THE INFLUENCE OF *PHRAGMITES* DOMINANCE ON MARSH RESIDENT FISH IN THE HACKENSACK MEADOWLANDS, NEW JERSEY

by

DIANA L. RAICHEL

A thesis submitted to the Graduate School - New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

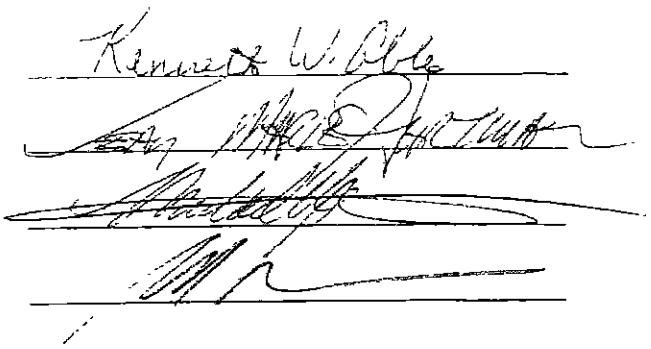
Master of Science

Graduate Program in Ecology and Evolution

written under the direction of

Professor Kenneth W. Able and Associate Professor Jean Marie Hartman

and approved by



New Brunswick, New Jersey

May, 2001

RECEIVED

FEB 14 2001

Newark Bay Study Area

NBSA-00015

ABSTRACT OF THE THESIS

THE INFLUENCE OF PHRAGMITES DOMINANCE ON MARSH RESIDENT FISH IN THE HACKENSACK MEADOWLANDS, NJ

By Diana L. Raichel

Thesis directors:

Professor Kenneth Able and Associate Professor Jean Marie Hartman

In the northeastern United States, *Phragmites australis* (common reed) has been rapidly replacing extant dominant macrophytes over the last century. However, information regarding faunal response to this replacement is limited. This study investigates the influence of *Phragmites* invasion on the habitat of the marsh resident fish *Fundulus heteroclitus* (mummichog) in the Hackensack Meadowlands, NJ. These abundant fish have an important role in estuarine food web structure and the transfer of energy from the marsh surface to adjacent subtidal waters.

The objectives of this two-year study were to first make an assessment of the distribution and abundance of the various life history stages of fishes among *Spartina alterniflora*-dominated marshes, *Phragmites*-dominated marshes, and bare substrate. Second, based on these findings, 1) further compare abundances of larval/small juvenile fish in *Phragmites* and *Spartina alterniflora* dominated

marshes, 2) experimentally investigate the influence of marsh surface microtopography on larval fish abundance within *Phragmites*-dominated marshes, 3) investigate if spawning site preferences influence larval distribution, and finally, 4) compare intertidal invertebrates, a food resource for resident fishes, in *Phragmites* and *Spartina alterniflora* dominated marshes.

For both years, the abundance of larval/small juveniles (4 mm - 20 mm) in *Spartina alterniflora* was significantly greater than in *Phragmites*-dominated marshes ($\alpha \leq 0.05$), while larger individuals (>20 mm) were similarly abundant in all habitat types the year in which they were sampled (1999). The overall abundance of larvae/small juveniles in the microtopography experiment was significantly greater in *Phragmites* treatment plots than in *Phragmites* control plots. Spawning occurred on deployed spawning substrate in *Phragmites*-dominated marsh. Major invertebrate taxa showed differences between marsh types, with larval fish prey significantly greater in *Spartina alterniflora* marshes.

As a result of the above, *Phragmites*-dominated marshes may not be providing the habitat necessary for the early life history stages of resident fishes such as the mummichog. The low abundance of larvae and small juveniles in *Phragmites* marshes is likely due to a combination of factors that include altered hydrology over the marsh surface, smoothed microtopography, scant egg deposition sites and reduced larval prey availability.

ACKNOWLEDGEMENTS

The invaluable advice and direction from Ken Able, Stacy Hagan, Mike Weinstein, and Jean Marie Hartman is greatly appreciated. I am especially grateful for field assistance and expertise provided by Andrew Krivenko, Maria Calisto, and Brett Bragin. I would also like to thank Chidubem Orazulike for his assistance in fish measurements. Special thanks are extended to Kelly Smith for helpful advice at the onset of my study. Experimental design suggestions from Ron Kneib are also acknowledged. This study was supported by a grant from the Hackensack Meadowlands Development Commission under the direction of Jean Marie Hartman. Additional funding was provided by New Jersey Sea Grant and the Manasquan River Marlin and Tuna Club.

TABLE OF CONTENTS

TITLE PAGE i

ABSTRACT OF THE THESIS ii

ACKNOWLEDGEMENTS iv

TABLE OF CONTENTS v

LIST OF TABLES vii

LIST OF FIGURES viii

I. INTRODUCTION 1

II. METHODS AND MATERIALS 10

2.1 Study site history and description 10
2.2 Site selection 11
2.3 Physical parameters 12
2.4 Vegetation 13
2.5 Large juvenile/adult fish 14
2.6 Larval/ small juvenile fish and invertebrates. 15
2.7 Larval fish prey availability 17
2.8 Larval fish habitat manipulation 18
2.9 Spawning substrate trial 19
2.10 Statistical Analyses 21

III. RESULTS 22

3.1 Physical parameters 22
3.2 Vegetation 22
3.3 Large juvenile/ adult fish 23
3.4 Larval/ small juvenile fish. 23
3.5 Habitat manipulations 25
3.6 Invertebrates 26
3.7. Larval fish prey availability 28

IV. DISCUSSION 64

V. CONCLUSIONS 69

VI. BIBLIOGRAPHY 73

Appendix A. Invertebrate Taxa List from Pit Trap Collections in 2000 80

Appendix B. Taxa abundance in *Phragmites* and *S. alterniflora*-dominated marshes as collected by pit traps (n = 54 samples per marsh type). 82

LIST OF TABLES

Table 1. Summary of sampling effort for 1999 and 2000. 16

Table 2. Summary of sampling effort for habitat manipulations in 2000 within *Phragmites*-dominated marshes in Mill Creek, Secaucus, NJ. 20

Table 3. Physical characterization of marsh types in 2000. 29

Table 4. Characteristics of water samples for 1999 and 2000 in Mill Creek, Secaucus, NJ. 30

Table 5. Abundance of juvenile and adult mummichogs (*Fundulus heteroclitus*) along Mill Creek, Secaucus, NJ in 1999 based on minnow trap collections. . 31

Table 6a. Abundance of mummichog (*Fundulus heteroclitus*) based on pit trap samples collected in Mill Creek, Secaucus, NJ in 2000. 32

Table 6b. Abundance of mummichog (*Fundulus heteroclitus*) based on pit trap samples collected in Mill Creek, Secaucus, NJ in 2000. 33

Table 7 Size of dominant invertebrates collected by pit traps in Mill Creek, Secaucus, NJ in 2000. 34

LIST OF FIGURES

Figure 1. Mill Creek study sites located off of the Hackensack River in Secaucus, New Jersey in 1999. 35

Figure 2. Mill Creek study sites located off of the Hackensack River in Secaucus, New Jersey in 2000 37

Figure 3. Abundance (average catch per unit effort, CPUE) of large juvenile/adult mummichog as collected by habitat at Mill Creek, NJ in 1999. 39

Figure 4. Length frequency distribution of large juvenile/adult mummichog as collected by habitat with minnow traps at Mill Creek, NJ in 1999. 41

Figure 5. Abundance (average catch per unit effort, CPUE) of larval/small juvenile mummichog at Mill Creek, NJ in 1999 (a) and 2000 (b). 43

Figure 6. Length frequency distribution of larval/small juvenile mummichog as collected by habitat with pit traps at Mill Creek, NJ in 1999. 45

Figure 7. Length frequency distribution of larval/small juvenile mummichog as collected by habitat at Mill Creek, NJ in 2000. 47

Figure 8. Abundance (average catch per unit effort, CPUE) of larval/small juvenile mummichogs in *Phragmites* control plots vs. *Phragmites* treatment plots as collected by pit traps at Mill Creek, NJ in 2000. 50

Figure 9 A comparison of major invertebrate groups (taxa that comprise over 5% of the total organisms collected from all habitat types) collected by pit traps at Mill Creek, NJ in 1999 (a) and 2000 (b). 52

Figure 10 Invertebrate assemblages at *Spartina alterniflora* (a) vs. *Phragmites* (b) dominated marshes as collected by pit traps (54 samples / marsh type) at Mill Creek, NJ in 2000 54

Figure 11. Abundance and composition of copepods collected in pit traps at *Spartina alterniflora* and *Phragmites* dominated marshes at Mill Creek, NJ in 2000 57

Figure 12. Abundance and composition of insect larvae and nymphs collected in pit traps at *Spartina alterniflora* (a) and *Phragmites* (b) dominated marshes at Mill Creek, NJ in 2000 59

Figure 13. The relationship between total length and width of gape for mummichog (n = 98). 62

I. INTRODUCTION

The expansion of common reed, *Phragmites australis* (hereinafter *Phragmites*), into tidal wetlands of the northeastern United States has been extensive over the past century. *Phragmites* has been replacing extant dominant macrophytes in Atlantic coast marshes at rates of 1 - 6% of the marsh surface per year (Warren and Fell 1996, Chambers *et al.* 1999), largely in areas that have undergone disturbance or stress (Marks *et al.* 1994, Chambers *et al.* 1999), but also in relatively unaltered areas (Rosza 1995, Windham and Lathrop 1999). Although *Phragmites* establishment can serve positive functions such as ameliorating eutrophication (Templer *et al.* 1998, Meyerson *et al.* 1999), stabilizing eroding shorelines (Rice *et al.* 2000, Rooth and Stevenson 2000) and sequestering heavy metals (Ye *et al.* 1997), it reduces plant diversity (Fell *et al.* 1998, Meyerson *et al.* 1999, Chambers *et al.* 1999, Windham and Lathrop 1999). An overall reduction in avian species richness (Cross and Fleming 1989, Marks *et al.* 1994, Benoit and Askins 1999) has also been noted in North American Atlantic coast *Phragmites*-dominated marshes. In addition, changes in landscape features such as decreased topographic relief (Windham and Lathrop 1999) and drainage density (Weinstein and Balletto 1999) have been suggested. However, there is limited information regarding faunal response to this habitat alteration. In the case of resident fishes, faunal response is particularly important because of their association with the trophic transfer of production in the estuarine ecosystem.

