Abstract

Former salt hay farms in Delaware Bay have been the site of extensive restorations aimed at restoring tidal flow to the sites, encouraging Spartina alterniflora (smooth cordgrass) recolonization and creating high-quality juvenile fish habitat. We assessed the 234 ha Dennis Township restoration site as habitat for juvenile Cynoscion regalis (weakfish), Leiostomus xanthurus (spot) and Micropogonias undulatus (Atlantic croaker) by comparing abundance, prey types consumed, stomach fullness and condition factor at the restored site and at a nearby reference marsh, Moores Beach. The three sciaenid species were equally or more abundant at the restored marsh. Measures of feeding were generally equal or higher at the restored site and stomach fullness was equal to or significantly higher at the restored marsh compared with the reference marsh. Fish condition, as measured by predicted weight-at-length, was generally at least equal between the sites and was occasionally higher at the restored site. At both sites, a seasonal pattern typical of mid-Atlantic estuaries of recruitment, ontogenetic change in food habits and emigration of transient fishes was apparent. Three years following restoration, the Dennis Township site provided equivalent to enhanced conditions for feeding and growth for large numbers of juvenile sciaenid fish, compared to a nearby reference site.

Keywords: Marsh restoration, Delaware Bay, Food habits, Juvenile fish, Sciaenidae

1. Introduction

Wetland creation and restoration is of increasing importance in the United States as public policies mandate wetland mitigation projects to offset habitat losses and other environmental impacts (Zedler, 1996; Anderson and Dugger, 1998). One of the most ambitious of such projects is ongoing in the mesohaline region of Delaware Bay, where nearly 1780 ha of previously diked salt hay farms have undergone restoration since 1996 by the Public Service Enterprise Group (PSEG), as required by a permit issued to operate the company’s Salem Generating Facility (Weinstein et al.,...
Prior to restoration, perimeter dikes surrounded these sites, preventing regular, diurnal tides from flooding the marsh plain and eliminating marsh creek channels. Together, these resulted in the colonization of the sites by *Spartina patens* (salt hay grass) and other high marsh plant species and the loss of access to the marsh by natant fauna. PSEG restored the sites by selectively breaching the dikes and excavating new channels in the marsh surface with the goal of restoring a natural flooding–draining cycle (hydroperiod) to the marshes and promoting the subsequent recolonization of *Spartina alterniflora* (smooth cordgrass; Weinstein et al., 1997, 2001).

The stated objective of these restorations was to create salt marshes with the structural and functional attributes of natural marshes, and further, that the marshes would promote the production of the young of transient marine fishes that use salt marshes during their early life history (Weinstein et al., 1997). Reference marshes were selected near the restoration sites to act as standards against which the outcomes of the restorations could be measured (Weinstein et al., 1997; Zedler et al., 1997; Anderson and Dugger, 1998).

Previous evaluations of the restored sites have shown that they were inhabited by typical resident and transient fish fauna shortly after restoration (Able et al., 2000, 2004). One to two years following restoration, fish size, assemblage structure and growth of the most abundant species, *Micropogonias undulatus* (Atlantic croaker), *Leiostomus xanthurus* (spot) and *M. undulatus*, at one restored marsh and at a nearby reference marsh. Sciaenids have dominated catches at these marshes (Able et al., 2000, 2004), and members of this family often dominate estuarine fish assemblages on the Atlantic and Gulf coasts of the US (Chao and Musick, 1977; Bozeman and Dean, 1980; Able and Fahay, 1998), making the response of sciaenids important to the assessment of many restorations. Furthermore, these three species exhibit distinctly different feeding morphologies and behaviors (Chao and Musick, 1977). They consume prey of different sizes and types from in the sediments to the sediment boundary and the water column (Nemerson, 2001; Nemerson and Able, 2004). Taken together, they provide valuable information on how fish of disparate feeding modes responded to restoration.

