resident nekton, like gobies. Further, if this generally ubiquitous, euryplastic demersal resident species is continually found in low numbers along altered *Juncus/Spartina* habitat, less tolerant, recreationally-important transient species may be even more susceptible to the effects of physical alteration on these estuarine landscapes. Subsequent declines in these recreational and commercial stocks because of lost feeding and/or nursery habitat may thus have detrimental effects on local economies (Thomas, 1995).

Abood and Metzger (1996) asserted that there is difficulty in distinguishing between anthropogenic and natural impacts on estuarine community assemblages, but many studies assessing impacted habitats have shown that reduced habitat quality has resulted in lower diversity and abundance of organisms within altered areas (Herke et al., 1987; Herke, 1995; Hoese and Konikoff, 1995; Simenstad and Fresh, 1995; Jude and DeBoe, 1996; Able et al., 1998). For example, semi-impounded areas in Louisiana, similar to bulkheaded sites 9 and 12 of the present study, were found to support only relatively low abundances of several fisheries species (Herke et al., 1987). In these semi-impounded habitats, *Farfantepenaeus aztecus* were four times less abundant than in natural marsh areas. In a similar study by Mock (1967) in Galveston Bay, Texas, *F. aztecus* were 2.5 times more abundant, and *Litopenaeus setiferus* were 12.5 times more abundant in natural marsh than in bulkheaded areas. Lower abundance of these species at bulkheads was attributed to sediment changes (lower organic carbon content), increased water depths, and loss of attached vegetation, each of which was apparent at the bulkheaded sites in the present study. The loss of vegetation at bulkheads shown by Mock (1967) is particularly relevant to the present study, as Rozas and Minello (1998) found significantly lower abundances of *G. bosc* in non-vegetated muddy bottoms in relation to vegetated habitats. Hoese and Konikoff (1995) further showed that water control within impoundments generally resulted in the presence of larger individuals because of reduced predation pressure and/or decreased competition and, as a result, recruitment of larvae and small juveniles into the area decreased. Despite their ecological harm, impoundments along the marsh-edge have become more common as private landowners attempt to reduce land loss to marsh areas (Herke, 1995).

While impounding marsh is a common, ecologically-harmful practice, the addition of gravel or riprap, as was done at site 5, has also been shown to have detrimental effects on estuarine community structure and abundance. In Pacific Northwest estuaries, Simenstad and Fresh (1995) found that the addition of gravel to one estuarine mud flat enhanced clam production but significantly reduced abundances of certain invertebrate taxa that

are important prey for early life stages of pleuronectid flounder. In another habitat modification, the placement of riprap along natural sand flats within the St. Clair River in Michigan supplied settlement habitat for the zebra mussel, *Dreissena polymorpha*. The immigration by the zebra mussel into this formerly unaltered habitat consequently fostered an increase in population growth of an introduced species, the round goby, *Neogobius melanostomus*, which shifted community dynamics of the system (Jude and DeBoe, 1996).

In conclusion, *G. bosc* is a more abundant component of marsh-edge communities of the northcentral Gulf of Mexico than previously thought, and it is likely that the larvae of this species are a productive link in the trophic web of the estuarine ecosystem. Also, this species is apparently flexible enough in its life history strategies to adjust spawning based on certain environmental fluctuations, such as those observed in water temperature, presumably to maximize offspring survival. The high abundance of this demersal resident species in natural marsh habitat relative to altered habitat emphasizes the importance of unaltered *Juncus/Spartina* marsh as essential fish habitat. The balance of estuarine ecosystems can be affected by habitat alteration from direct effects, such as habitat loss or degradation, affecting multiple species in the same manner, and/or indirect effects, such as lowered abundances of certain trophic-link-species, e.g., gobiids, affecting both lower and higher levels of the food web. Natural *Juncus/Spartina* marsh habitats are thus both ecologically and economically important (Thomas, 1995), as many species, including numerous commercial and recreational taxa, may be significantly affected by their modification.

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