A large component of ecosystem function in marshes involves the material exchange between the intertidal marsh plain, where production occurs, and the adjacent subtidal waters. Marsh resident fishes play an important role in this energy exchange. The translocation of intertidal marsh production may occur when resident species such as *Fundulus heteroclitus*, the mummichog, feed within the vegetation on the marsh surface and either excrete material to deeper estuarine waters at low tide or are consumed by predators (Valiela *et al.* 1977, Valiela *et al.* 1977, Deegan 1993, Weisberg and Lotrich 1982, Kneib 1997). Many species of transient marine nekton feed on the resident mummichog. They occur frequently in the juvenile diets of *Paralichthys dentatus*, summer flounder (Meredith and Lotrich 1979), *Morone saxatilis*, striped bass (Valiela et al. 1977, Tupper and Able in press), and *Pomotomus saltatrix*, bluefish (Horton 1965). Adults of smaller transient species, such as *Menidia menidia*, Atlantic silverside, may also prey upon young *Fundulus* in tidal marsh creeks (Cadigan and Fell 1985). Transient crustaceans such as *Callinectes sapidus*, blue crab, may be one of the most important predators of the mummichog (Kneib 1986). In addition, many wading birds (Ardeidae) include mummichogs in their diets and may exert heavy predation pressure at low tide when these fish are concentrated in tidal pools and shallow creeks (Kneib 1986).

The young of the year may contribute the most to the trophic transfer of production from the marsh to the adjacent subtidal waters. They are the

dominant life history stage on the marsh surface in both abundance and biomass (Taylor *et al.* 1979, Talbot and Able 1984, Kneib 1986, Smith 1995, Teo 1999), experience the greatest mortality and are the fastest growing portion of the life cycle (Meredith and Lotrich 1979). In addition, they have higher food conversion efficiency than adults (Prinslow *et al.* 1974, Kneib and Parker 1991).

Several recent studies establish a trophic link between resident fishes and *Phragmites*-dominated marshes (Fell *et al.* 1998, Rilling 1998, Wainright *et al.* 2000, Weinstein *et al.* 2000). However, there is recent evidence to suggest that *Phragmites* may not be providing suitable habitat for the early life history stages of the mummichog (Able and Hagan 2000). Negative effects on mummichog reproduction and survival could have profound impacts on salt marsh food webs and the "trophic relay" (Kneib 1997) of production from the marsh surface to the adjacent subtidal waters.

Life history and ecology

Mummichogs are marsh residents that complete their entire life cycle within the marsh (Hettler 1989). On spring tides, eggs are deposited within the first axils of *Spartina alterniflora* (Taylor and DiMichele 1983), the empty shells of the ribbed mussel, as well as cracks, crevices and other small interstices on the marsh surface and creek banks (Able and Castagna 1975, Able 1984, Able and Hata 1984). After hatching on the next spring tide, the larvae reside in shallow aquatic

microhabitats and protected pools on the marsh surface (Taylor *et al.* 1977, Kneib 1987, Able and Hagan 2000), which may reduce predation rates (Kneib 1987) while providing invertebrate food resources. When the young become too large for these refuges, they adopt the migration patterns of the adults (Kneib 1984, Kneib 1997), gaining access to the marsh surface to feed during high tides and returning to deeper waters with the ebb tides.

Phragmites and essential fish habitat

Phragmites influences the hydroperiod of the marsh by decreasing tidal attenuation, lowering drainage density (CH2MHill a,b 1995), and shortening flood duration as a result of increased marsh surface elevation (Rooth and Stevenson 2000). Although these alterations may influence access to the marsh surface for many fishes (Rozas and Odum 1987, Rozas *et al.* 1988, Rozas and Reed 1993, Kneib and Wagner 1994, Rozas 1995, Minnello and Webb, Jr. 1997), recent studies investigating fish utilization of *Phragmites* vs. "*Phragmites*-free" oligo-mesohaline marshes found no significant differences in the relative numbers and biomass of juvenile and adult mummichog that utilize these systems (Fell *et al.* 1998, Rilling *et al.* 1998, Able and Hagan 2000, Meyer *et al.* in press). Measurements of stable isotopic compositions in juvenile mummichog and other species confirmed that *Phragmites* is contributing to aquatic food webs in Delaware Bay tidal marshes (Wainright *et al.* 2000, Weinstein *et al.* 2000). This linkage appears to represent a direct trophic connection between *Phragmites*

marshes and the adjacent waters. However, results of a recent study in the Mullica River, NJ (Able and Hagan 2000) strongly suggest that *Phragmites* may not be providing the habitat necessary for the early life history stages of mummichog. In 1998, pit trap collections targeting larvae and small juveniles found an overall CPUE of 0.08 in *Phragmites*-dominated marshes in contrast to an overall CPUE of 2.67 in *Spartina*-dominated marshes.

Microhabitats on the marsh surface have been observed to be an important habitat component for the larval stage of mummichog development (Taylor *et al.* 1979, Talbot and Able 1984, Yozzo *et al.* 1994, Kneib 1997a,b). These shallow pools and depressions, as little as 1 cm deep and 10 cm wide (Taylor *et al.* 1979), are thought to serve as refuges from predators while providing invertebrate food resources (Kneib 1987, Kneib 1994). In contrast to the hummock-building morphology of *Spartina alterniflora*, *Phragmites* communities have much less pronounced microtopographic relief (Windham 1995, Windham and Lathrop 1999) that may not provide the standing water refugia necessary for the larval habitat. The smooth "table-top" microtopography of *Phragmites*-dominated marshes may be influenced by the water flow conditions dictated by the morphology of the plant (Leonard and Luther 1995) as well as by the increased amount of litter production, which fills in hollows and rivulets (Chambers *et al.* 1999, Windham and Lathrop 1999) and thus maximum relief is close to zero (Windham 1995, personal observation). The degree of relief seems to have an

inverse relationship with the length of time *Phragmites* has been established (Windham and Lathrop 1999).

Phragmites dominance may also influence available spawning substrate for mummichogs which utilize the pockets provided by the first axils of *Spartina alterniflora* for egg deposition (Taylor and DiMichele 1983) as well as other cracks, crevices and small interstices (Able and Castagna 1975, Able 1984, Able and Hata 1984) along the marsh edge. *Phragmites* leaves are attached to the stems with tightly bound culm sheaths, rendering them inaccessible as egg deposition sites. In addition, the dense shade caused by the tall culms precludes the growth of other plant species (Haslam 1971) which could provide egg deposition sites. However, egg deposition has been observed in broken dead culms 5 - 9.7 mm in outer diameter and short enough to be submerged at high tide (Able and Hagan unpublished data), which seems to indicate that mummichogs may spawn in *Phragmites* marshes given accessible spawning substrate.

The hydrological and physical changes that accompany the conversion of a *Spartina*-dominated marsh to a *Phragmites*-dominated marsh may also affect intertidal invertebrates, an important food resource for the mummichog (Weisberg and Lotrich 1982, Kneib 1986, Smith *et al.* 2000). The differences in the invertebrate assemblages of these two marsh types are poorly known. At their study site in the Mullica River, NJ, Angradi *et al.* (in press) determined the

composition of the dominant macroinvertebrates in *Phragmites*-dominated marshes to be similar to that found in *Spartina*, while the subdominant intertidal invertebrates in *Phragmites* marshes were different - with a higher mean taxa richness in the *Spartina* marshes. They concluded that the density of intertidal standing-water microhabitats and possibly microalgal productivity in the *Spartina* marshes may be the sources of the spatial variation in assemblage composition

Larval and small juvenile mummichogs (5 - 25 mm TL) are largely carnivorous and show size specific preferences for certain prey (Kneib and Stiven 1978, Kneib 1986), feeding mainly on benthos associated with the detritus. The types of invertebrates available on or just above the marsh surface may influence feeding success Some prey may be either too large or too small to be effectively handled by a fish of a given size and thus are unavailable (Kneib 1986). In a Delaware Bay study, meiofauna (copepods, foraminiferans, ostracods, and nematodes) were found to compose the majority of the smallest fishes diets, but these declined in occurrence in fish > 20 mm SL. The relative importance of crustaceans (primarily amphipods) tended to increase with fish size (Smith *et al.* 2000). In a Georgia salt marsh, harpacticoid copepods, tanaids, and sabellid polychaetes (*Manayunkia aestuarina* and *Fabricia* spp.) were the most abundant taxa in the diets of young mummichogs, while *Nereis succinea* and amphipods occurred only in the guts of the larger individuals (Kneib 1986).