High food availability is one of the primary functional attributes of good juvenile fish habitat (Teal, 1962; Nixon, 1980; Boesch and Turner, 1984; Barry et al., 1996; Kneib, 1997; Craig and Crowder, 2000), and as such fish feeding is an appropriate attribute to measure when assessing marsh function (Shreffler et al., 1992; Simenstad and Thom, 1996; Llanso et al., 1998; Williams and Zedler, 1999). We assessed fish condition in the sites because higher weight at length can be correlated with increased future survival in juvenile fish (Grant and Brown, 1999; Hales and Able, 2001). Specifically, we tested the null hypotheses that per capita prey consumption, diet composition and fish condition were equal at the restored and reference site.

2. Materials and methods

2.1. Study sites

Construction associated with the restoration at a former salt hay farm, Dennis Township, began in January 1996 and was completed in August 1996 (Able et al., 2000, 2004). This site (Fig. 1) covered 234 ha and had 5500 m of created channels that ranged from about 6–10 m wide and about 2–3 m deep at high tide (Strait, 1997; Able et al., 2000). These dimensions are typical for salt marshes in Delaware Bay generally, and closely matched those at the reference site, Moores Beach. Although part of the Moores Beach site was also previously a salt hay farm until tidal flow was restored to the site by storms that breached the perimeter dikes in 1979 (Talbot et al., 1986), the area sampled in this study was relatively undisturbed and retained its natural drainage density (Able et al., 2000). Each site was located along an existing, large, natural creek feeding directly into Delaware Bay. West Creek at Dennis Township and Riggins Ditch at Moores Beach (Fig. 1).
Fig. 1. Map of Delaware Bay restored (Dennis Township) and reference (Moore's Beach) marshes and sampling sites. Numbers in Delaware Bay indicate distance (km) from the mouth of the bay.
2.2. Field sampling

The sampling effort for this study has been described in detail elsewhere (Able et al., 2000, 2004; Nemerson and Able, 2004). Briefly, fish in marsh creeks were sampled with a 4.9-m otter trawl (6 mm cod end mesh) monthly April–November 1997–1999, near the time of high tide. At each site, four replicate, 2 min tows, conducted against the tide, were completed at six stations located in representative marsh creeks (Fig. 1). Fish were also collected monthly, June–September, near low tide with a 20 m bag seine (6 mm mesh in the bag) at one location coincident with a trawling station at each site in 1997 and 1998 (Fig. 1). Fish retained for stomach contents analysis were stratified as follows: collected by otter trawl on the flood prior to high tide (“high flood”), collected by otter trawl on the ebb after high tide (“high ebb”), collected by seine on the ebb prior to low tide (“low ebb”) and collected by seine on the flood after low tide (“low flood”). Individuals of all three species were retained in 1997 and 1998, while only L. xanthurus and M. undulatus were retained for stomach contents analysis in 1999.

All fish caught in otter trawls were enumerated and a subsample of up to 20 individuals from each tow was measured to the nearest millimetre (fork length (FL) for fish with forked tails, total length (TL) for all others). Fish caught in seines were not enumerated and were not used in abundance analyses in this study, but were retained and handled in a manner identical to others retained for food habits analysis. All fish retained for food habits and length/weight analyses were either immersed in buffered 10% formalin (fish <140 mm) or injected with buffered 10% formalin and frozen (≥ 140 mm).

2.3. Laboratory procedures

In the laboratory, fish retained for food habits and condition analyses were sorted to species, measured to the nearest 0.5 mm FL or TL, and then pooled into 10 mm size classes up to 139.5 mm, 30 mm size classes from 140 to 199.5 mm and 100 mm size classes starting at 200 mm. The stomach contents of up to 12 individuals per size class and species (per sampling stratum) were retained, pooled in a common vial filled with a solution of rose bengal and 95% ethyl alcohol and the proportion by weight of each prey category was determined according to the sieve fractionation method of Carr and Adams (1972). Twelve fish per size class was deemed to be an adequate sample as prey diversity within samples of 1–12 fish began to asymptote at 7–8 fish per sample (Nemerson and Able, 2004). All fish retained for food habits analysis <140 mm were dried to constant weight at 80 °C and then weighed to the nearest 0.0001 g while all those ≥140 mm were weighed wet to the nearest 0.01 g. Occasionally, fish >140 mm were mistakenly immersed in formalin. These fish were dried to constant weight prior to weighing.