Questions to be addressed in this two-year study are as follows: 1) What is the abundance and distribution of the various life history stages of the mummichog among the habitat types within the study site? 2) Is a *Phragmites*-dominated marsh functioning in a similar manner to a *S. alterniflora*-dominated marsh as nursery grounds for the mummichog? 3) Does the microtopography of the *Phragmites* marsh limit larval habitat? 4) Is access for egg deposition inhibited in *Phragmites* marsh? 5) Are the major invertebrate taxa significantly different in *Phragmites*-dominated marshes in contrast with *S. alterniflora*-dominated marshes?

The first objective of this study was to assess the differences in the abundance and distribution of the different size classes of mummichog among the habitat types present at the study site to provide the basis for a more detailed investigation. The remainder of the study focused on 1) contrasting the abundance of larval/small juvenile mummichog in *Phragmites* and *S. alterniflora* dominated marshes, 2) experimentally investigating the influence of marsh surface microtopography on larval abundance within *Phragmites*-dominated marshes, 3) investigating if egg deposition will occur on deployed spawning substrate within *Phragmites*-dominated marsh, and 5.) contrasting the intertidal invertebrate assemblages within *Phragmites*-dominated and *S. alterniflora*-dominated marshes - making inference to known larval prey items. The data

resulting from these objectives will help investigators gain a better understanding of how *Phragmites* invasion affects marsh resident fish populations and why these effects may occur. In addition, an investigation of the invertebrate assemblages found in *Phragmites*-dominated marshes may help to characterize the changes in intertidal salt marsh fauna brought about by its establishment.

II. METHODS AND MATERIALS

2.1 Study site history and description

The study site is located in oligo-mesohaline marshes along Mill Creek, which lies within the Hackensack Meadowlands in Secaucus, New Jersey (Fig. 1,2). The Hackensack Meadowlands District consists of 7,985 ha of predominantly tidal marsh (Quinn 1997) occurring along the Hackensack River in northeastern New Jersey. Marsh elevations range from 0 - 3.1 meters, with most areas being less than 1.53 meters above mean sea level (Sipple 1971).

The Meadowlands has a long history of disturbance and alteration of tidal flow via impoundments, dikes, tide gates, and the construction of Oradell Dam and New Jersey Turnpike. Most diking occurred around 1869 in an effort to reclaim the marshlands for salt hay farming, agriculture and livestock. Other marsh alterations include filling, dumping and mosquito ditching. (Sipple 1971, Quinn 1997). Extensive drainage networks for mosquito control led to domination of the area by *Typha spp.* and *Phragmites* by 1932 (Sipple 1971).

At the northern portion of Mill Creek is a 25.5 ha Hartz Mountain Industries mitigation site. Prior to 1985, this area was a tidal marsh dominated by *Phragmites*. The mitigation design, which was completed in 1990, incorporated channels, open water, intertidal areas planted with *S. alterniflora*, and upland

planted with woody vegetation (HMDC 2000). The southern portion of Mill Creek is a 56.7 ha site currently under mitigation and was bare substrate the spring and summer of 1999. The marshes on the western side of the creek were left undisturbed in both mitigations and remain *Phragmites* dominated. Analysis of aerial photographs suggests that the *Phragmites* stands along the western side of Mill Creek have been established for at least 30 years. The tide range, as determined from tide charts (Tides and Currents for Windows ®, Nautical Software, version 2.5b), fell between 0.79 m - 2.10 m during June 4 – August 27, 1999, and between 1.48 m - 2.38 m during May 23 - August 17, 2000.

2.2 Site selection

During 1999, locations along Mill Creek with similar flood depths (± 8 cm) at a distance of 5 - 9 m from the marsh edge were chosen for sampling. Six stations were established (Fig. 1) in late April, before seasonal macrophyte growth began. Two stations were located in each of the following habitats: *Spartina alterniflora*-dominated, *Phragmites*-dominated, and bare substrate (Hackensack Meadowlands Development Commission mitigation site).

In 2000, a greater effort was taken to eliminate as many confounding factors as possible by ensuring a similarity of marsh surface accessibility to fishes within the marsh types. An investigation was completed to determine locations with statistically similar flood depth and elevation at a uniform distance of 5 m from

the marsh edge. Once these locations were determined, three 2 m x 7 m replicate stations of both marsh types (n = 6) were established (Fig. 2). It should be noted that two of the *Phragmites* stations, P1 and P2, had small creeks (~ 0.7 m wide, 5 m from marsh edge) along the edge of the plots. For both years, all stations were located within 0.56 km.

2 3 Physical parameters

In early April 1999, flood depth was measured on three consecutive days by setting out arrays of tide sticks (3/array) at various locations 5 - 9 m from the marsh edge along Mill Creek. The tide sticks were composed of wooden dowels, each with a small buoy and lightweight plastic mesh placed above the buoy. The rising tide would lift the buoy and mesh to the high tide mark. The mesh would remain in place after the tide dropped, thus giving a measurement of flood depth. The sites with the most similar flood depths were chosen (±8 cm). In early April 2000, flood depth was determined by again using tide sticks (3/array) 5 meters from the marsh edge at various locations along Mill Creek. The sites with the most similar flood depths were chosen and an ANOVA was used to determine if these depths were significantly different ($\alpha \leq 0.05$) in the two marsh types. The elevations of the stations were then determined by using GPS Real Time Kinematic methods. Three random replicate readings were taken within

each station and averaged. Position and elevation accuracy was ± 1 cm and ± 3 cm, respectively.

Maximum topographic relief was measured within each plot by point estimates of rugosity utilizing a meter stick attached to a combination square with a level that ensured that measurements were taken at a 90° angle. The plots were divided into a grid of 1.0 m^2 quadrats and six were randomly selected for readings. The meter stick was laid down horizontally and rested on the highest point of the quadrat while the perpendicular ruler measured the maximum topographic relief.

For both years, measurements of salinity, temperature, pH, and dissolved oxygen were taken on one day of each pair of sampling dates using a hand held refractometer, a HANNA model HI9023 pH meter, and a portable YSI model 95 dissolved oxygen meter. Each of these measurements was read in a central location among the sampling stations. The proximity and similarity of conditions of the sampling stations made additional readings unnecessary.

2.4 Vegetation

For both years, relative plant coverage was determined within each of these study sites and expressed as a proportion of the total coverage for all species

Coverage estimates were measured in five random 0.5 m x 0.5 m quadrats within each station and averaged. In 2000, basal area coverage was also determined within all *S. alterniflora*-dominated and *Phragmites*-dominated control plots to provide a more detailed description of the marsh surface of the two marsh types. Basal coverage was estimated by the basal area covered by a species divided by the total area sampled. Units of measurement for basal area are defined as culms for *Phragmites* and multi-stemmed clumps for *S. alterniflora* and *P. purpurascens*. The diameter of each unit was measured approximately 3 - 5 cm above the soil surface in five random 0.25 m^2 quadrats within each station and averaged (Brower, Zar, and von Ende 1990).

2.5 Large juvenile/adult fish

In 1999, large juvenile and adult fish were sampled biweekly during the months of July and August at each of the existing stations (Table 1). Three minnow traps were deployed per station on each sampling date in the intertidal zone just before high tide and collected 1 - 2 hours after high tide. Traps included a triangular, 3-chambered "heart" minnow trap (30 cm high with three 56 cm long sides, 3 mm mesh) and collapsible minnow traps (41 cm x 24 cm x 24 cm, 2 mm mesh). Fish were identified, measured total length (TL), counted and released in the field.

2.6 Larval/small juvenile fish and invertebrates

In 1999, three shallow pit traps (20.3 cm x 27.9 cm x 5.1 cm) were installed flush with the marsh substrate at each station and anchored with tent stakes. All pit traps were located 5 - 9 m from the marsh edge. Samples were collected on a biweekly basis (n = 36 samples/month) that coincided with spring high tides starting June 4 through August 27 (Table 1). In 2000, efforts were taken to avoid alteration of the marsh surface by installing boardwalks perpendicular to the marsh edge at each station in April before seasonal macrophyte growth began. At each station, four of the same shallow pit traps were installed flush with the marsh surface and anchored with tent stakes. These traps were placed 0.5 m apart and 5 m (± 0.5 m) from the marsh edge. Pit trap samples were collected on a biweekly schedule (n = 24 traps/2 weeks) on the two days following spring tides from May 23 through August 17 (Table 1).

Table 1. Summary of sampling effort for 1999 and 2000.

In 1999, samples were collected from two replicate stations of each habitat type with three pit traps and three minnow traps at each. Minnow traps targeted the large juvenile/adult fish. Pit traps targeted larval/small juvenile fish as well as invertebrates. In 2000, samples were collected from three replicate stations of each marsh type with four pit traps at each. For both years, biweekly collections coincided with spring high tides. SA = *S. alterniflora*, P = *Phragmites*, B = bare substrate See Figures 1 and 2 for sampling locations.