All prey items were identified to the lowest practical taxonomic level. For most analyses, fish prey was grouped into eight general categories. These prey categories were chosen to highlight different feeding modes, and consequently their names are not taxonomically precise (Table 1). For example, mysids, crustaceans and zooplankton were each assigned to discrete categories, although mysids can be considered zooplankton and both are crustaceans. Similarly, harpacticoid copepods, while crustaceans, were assigned to the microbenthos category. The categories are mutually exclusive with the following exception: all unidentified

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Names and constituents of prey categories used in trophic analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category name</td>
<td>Constituents</td>
</tr>
<tr>
<td>Annelid</td>
<td>All annelids including ampharetid, capitellid, cirratulid, nereid, phyllodocid, spionid polychaetes and oligochaetes</td>
</tr>
<tr>
<td>Crustacean</td>
<td>Cragon septemspinosa, gammarid amphipods, Palaemonetes spp., all other non-planktonic crustaceans</td>
</tr>
<tr>
<td>Fish</td>
<td>Anchoa mitchilli, Fundulus heteroclitus, Menidia menidia, all other fish</td>
</tr>
<tr>
<td>Microbenthos</td>
<td>Harpacticoid copepods, ostracods, insect larvae, nematodes</td>
</tr>
<tr>
<td>Mollusk</td>
<td>All mollusks including siphons</td>
</tr>
<tr>
<td>Mysid</td>
<td>All mysid shrimps (almost exclusively Neomysis americana)</td>
</tr>
<tr>
<td>Unidentified</td>
<td>All unidentified animal parts</td>
</tr>
<tr>
<td>Zooplankton</td>
<td>Calanoid copepods, decapod zoae, cumaceans</td>
</tr>
</tbody>
</table>
crustaceans and crustacean parts were assigned to the crustacean category, with the result that the crustacean category likely includes some quantity of unidentified mysids, microbenthos or zooplankton that would have been credited to these category had they been identifiable. Unidentified prey items were eliminated prior to the calculation of gravimetric prey proportions, but were included in the calculation of total fullness (see below).

All L. xanthurus and C. regalis included in this study were young-of-the-year (YOY) individuals. That is, they hatched early in the year of sampling and had yet to go through their first winter. M. undulatus are present in Delaware Bay marshes as both newly recruited YOY individuals, which first appear in August or September, and overwintered individuals that are present in the sites in April–September or October (Miller et al., 2003). We refer to these overwintered fish as age-1, even though they may not have passed their first birthday. These 2-year classes were treated as separate taxa in all analyses. A small number of age-1 or older L. xanthurus and C. regalis individuals (n < 5) were collected but not included in this study.

2.4. Data analysis

Principal components analysis (PCA) was used to compare general patterns of prey consumption over time at the restored and reference sites. This technique was useful in displaying the complex prey consumption data that were stratified by year, month, site, predator, tide stage and size class. The PCA was performed on individual samples (i.e. the pooled contents of 1–12 fish). The weight of each prey type in each sample was first divided by the number of fish in the sample and then square root transformed to reduce the undue influence of very heavy samples (ter Braak, 1995). Samples containing the stomach contents of 1–12 fish were weighted equally in this analysis. A modified version of the index of relative fullness (IRF), recommended by Herbold (1985), was used to assess the total quantity of prey found in each sample. This index seeks to remove possible bias introduced when the fullness of fish of different sizes are compared by using regression analysis to predict a maximum fullness for each fish, and then presenting the actual fullness of each fish as a percentage of this maximum. Detritus, sand, sediments and all other non-digestible items were eliminated prior to conducting fullness analyses. Unidentified prey was included in the fullness analyses. The IRF data were first standardized to unity (a small number of values were slightly greater than 1 as some fish were fuller than the value predicted by the regression) and then arcsine-square-root transformed prior to analysis (Herbold, 1985). This transformation helps to normalize percentage data (Sokal and Rohlf, 1995). Differences in IRF values between sites (within year, species and tide stage) were examined with the non-parametric Kruskal–Wallis test.

Catch-per-unit-effort (CPUE) was used to compare fish species abundance among sites, months, etc. CPUE was calculated by first taking the mean of the catch of a given species across each set of four replicate tows and then taking the mean of these values across the element of interest (e.g. site, year and month). This was necessary because the replicate tows were not independent observations. Note that the sample size used in the determination of standard error values is not the total numbers of tows, but rather the number of times a trawling station was visited.

Many methods have been used to assess the condition of fish (see Bolger and Connolly, 1989 for a review). All methods that use length–weight relationships are based on the assumption that a fish that weighs more at a given length is in superior condition to a fish that weighs less. Because the weight-to-length relationship of fish changes with fish size, methods that assign a single condition value to individual fish, such as the widely used Fulton condition factor, can be problematic when comparing groups of fish of different sizes (Bolger and Connolly, 1989). Other refinements of this method are also subject to possible bias when comparing groups of fish of different sizes (Bolger and Connolly, 1989). We used analysis of covariance (ANCOVA) to compare weight at length (Grecay and Targett, 1996), after determining the range of lengths for each species at each site and month and eliminating any fish longer or shorter than the intersection of the two ranges. This ensured that only fish of similar sizes were being com-
pared, eliminating bias due to fish size, and helped ensure that recent immigrations and emigrations of fish to and from the sites did not bias the results. All fish lengths and weights were log transformed prior to analysis to linearize the length–weight relationship. This analysis was run for each month and for each species after spring immigration appeared to be complete and before fall emigration appeared to begin because these events could bias the results. For example, if migrants were still arriving from outside a site, their physical condition would be based on factors outside the site. Similarly, after emigration began, the results could be biased if fish in the best condition tended to emigrate from one site preferentially. While these methods do not eliminate these possible biases, they do reduce them. If the regression relationships for a species and month were not parallel, no test for a site effect on fish weight at length could be performed. We concluded that a significant site effect existed when the length-adjusted mean weights at the sites differed significantly ($\alpha < 0.05$).

No condition analyses were performed on YOY $M. undulatus$ during the period of fall immigration to the sites.

3. Results

3.1. Abundance

The three sciaenids in this study were generally equally to more abundant at the restored site, with only scattered instances of greater monthly abundance at the reference site (Fig. 2). In all months sampled, $C. regalis$ were more abundant at the restored site, while $L. xanthurus$ were more abundant at the restored site in all months except June 1998 and June 1999. Similarly, age-1 $M. undulatus$ were more abundant at the restored site in all months, while YOY $M. undulatus$ were more abundant at the reference site only in November 1997, November 1999 and October 1998. Age-1 $M. undulatus$ were often more than an order of magnitude more abundant at the restored site, and in April 1998 and May 1999, were more than 500 times more abundant (Fig. 2).
3.2. Fish feeding

Most measures of feeding and prey composition indicated equal to enhanced feeding at the restored site compared to the reference site. *C. regalis* showed very similar tidal patterns of relative stomach fullness at both sites (Fig. 3), with no significant differences in IRF within year and tide stage. *C. regalis* stomachs were generally fullest during low tides at both sites. *L. xanthurus* displayed a different tidal feeding periodicity, with the highest values uniformly occurring on high ebb tides at both sites in all years (Fig. 4). In 1997 and 1998, *L. xanthurus* were significantly fuller (Kruskal–Wallis test, $p < 0.05$) at the restored marsh during high ebb tides, the time of most active feeding. All other comparisons of stomach fullness were similar between the restored and reference marshes for this species.

In all three years, age-1 *M. undulatus* tended to feed throughout the tidal cycle with intermediate and similar values on flood and ebb tides at both the restored and reference marshes (Fig. 5). The only significant comparisons, 1997 high flood and 1998 high flood and low ebb, indicated higher fullness at the restored marsh. Although there was considerable variability in the fullness of YOY *M. undulatus* across both sites and years, overall, fullness of this taxon was comparable at the restored and reference site (Fig. 6). Again, the only significant difference, 1998 high ebb, indicated greater fullness at the restored marsh. Young-of-the-year *M. undulatus* were not caught during low tide seining.