Sampling dates	Minnow traps			Pit traps		
	SA	*P*	*B*	*SA*	*P*	*B*
June 4/5, 1999	0	0	0	6	6	6
June 14/16, 1999	0	0	0	6	6	6
June 30/July 1, 1999	0	0	0	6	6	6
July 12/13, 1999	12	12	12	6	6	6
August 2/3, 1999	12	12	12	6	6	6
August 14/15, 1999	12	12	12	6	6	6
May 23/25, 2000	0	0	0	12	12	0
June 3/4, 2000	0	0	0	12	12	0
June 18/19, 2000	0	0	0	12	12	0
July 2/3, 2000	0	0	0	12	12	0
July 17/18, 2000	0	0	0	12	12	0
July 31/Aug 1, 2000	0	0	0	12	12	0
Aug 16/17, 2000	0	0	0	12	12	0
Total	36	36	36	120	120	36

In both years, the traps were emptied just prior to high tide and collected ≈2 hours after high tide receded. Samples were poured into plastic bags and placed in a cooler with ice packs. Upon return to the laboratory, samples were passed through a 300 μm sieve to retain macrofauna and large meiofauna. The organisms were then preserved in a buffered 20% formaldehyde solution. After one week, samples were transferred to 70% ethanol with rose bengal stain. After stain had set, all organisms were sorted from debris and identified to lowest taxonomic level possible using a variety of identification keys (Hardy 1978, Merritt and Cummins 1978, Wang and Kernehan 1979, Weiss 1995, Able and Fahay 1998, Pollock 1998) under a dissecting microscope and enumerated. Copepods were identified to order in 2000. Total length measurements of the fish were made to the nearest 0.1 mm with calipers.

2.7 Larval fish prey availability

To evaluate the relationship between invertebrate size and availability as fish prey, gape measurements for fish and invertebrate measurements were carried out using a dissecting microscope with an ocular reticule. Fish were positioned perpendicularly to the reticule and illuminated laterally and from below, which allowed a clear view of mouth gape. The lateral traverse of the gape was measured and only specimens with gapes fully open were used. Invertebrates

were measured by the narrowest width, assuming the fish may handle the prey to minimize width relative to gape for ingestion.

2.8 Larval fish habitat manipulation

To determine if changes in marsh surface microtopography would influence larval abundance, three experimental plots were established in which depressions were created on the marsh surface of *Phragmites*-dominated sites to simulate the microtopography of a *S. alterniflora* marsh (i.e. more small depressions and pools) These treatment plots were paired with control plots and separated by a distance of 3 - 5 m. Two of the paired plots contained small creeks (~ 0.7 m wide, 5 m in from marsh edge) that separated the control from the treatment. The treatment involved using three techniques that included 1) installing 6 sections of PVC cylinders (10 cm diameter and 10 cm deep) flush with the marsh surface, then removing the upper 2 cm of soil from the center of each cylinder, 2) physically stamping the substrate and finally, 3) installing 4 shallow pit traps (20.3 cm x 27.9 cm x 5.1 cm) flush with the marsh surface. In order to determine whether these techniques adequately altered the microtopography, measurements were conducted within each plot using a meter stick attached to a combination square (described earlier). An ANOVA was used to compare rugosity in the treatment plots against the control plots. Boardwalks were installed in April to avoid alteration of the marsh surface within the control

plots. To separate out the effects of the presence of the traps, traps placed in the control plots were kept covered until just before high tide on sampling days. Possible disturbance of water flow was matched up in the treatment plots by installing wooden boards to simulate the legs of the boardwalks that were installed in the control plots. Pit trap samples were collected on a biweekly schedule (n = 24 traps/2 weeks) on the two days following spring tides from June 18 through August 17 (Table 2).

2.9 Spawning substrate trial

To determine if spawning by mummichogs could occur in *Phragmites*-dominated marshes, egg deposition was investigated (June 18 and July 3, 2000) within the *Phragmites* treatment plots by deploying 5 scrub brushes (14 cm x 6.5 cm x 3.5 cm). These were anchored to the marsh surface with metal pins 1 - 5 m from the marsh edge (Table 2). Before sampling, the brushes were set out in the marsh for 2 days to allow them to be coated with marsh biofilms. Subsequently, brushes were set out before high tide the day before collection, thus allowing two high tides for spawning access. At the time of collection, the brushes were placed in plastic bags and then immediately into a cooler with ice. Upon return to lab, eggs were removed from brushes, preserved in 70% ethanol, identified (Armstrong and Child 1965) and counted with the aid of a dissecting microscope.

Table 2. Summary of sampling effort for habitat manipulations in 2000 within *Phragmites*-dominated marshes in Mill Creek, Secaucus, NJ.

Samples were collected from three replicates each of *Phragmites* control (*PC*) and *Phragmites* treatment (*PT*) plots. Four pit traps were sampled at each plot for the microtopography experiment and 5 spawning substrates were deployed per treatment plot for the egg deposition investigation. Sampling coincided with spring high tides.

Sampling dates	Microtopography		Egg deposition
	PC	*PT*	*PT*
June 18/19, 2000	0	0	15
July 2/3, 2000	12	12	15
July 17/18, 2000	12	12	0
July 31/Aug 1, 2000	12	12	0
Aug. 16/17, 2000	12	12	0
total	48	48	30

2.10 Statistical Analyses

The influence of vegetation type on large juvenile/adult mummichogs in 1999 was tested using an analysis of variance (ANOVA) model with SAS software (version 7.0, SAS Institute Inc., Cary, North Carolina). Marsh type was the experimental unit (replicate), minnow traps were the sampling units (repetitions), and abundance was the response variable. The larval/small juvenile fish abundance data did not meet the assumptions of ANOVA, thus a nonparametric procedure was used. The Kruskal-Wallis model (Hollander and Wolfe 1973) was employed using SAS software to determine the influence of vegetation type on abundance using marsh type as the experimental unit (replicate), pit traps as the sampling unit (repetition), and abundance as the response variable. Abundance was analyzed by sampling month and overall results in 1999, and by individual sampling periods and overall results in 2000. Major invertebrate taxa were analyzed by a seasonal total within each vegetation type. The Simpson's Index (Krebs 1989) was used on the seasonal totals of *Phragmites* and *S. alterniflora* invertebrate collections in 2000 as a measure of taxa diversity. The ANOVA model was used with SAS software on all physical parameters.

III. RESULTS

3.1 Physical parameters

The majority of the marsh physical parameters measured did not significantly vary between vegetation types (Table 3). Flood depth was not significantly different between the vegetation types (ANOVA: F = 0.04, Pr>F = 0.85) although the variance was higher in *Phragmites* than in *S. alterniflora* (s^2 = 17.22 and 7.18, respectively). Also, mean elevation was not significantly different between the *S. alterniflora* plots and the *Phragmites* control plots (ANOVA: F = 6.49, Pr>F = 0.06). Mean topographic relief was significantly greater in the *S. alterniflora*-dominated marshes (ANOVA: F = 126.71, Pr>F = <.0001) (Table 3). The average relief of the created microtopography within the *Phragmites* treatment plots was significantly greater than the relief in the control plots (ANOVA: F = 180.86, Pr>F = <.0001) with a mean of 5.66 cm relative to 0.41 cm. The average water salinity varied between years with an average of 11 ppt in 1999 and 5 ppt in 2000 (Table 4).

3.2 Vegetation

Vegetation dominance was characterized as >70% coverage in both marsh types. *Pluchea purpurascens* (9.1%), *Eleocharus spp.* (3.7%) and *Scirpus americanus* (0.5%) were also present at the *S. alterniflora*-dominated stations. The bare substrate stations in 1999 had a "ring" of *Atriplex patula* and *Pluchea purpurascens* within the

high intertidal zone by late June. The average basal area coverage of the vegetation in the *S. alterniflora*-dominated marshes (353.69 $cm^2/0.25\ m^2$) was significantly higher than *Phragmites*-dominated (82.70 $cm^2/0.25\ m^2$) (ANOVA: F = 2.30, Pr>F = 0.0001).

3.3 Large juvenile/ adult fish

Combining the results of both minnow trap types, the average catch per unit effort (CPUE) for large juveniles and adult mummichogs was similar in all habitats on each sampling day in 1999 (Fig. 3). There were no significant differences in abundance on any of the three sampling dates (Table 5). Juvenile *Menidia beryllina,* the inland silverside, were present on August 14 (13 individuals total) Total length ranged from 20 mm - 100 mm over the sampling period, with most individuals between 26 mm - 54 mm (Fig. 4).