Seasonal prey utilization at high tide, as indicated by PCA, was generally similar for all three species during all 3 years at the reference and restored site (Fig. 7).
In the spring months, when most of the transient fishes are small, consumption was dominated by mysids and other small crustaceans. On the PCA biplot, many of these points occur in the lower left quadrant in proximity to the mysid and zooplankton vectors. In the summer and early fall months, the assemblage tends to diverge into more species-specific feeding modes characterized by larger prey items including decapod crustaceans, annelids and small fish. These points tend to be distributed across the upper left, upper right and lower right quadrants and appear near the vectors that best characterize their diets. For example, *C. regalis* points tend to be toward the left side of the biplot, indicating mysid and fish in the diet, while *L. xanthurus* points tend to be toward the right side of the biplot, indicating annelids, mollusks and microbenthos in the diet. Age-1 *M. undulatus* points are generally intermediate between the *C. regalis* and *L. xanthurus* points. In the fall, when YOY *M. undulatus* begin to recruit in large numbers...
and *L. xanthurus*, *C. regalis* and age-1 *M. undulatus* start to leave the marshes, consumption is again dominated by mysids and small crustaceans. These points again tend to appear in the lower left quadrant of the biplot. This general pattern is clearly evident at both restored and reference marshes (Fig. 7). A strong and similar seasonal signal was also present in the low tide PCA (Fig. 8). May and June samples tended to be located near September samples and were characterized by mysids, microbenthos and zooplankton and a lack of crustacean and fish prey, which characterized the July and August samples.

### 3.3. Condition

The weight-at-length (condition) analyses also support the conclusion that the restored site was able to provide at least equivalent habitat, relative to the reference marsh, to the three fish predators in this study (Table 2). Only once during the study did this analysis indicate significantly superior condition for fish captured at Moores Beach, while in 4 months fish captured at Dennis Township were heavier over the range of lengths analyzed (different length-adjusted mean weight, \( p < 0.05 \)). All other comparisons were either non-significant or no statistical test was possible due to non-parallel regression relationships. In June 1997, *L. xanthurus* were significantly heavier at Moores Beach than at Dennis Township, weighing 0.19 g more (dry weight) at 93 mm TL. All other significant differences in weight-at-length indicated superior condition for fish at the Dennis Township restoration site compared with the Moores Beach reference site, *L. xanthurus* in July 1998 and August 1999 and age-1 *M. undulatus* in September 1997 and July 1998 (Table 2).

### 4. Discussion

#### 4.1. Reference site suitability

Juvenile sciaenid fish were abundant and appeared to consume the quantities and types of prey needed to maintain good condition at the restored marsh dur-
Fig. 8. Principal components biplot for stomach contents data of three sciaenid species collected at low tide in Delaware Bay marsh creeks 1997–1999. Small numbers next to plot symbols represent the month of collection. Filled symbols represent samples from the restored marsh; open samples the reference marsh. Samples for 1997 are plotted in red, samples for 1998 in green and samples for 1999 in blue. Young-of-the-year Micropogonias undulatus symbols are marked with a dot (○). Each plotted point is the centroid of all observations for that species/site/month/year. Vectors show the loading of each prey category on the principal component axes. Prey categories are as follows: ANLD, annelid; CRST, crustacean; FISH, fish; MCBN, microbenthos; MLSK, mollusk; MYSD, mysid; ZOOP, zooplankton. See Table 1 for category definitions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

ing the 3 years following restoration, compared to the nearby reference site. However, in judging any restoration, it is important that reference sites provide an appropriate standard against which to measure restored sites (Anderson and Dugger, 1998). This problem is potentially exacerbated in Delaware Bay due to the extensive history of anthropogenic influence (Sebold, 1992) and the lack of suitable, pristine and available sites in close proximity to the restored sites. We chose the Moores Beach reference site after extensive reconnaissance and review of aerial photos and maps of the region near the restored site for its proximity, relatively pristine condition and similarity to the restored site in creek layout. While the Moores Beach reference site appeared to have a natural drainage density and flora, it is possible that the site may have had differed from the restored site in ways that affected fish abundance there. The following is an attempt to address this possibility.