3.4 Larval/ small juvenile fish

In both years, larvae and small juvenile mummichogs were consistently more abundant in *S. alterniflora*-dominated marsh (Fig. 5). In 1999, mummichogs dominated the pit trap collections in all habitat types. The average monthly CPUE of larvae and small juveniles showed dramatic differences among the different marsh habitats (Fig. 5a). The average abundance in June for *S. alterniflora*-dominated and bare substrate were 9.33 and 9.50, respectively, while

Phragmites had a very low CPUE of 0.60. For the month of June, there was no significant difference between the *S. alterniflora*-dominated collections and the bare substrate collections (Kruskal-Wallis: $\chi^2 = 0.84$, $Pr>\chi^2 = 0.36$). However, there was a significant difference between *S. alterniflora* and *Phragmites* (Kruskal-Wallis: $\chi^2 = 4.17$, $Pr>\chi^2 = 0.04$) as well as between *Phragmites* and bare substrate (Kruskal-Wallis: $\chi^2 = 4.18$, $Pr> \chi^2 = 0.04$). Individuals were not collected from either *Phragmites*-dominated marshes or bare substrate on any of the remaining sampling dates. Length frequency graphs for this period (Fig. 6) do not clearly indicate separate cohorts, but this may be due to a small sample size. The low numbers of larvae and small juveniles collected in *S. alterniflora* marshes in July (29 total) may be due to unusually strong east winds on the July 1 sampling date. The wind produced wave action along the marsh edge, which may have decreased the efficiency of the traps. The length frequency for the August pit trap collections (average length 18.4 mm) indicated the prevalence of juveniles in the system.

In 2000, mummichogs again dominated the pit trap collections in both marsh types (Table 6a, Fig. 5b). Abundance was significantly higher in *S. alterniflora*-dominated marshes on all sampling dates. The overall CPUE in *S. alterniflora*-dominated marsh was 17.01, compared to 0.35 in *Phragmites*-dominated marsh. (Kruskal-Wallis: $\chi^2 = 90.79$, $Pr> \chi^2 = <0.0001$). Out of the total 1,469 fish collected, only 29 individuals were captured in *Phragmites*-dominated marsh. In length

frequency distribution graphs, several cohorts (5 mm - 11 mm, 11 mm - 16 mm, 16 mm - 23 mm) are discernable in August (Fig. 7b).

3.5 Habitat manipulations

In the larval fish habitat manipulation experiment, there was a trend for higher larval mummichog abundance within the *Phragmites* treatment plots *vs.* the *Phragmites* control plots over the sampling periods (Fig. 8). Although the results of the first three sampling periods were not significantly different, the final sampling period and the overall differences were significant (Kruskal-Wallis: $\chi^2 = 4.56$, $Pr>\chi_2 = 0.03$; Kruskal-Wallis: $\chi^2 = 5.03$, $Pr>\chi^2 = 0.02$) (Table 6b), with the more rugose plots having a greater abundance of mummichog.

Although the *Phragmites*-dominated marshes had a very low abundance of larvae on the marsh surface, 891 eggs were collected on the two sampling dates. A total of 98 eggs were collected from the P2 treatment station on June 28, and a total of 793 eggs were collected from stations P1 and P2 treatment stations on July 3 (Fig. 2). With the exception of the 16 eggs collected at the P1 station on July 3, all eggs were deposited ≈ 2 m from the marsh edge. Eggs were only collected from the two stations with creeks adjacent to them.

3.6 Invertebrates

In both years, the major invertebrate groups (> 2% of total organisms) collected in pit traps differed in abundance between vegetation types (9a,b). In 1999, high numbers of copepods (2,060 individuals) were found in *S. alterniflora*-dominated marshes in contrast with much lower numbers in *Phragmites*-dominated and bare substrate (37 and 44 individuals, respectively). Ostracod distribution displayed a similar pattern with 4,821 individuals collected in *S. alterniflora* in contrast with 139 and 636 individuals collected in *Phragmites*-dominated and bare substrate habitats. Nematodes and oligochaetes were also much more abundant in *S. alterniflora*-dominated marshes (670 and 1459 individuals), compared with *Phragmites*-dominated (0 and 57 individuals, respectively) and bare substrate (7 and 14 individuals, respectively). Gammarids and gastropods were much more prevalent in the *Phragmites*-dominated marshes (212 and 1458 individuals, respectively) compared with *S. alterniflora*-dominated (73 and 557 individuals, respectively) and bare substrate (10 and 606 individuals, respectively). Hydromedusae were only found to be abundant at the bare substrate stations (739 individuals) compared with 97 in *S. alterniflora* and 0 in *Phragmites* dominated marshes and only occurred in mid-June.

In 2000, taxa diversity calculated from the Simpson's Index was slightly higher in the *Phragmites* collection, yielding a D_s value of 0.85 whereas the *S. alterniflora* collection yielded a D_s value of 0.78. The major taxa collected in the pit traps

again showed significant differences in abundance between the two marsh types (Fig 9b, 10a,b) Chironimids were more abundant in the *Phragmites*-dominated marshes (Kruskal-Wallis: $\chi^2 = 14.61$, Pr> $\chi^2 = 0.0001$), as were gastropods, predominantly *Hydrobia spp.* (Kruskal-Wallis: $\chi^2 = 38.00$, Pr> $\chi^2 = <0.0001$), and Gammarus *spp.* (Kruskal-Wallis: $\chi^2 = 15.46$, Pr> $\chi^2 = <0.0001$). Harpacticoid copepods were more prominent in *S. alterniflora*-dominated marshes (Kruskal-Wallis: $\chi^2 = 55\ 65$, Pr> $\chi^2 = < 0.0001$). The *S. alterniflora*-dominated marsh collections were also higher in nematodes (Kruskal-Wallis: $\chi^2 = 5.14$, Pr>$\chi^2 = 0.02$), oligochaetes (Kruskal-Wallis: $\chi^2 = 15.69$, Pr>$\chi^2 = <0.0001$), ostracods (Kruskal-Wallis: $\chi^2 = 23.19$, Pr> $\chi^2 = < 0.0001$), and the sabellid polychaete *Manayunkia aestuarina* (Kruskal-Wallis: $\chi^2 = 11.43$, Pr> $\chi^2 = 0.0007$). A total of 13,109 individuals were collected in *S. alterniflora* while a markedly lower number, 7,182 individuals, were collected from *Phragmites*. The abundance of harpacticoid copepods was magnitudes greater in *S. alterniflora*-dominated marshes (Fig. 11). Although, as a group, insects are similarly abundant in both marsh types (428 individuals in *S. alterniflora* and 398 individuals in *Phragmites*), the assemblages within these groups were quite different (Fig. 12a,b). Most notably, chironimids comprised the majority of the *Phragmites*-dominated marsh collection while collembola comprised the largest percentage in the *S. alterniflora*-dominated collection. The salt marsh dragonlet, *Erythrodiplax berenice*, only occurred in the *S. alterniflora*-dominated marshes.

3.7. Larval fish prey availability

The relationship between width of gape and invertebrate size indicates that larval fish prey was more available in *S. alterniflora* marsh than in *Phragmites*-dominated marsh. There was a positive correlation ($R^2 = 1.00$) between total length and gape width measurements (Fig.13). At the smallest fish length measured of 6.5 mm, harpacticoid copepods, *Manayunkia aestuarina*, nematodes, oligochaetes, and ostracods were available as prey items to this smallest size class (Table 7). These taxa were found to be significantly more abundant in pit trap collections from *S. alterniflora*-dominated marsh and would be available as food to this smallest size class. On average, gammarids and gastropods were not available to fish less than 14 mm total length because of gape limitations.

Table 3. Physical characterization of marsh types in 2000.

Flood depth and elevation were measured to ensure similarity of marsh surface accessibility to fishes within the study sites along Mill Creek, Secaucus, NJ. Maximum relief was measured to illustrate the differences in marsh surface microtopography between the marsh types. An ANOVA was used to determine significant differences ($\alpha \leq 0.05$).

Physical characteristic	*S. alterniflora*-dominated marsh	*Phragmites*-dominated marsh	F	Pr>F
Flood depth	Mean = 11.72 cm S^2 = 7.18 (n = 9)	Mean = 12.03 cm S^2 = 17.22 (n = 9)	0.04	0.85
Elevation above mean sea level	Mean = 0.75 m S^2 = 0.02 (n = 9)	Mean = 0.69 m S^2 = 0.01 (n = 9)	6.49	0.06
Maximum relief	Mean = 4.37 cm S^2 = 1.82 (n = 18)	Mean = 0.41 cm S^2 = 0.42 (n = 18)	126.71	<.0001

Table 4. Characteristics of water samples for 1999 and 2000 in Mill Creek, Secaucus, NJ.

Measurements were taken on one of the two sampling dates following spring high tides in a central location among the closely spaced study sites.

Sampling date	Salinity	Temp. (°C)	DO (mg/L)	pH
June 4, 1999	9	23.1	9.55	7.46
June 16, 1999	10	24.6	3.18	7.20
July 1, 1999	13	25.8	5.98	7.38
July 13, 1999	11	24.8	6.63	7.32
Aug 2, 1999	13	30.2	8.01	7.43
Aug. 14, 1999	12	25.7	6.02	7.28
May 23, 2000	5	25.7	4.72	7.46
June 3, 2000	5	27.8	3.89	7.50
June 18, 2000	3	26.6	4.34	7.43
July 2, 2000	5	27.5	5.80	7.33
July 17, 2000	7	25.9	5.55	7.22
July 31, 2000	5	24.4	2.61	7 03
Aug 16, 2000	4	25.2	3.43	7.20

Table 5. Abundance of juvenile and adult mummichogs (*Fundulus heteroclitus*) along Mill Creek, Secaucus, NJ in 1999 based on minnow trap collections. Habitat types sampled were *S. alterniflora*-dominated marsh (SA), *Phragmites*-dominated marsh (P), and bare substrate (B). An ANOVA was used to determine significant differences ($\alpha \leq 0.05$) in abundance between the habitat types.

Sampling dates	Total in *SA*	Avg CPUE in *SA*	Total in *P*	Avg CPUE in P	Total in B	Avg CPUE in B	F	Pr >F
July 13/14	27 (n = 12)	4.5	21 (n = 12)	3.5	25 (n = 12)	4.2	1.04	0.45
August 2/3	104 (n = 12)	17.3	100 (n = 12)	16.7	75 (n = 12)	12.5	0.46	0.67
August 14/15	61 (n = 12)	10.2	59 (n = 12)	9.8	51 (n = 12)	8.5	0.54	0.63

Table 6a. Abundance of mummichog (*Fundulus heteroclitus*) based on pit trap samples collected in Mill Creek, Secaucus, NJ in 2000.

Samples were collected from 4 pit traps at three replicate stations per marsh type. Sampling coincided with spring high tides. The Kruskal-Wallis test was used to determine significant differences ($\alpha \leq 0.05$) in abundance between marsh types. *P* = *Phragmites*, *SA* = *S. alterniflora*.

Sampling dates	Total catch in *P*	Avg CPUE in *P*	Total catch in *SA*	Avg CPUE in *SA*	χ^2	Pr>χ^2
May 23/24, 2000	2 (n = 12)	0.17	12 (n = 12)	1.00	11.46	0.0007
June 3/4, 2000	7 (n = 12)	0.58	399 (n = 12)	33.25	16.79	<.0001
June 18/19, 2000	0 (n = 12)	0	97 (n = 12)	8.08	13.80	0.0002
July 2/3, 2000	2 (n = 12)	0.17	478 (n = 12)	39.83	18.86	<.0001
July 17/18, 2000	5 (n = 12)	0.42	148 (n = 12)	12.33	6.04	0.0140
July 31, 2000	13 (n = 12)	1.08	223 (n = 12)	18.58	14.91	0.0001
Aug 16/17, 2000	0 (n = 12)	0	72 (n = 12)	6	13.18	0.0003
Overall	29 (n = 84)	0.35	1,429 (n = 84)	17.01	90.79	<.0001

Table 6b. Abundance of mummichog (*Fundulus heteroclitus*) based on pit trap samples collected in Mill Creek, Secaucus, NJ in 2000.

Samples were collected from 4 pit traps at 3 replicate stations each of *Phragmites* control plots and *Phragmites* treatment plots. Treatments involved creating a microtopography similar to that of *S. alterniflora* (i.e. more depressions and small pools). Sampling coincided with spring high tides. The Kruskal-Wallis test was used to determine significant differences ($\alpha \leq 0.05$) in abundance between control and treatment plots. PC = *Phragmites* control, PT = *Phragmites* treatment.

Sampling dates	Total catch in PC	Avg CPUE in PC	Total catch in PT	Avg CPUE in PT	χ^2	Pr>χ^2
July 2/3, 2000	2 (n = 12)	0.17	7	0.58 (n = 12)	2.10	0.15
July 17/18, 2000	5 (n = 12)	0.42	9	0.75 (n = 12)	0.10	0.76
July 31/Aug 1, 2000	13 (n = 12)	1.08	22	1.83 (n = 12)	1.47	0 23
Aug 16/17, 2000	0 (n = 12)	0	8	0.67 (n = 12)	4.56	0.03
Overall	20 (n = 48)	0.42	46	0.96 (n = 48)	5.03	0.02

Table 7. Size of dominant invertebrates collected by pit traps in Mill Creek, Secaucus, NJ in 2000.

Measurements were made under a dissecting microscope containing an ocular reticule. The narrowest width was measured for each taxa.

Taxa	n	Average (mm)	Standard error
Harpacticoids	50	0.24	0.01
Manayunkia Spp..	50	0.17	0.01
Nematoda	50	0.09	0.00
Oligochaetae	50	0 30	0.01
Ostracoda	50	0.32	0.01
Gammaridae	50	1.89	0.16
Gastropoda	50	1.74	0.08

Figure 1. Mill Creek study sites located off of the Hackensack River in Secaucus, New Jersey in 1999.

The *Spartina alterniflora* sampling stations (S) were located on the Hartz Mountain restoration site, which was completed in 1990. *Phragmites* stations (P) were located on the west side of Mill Creek and, according to aerial photographs, have been established at least 30 years. The bare substrate stations (B) were located on a current mitigation site that had not yet revegetated.

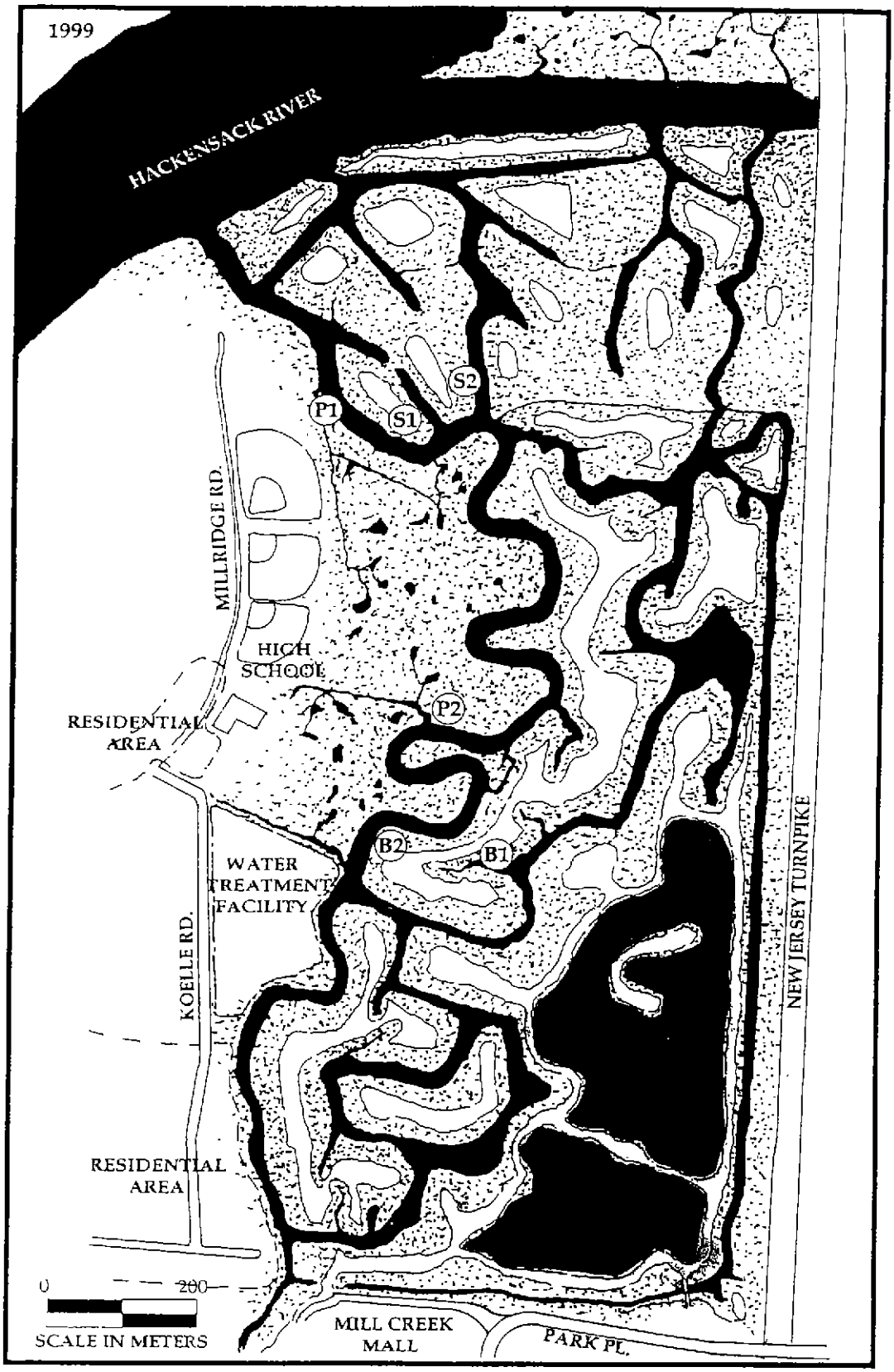

1999
HACKENSACK RIVER
S2
P1
S1
MILLRIDGE RD.
HIGH SCHOOL
P2
RESIDENTIAL AREA
B2
B1
WATER TREATMENT FACILITY
KOELLE RD.
NEW JERSEY TURNPIKE
RESIDENTIAL AREA
0
200
SCALE IN METERS
MILL CREEK MALL
PARK PL.

Figure 2. Mill Creek study sites located off of the Hackensack River in Secaucus, New Jersey in 2000.

The *Spartina alterniflora* sampling stations (S) were located on the Hartz Mountain restoration site, which was completed in 1990. *Phragmites* sampling stations (P) were located on the west side of Mill Creek and, according to aerial photographs, have been established at least 30 years.