One of the two creeks sampled at the Dennis Township restoration was considerably closer to the mouth of the main creek and the Bay than the creeks sampled at Moores Beach (Fig. 1), potentially biasing the restoration/reference comparison if proximity influences fish abundance or feeding. The available evidence suggests that the presence of a creek closer to the Bay at the restored site did not bias the abundance comparisons. In earlier work at these sites, we sampled two additional creeks at the Moores Beach reference site that were closer to the Bay (Able et al., 2000, 2004), comparable in proximity to the closer Dennis Township creek, than the two sampled in this study. Fish abundance at the closer creeks was significantly less than at the creeks located farther from the Bay, and significantly less than at Dennis Township (Able et al., 2000, 2004). Additionally, fish abundance was generally greater at the upper Dennis Township creek compared with the creek located nearer the Bay (personal observation). All low tide diet data came from fish collected at the uppermost creek in both sites that were a comparable distance from the Bay (Fig. 1), eliminating concerns about bias due to proximity for these data.

While there is some limited information to indicate that Moores Beach may sometimes experience lower
Table 2
Comparison of condition (weight-at-length) of *Cynoscion regalis*, *Leiostomus xanthurus* and *Micropogonias undulatus* age-1 at the reference (Moores Beach) and restored (Dennis Township) marsh

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Month</th>
<th>Size range</th>
<th>Weight-at-length (g) Moores Beach</th>
<th>Weight-at-length (g) Dennis Township</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Month</td>
<td>Min</td>
<td>Med</td>
<td>Max</td>
</tr>
<tr>
<td><em>Cynoscion regalis</em></td>
<td>1997</td>
<td>August</td>
<td>30-106</td>
<td>0.03</td>
<td>0.42</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>July</td>
<td>30-106</td>
<td>0.04</td>
<td>0.25</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>August</td>
<td>38-116</td>
<td>0.07</td>
<td>0.19</td>
<td>2.46</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>September</td>
<td>37-95</td>
<td>0.06</td>
<td>0.14</td>
<td>1.33</td>
</tr>
<tr>
<td><em>Leiostomus xanthurus</em></td>
<td>1997</td>
<td>June</td>
<td>34-93</td>
<td>0.08</td>
<td>0.38</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>July</td>
<td>67-119</td>
<td>0.67</td>
<td>1.63</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>August</td>
<td>118</td>
<td>3.13</td>
<td>5.14</td>
<td>7.89</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>July</td>
<td>118-141</td>
<td>4.57</td>
<td>7.55</td>
<td>9.64</td>
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<tr>
<td></td>
<td>1997</td>
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<td>69-98</td>
<td>0.77</td>
<td>1.36</td>
<td>2.79</td>
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<td>1998</td>
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<td>101-132</td>
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<td>8.16</td>
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<td>1999</td>
<td>June</td>
<td>62-99</td>
<td>0.53</td>
<td>1.14</td>
<td>2.78</td>
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<tr>
<td><em>Micropogonias undulatus</em></td>
<td>1997</td>
<td>June</td>
<td>38-87</td>
<td>0.06</td>
<td>0.40</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>July</td>
<td>74-107</td>
<td>0.69</td>
<td>1.60</td>
<td>2.43</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>August</td>
<td>107-134</td>
<td>2.28</td>
<td>3.43</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>September</td>
<td>144-159</td>
<td>28.62</td>
<td>35.93</td>
<td>46.03</td>
</tr>
<tr>
<td></td>
<td>1998</td>
<td>June</td>
<td>59-113</td>
<td>0.29</td>
<td>0.93</td>
<td>2.64</td>
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<tr>
<td></td>
<td>1998</td>
<td>July</td>
<td>71-137</td>
<td>0.54</td>
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<td>92-142</td>
<td>1.43</td>
<td>3.98</td>
<td>6.40</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>August</td>
<td>121-145</td>
<td>3.47</td>
<td>5.24</td>
<td>7.04</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>June</td>
<td>86-115</td>
<td>0.86</td>
<td>1.22</td>
<td>3.21</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>July</td>
<td>99-114</td>
<td>2.46</td>
<td>4.32</td>
<td>8.24</td>
</tr>
</tbody>
</table>

Size range is the range of sizes over which condition was assessed with ANCOVA. Weight at length is the dry weight at the sizes indicated in the size range columns predicted from log10 length vs. log10 length regression relationships. Sig column gives the significance value for a site effect in the ANCOVAs; ns, not significant; NA, unequal slopes (test for site effect not possible). See text for additional details.

* p < 0.05.
** p < 0.01.
*** p < 0.001.

Daytime, surface dissolved oxygen (DO) conditions at Dennis Township, and that overall fish abundance there may be low, these data are quite limited. An ultrasonic tagging and food habits study comparing *Morone saxatilis* (striped bass) abundance and movements at the same two sites reported that DO was significantly lower (*t*-test, *p* < 0.05) at Moores Beach (mean 3.5 ppm) than at Dennis Township (4.9 ppm) during June–October 1998 (Tupper and Able, 2000). These authors speculated that the lower DO conditions at the reference site may have prevented *M. saxatilis* from making tidal foraging excursions as deeply into that site compared with the restored site. Nonetheless, they concluded that this species was more abundant at the restored site and exhibited similar tidal and diel movements and food habits at both sites.

Another study, conducted during April–November 1998, evaluated two restored sites in Delaware Bay, Dennis Township and Commercial Township, compared to the Moores Beach reference site, and reported significantly higher fish abundance at the Dennis Township site than either the other restored marsh or Moores Beach, which had similar fish abundance (Able et al., 2004). These authors did not find any difference in
DO levels between Dennis Township (5.7 ppm) and Moores Beach (5.9 ppm). The difference in measured DO between these sites in the two studies may be a result of the sampling regimens, as Tupper and Able (2000) included some low tide measurements while Able et al. (2004) measured DO at high tide only.

Evidence from the other restored marsh site, Commercial Township, located about 6 km north of the Moores Beach site, suggests that DO conditions do not account for the differences in fish abundance between the restored sites and the Moores Beach reference site. During April–November 1998, DO at Commercial Township (6.8 ppm) was significantly higher than at either Dennis Township (5.7 ppm) or Moores Beach (5.9 ppm) yet fish abundance at Commercial Township and Moores Beach were not significantly different. These findings indicate that fish abundance is not strongly related to DO at these sites, at least over the ranges encountered during the study, and suggests that fish abundance may be related to differences in habitat quality or possibly hydrographic or other exogenous factors.

Finally, there is anecdotal evidence addressing the question of fish abundance at the restored site and its reference site. In conversations with several long-time fishers and crabbers in this region of the bay, we have been told that fish were more abundant in West Creek, the large creek feeding the restored site at Dennis Township, than in Riggins Ditch, the large creek feeding the Moores Beach reference site for many years prior to restoration (personal observation). Although anecdotal, such local knowledge can often be a valuable source of information that is useful in describing long-term trends in fish abundance (Neis et al., 1999). The conservative conclusion is that the high fish abundance at Dennis Township is not definitively due to the quality of the restored habitat there, although large numbers of juvenile fish clearly found satisfactory conditions for feeding at the restored marsh during the 3 years following its restoration.

4.2. Habitat quality

Given that the restored marsh at Dennis Township appeared to receive larger influxes of transient fish each year following restoration than the nearby reference site, measuring functional aspects of habitat quality there, such as feeding, becomes even more important. If food consumption was lower at the site, this could be an indication that the quality of the marsh was not sufficient to support the high numbers of fish found there. However, all comparisons of stomach fullness between species during the same tide stage indicated either significantly higher fullness at the restored site or equal fullness between the sites. No comparisons indicated higher fullness at the reference marsh.