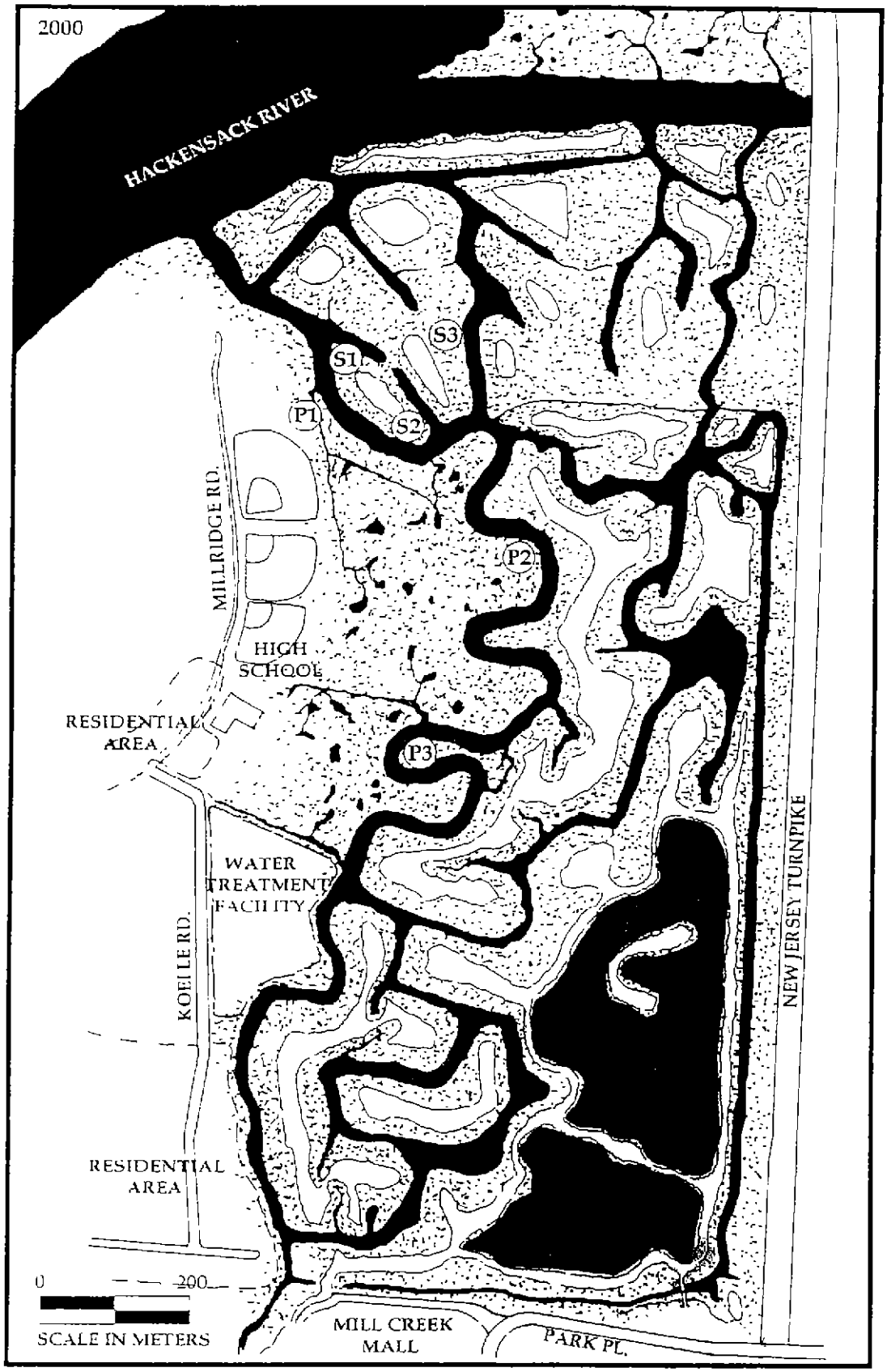

2000
HACKENSACK RIVER
S3
S1
P1
S2
MILLRIDGE RD.
P2
HIGH SCHOOL
RESIDENTIAL AREA
P3
WATER TREATMENT FACILITY
KOELLE RD.
NEW JERSEY TURNPIKE
RESIDENTIAL AREA
0
200
SCALE IN METERS
MILL CREEK MALL
PARK PL.

Figure 3. Abundance (average catch per unit effort, CPUE) of large juvenile/adult mummichog as collected by habitat at Mill Creek, NJ in 1999. Samples were collected from two replicate stations of each habitat type with three minnow traps per station (n = 6 traps/habitat type/2 weeks). Means (± 1 standard error) are displayed by sampling date.

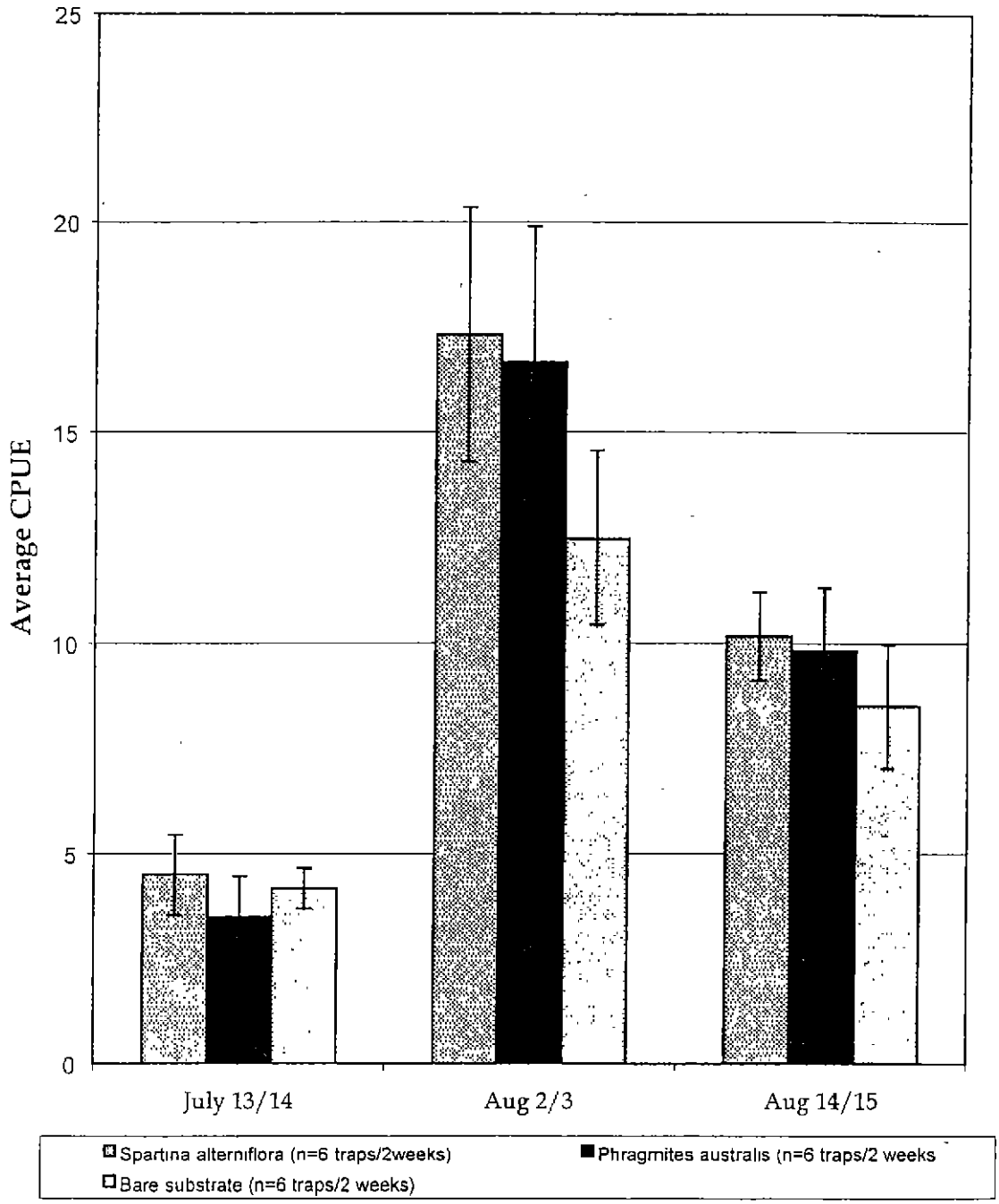

25
20
15
10
5
0
Average CPUE
July 13/14
Aug 2/3
Aug 14/15
Spartina alterniflora (n=6 traps/2weeks)
Phragmites australis (n=6 traps/2 weeks
Bare substrate (n=6 traps/2 weeks)

Figure 4. Length frequency distribution of large juvenile/adult mummichog as collected by habitat with minnow traps at Mill Creek, NJ in 1999.

Total length was measured to the nearest 0.1 mm and rounded to the nearest 1.0 mm for graphing purposes. Each size represents a range of 10 mm (ex: 30 mm represents 25 mm - 34 mm). Results are displayed by sampling date.