Taken together, the patterns of fullness over the tidal cycle at the restored site (Figs. 3–6) provide compelling evidence that this restored marsh is providing foraging habitat that is being used in similar manner as the reference site by juvenile sciaenids, one of the dominant groups of transient fish in Delaware Bay (Able et al., 2000, 2001, 2004) and in estuaries along the US east coast (Chao and Musick, 1977; Weinstein, 1979; Boone and Dean, 1980). This similarity in tidal foraging behavior was particularly true for L. xanthurus (Fig. 4), which has been reported to feed most actively at high tide in several other studies (Hodson et al., 1981; Archambault and Feller, 1991), and did so at both the restored and reference site in the current study. Thus, L. xanthurus are entering the restored marsh on flood tides and are being caught on ebb tides with stomachs full of prey captured while in the marsh. In many cases, L. xanthurus caught during the ebb had stomachs completely distended with prey. Most of these preys were annelids and microbenthos (Fig. 7; Nemerson, 2001), infaunal organisms that were most likely produced within the site. Similarly, both C. regalis and M. undulatus consumed substantial quantities of fish at Dennis Township (Figs. 7 and 8). These fish were mostly F. heteroclitus (Nemerson, 2001), which have a limited home range and were very likely locally produced as well (Teo and Able, 2003a,b). In addition, in a tagging study, age-1 M. undulatus exhibited little movement during the summer residency period at both Dennis Township and Moores Beach (Miller and Able, 2002), suggesting that the food resources they consumed were from the study sites.

Seasonal habitat use by the three sciaenids studied also supports the conclusion that the restored marsh provided habitat of at least equivalent value as the reference marsh. These fish species immigrated to the study marshes at consistent times and sizes in each of the three study years before taking up residence, growing and later emigrating in diminished numbers but at larger average sizes (Nemerson, 2001). This process
results in a predictable progression of the size structure and species composition of the fish assemblage, a pattern common in other Atlantic estuaries (Weinstein, 1979; Subrahmanyam and Coulas, 1980; Allen et al, 1995; Szellmayer and Able, 1996; Able and Fahay, 1998). The high and low tide PCAs indicated that fish go through a similar seasonal progression of prey use at both the restored and reference sites, as fish size and the available prey field change throughout the residence period.

Finally, the analysis of fish condition also revealed that the restored marsh at Dennis Township provided suitable conditions for feeding and growth, with four comparisons indicating superior condition for fish at Dennis Township and only one indicating superior condition at the reference site. This result has implications for the potential for the restored site to meet the stated goal of enhanced fish production, as fish that obtain superior condition during the first summer of life may have a higher probability of surviving their first winter and successfully joining the adult population (Grecay and Targett, 1996; Grant and Brown, 1999; Hales and Able, 2001).

5. Conclusions

The three sciaenid species we investigated were an abundant and integral part of the juvenile fish fauna at the reference site as well as at the restored marsh in the first 3 years following restoration. These fish were generally more abundant at the restored site compared to the nearby reference site, and occasionally far more abundant, although the difference in abundance could not be attributed solely to conditions at the restored site. General patterns of stomach fullness and prey consumption from April to November in all 3 years were either similar at the restored and reference marshes, or suggested superior conditions for feeding at the restored marsh.

Zedler et al. (1997) have cautioned that marsh restorations that appear to be approaching functional equivalency to natural marshes in the short term, with respect to fish occupancy, prey composition and feeding, may not be self-sustaining over the long-term. Later problems include high sedimentation rates and a lack of the development of complex tidal creek networks and shallow water transitions to the marsh surface. They concluded that marshes that maintain or approach the hydrology and morphology of natural marshes are more likely to sustain fish use and other indicators of functional equivalence to natural marshes.

While our study only lasted for 3 years, additional work in the restored site considered in this study appears to indicate that the restored salt hay farm at Dennis Township continues to evolve a natural creek network and support at least as many juvenile fish as the Moores Beach reference marsh 5 years after restoration (Able et al., 2004).

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