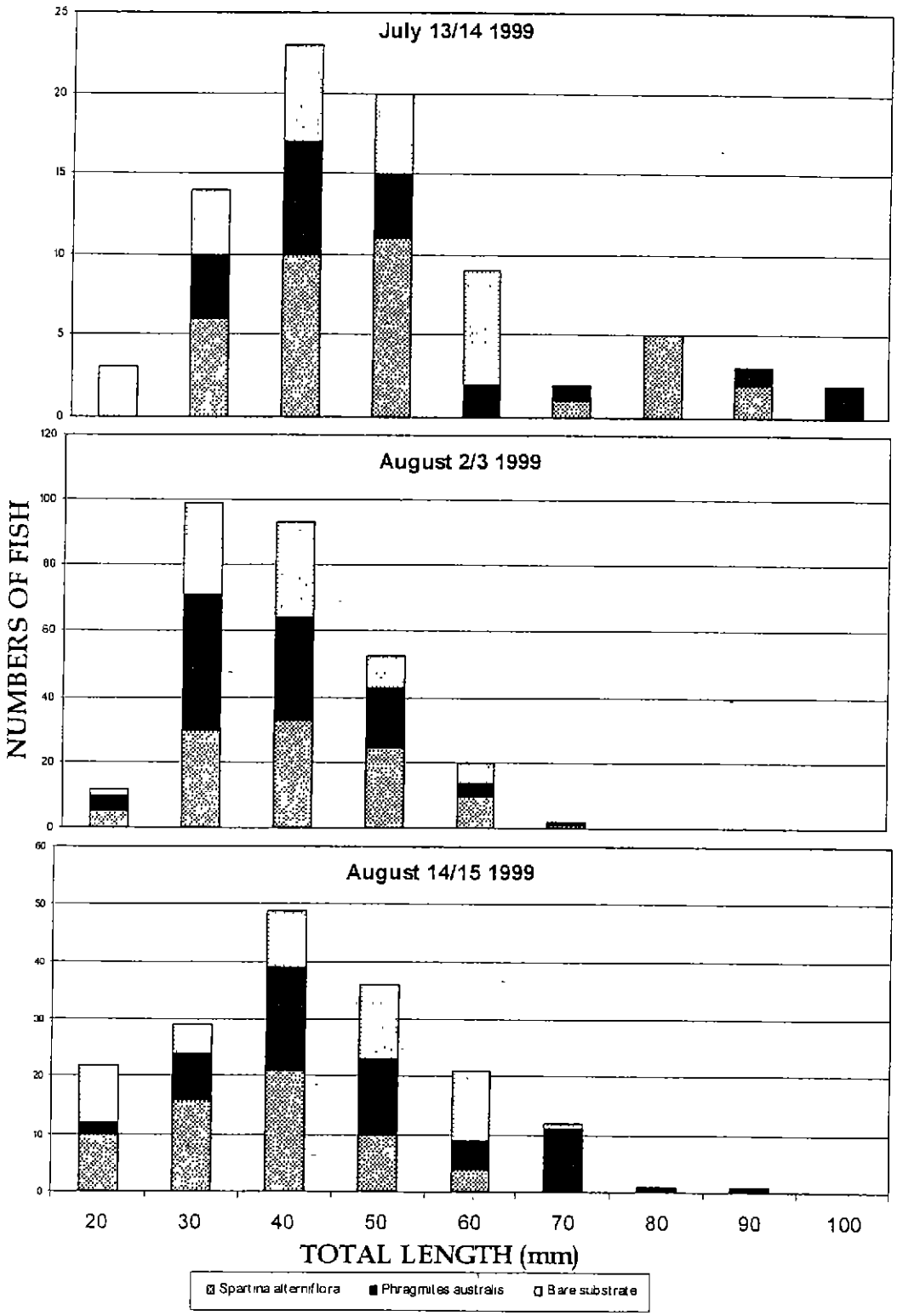
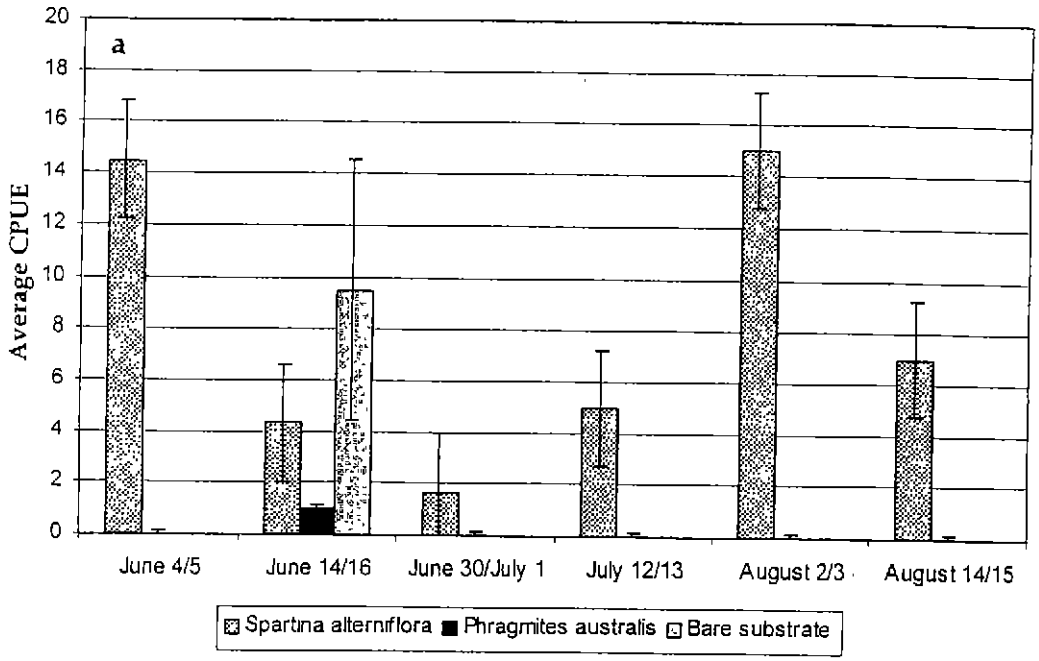

July 13/14 1999
August 2/3 1999
August 14/15 1999
NUMBERS OF FISH
TOTAL LENGTH (mm)
20
30
40
50
60
70
80
90
100
Spartina alterniflora
Phragmites australis
Bare substrate

Figure 5 Abundance (average catch per unit effort, CPUE) of larval/small juvenile mummichog at Mill Creek, NJ in 1999 (a) and 2000 (b).

In 1999, samples were collected from two replicate stations of each habitat type with three pit traps per station. In 2000, samples were collected from three replicate stations of each marsh type with four pit traps per station. Means (± 1 standard error) are displayed by sampling date for both years.


a
Average CPUE
20
18
16
14
12
10
8
6
4
2
0
June 4/5
June 14/16
June 30/July 1
July 12/13
August 2/3
August 14/15
Spartina alterniflora
Phragmites australis
Bare substrate

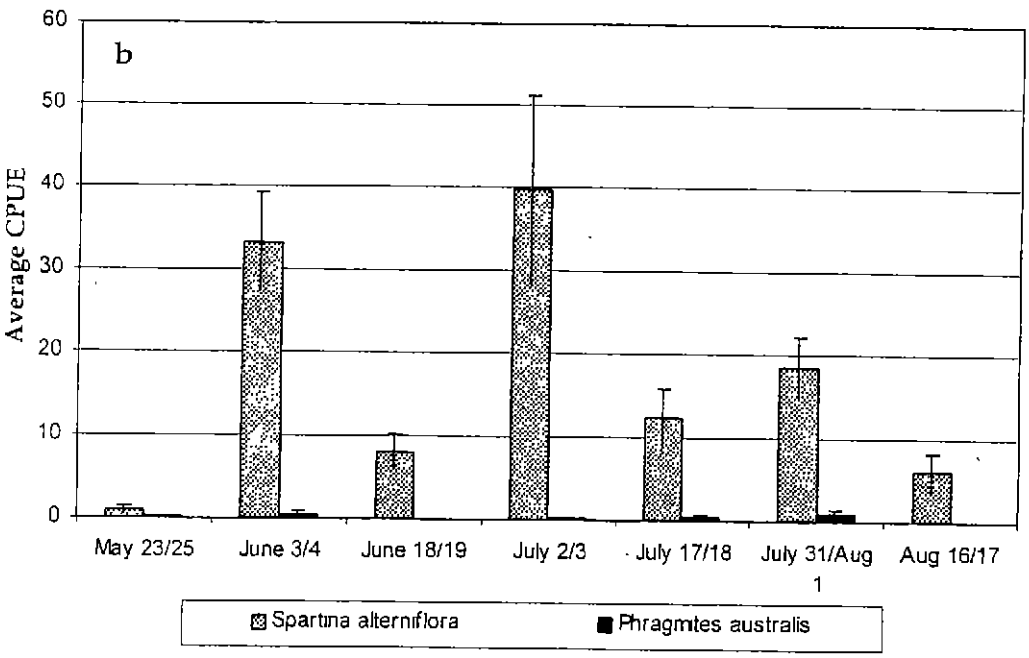

b
Average CPUE
60
50
40
30
20
10
0
May 23/25
June 3/4
June 18/19
July 2/3
July 17/18
July 31/Aug 1
Aug 16/17
Spartina alterniflora
Phragmites australis

Figure 6. Length frequency distribution of larval/small juvenile mummichog as collected by habitat with pit traps at Mill Creek, NJ in 1999.

Total length was measured to the nearest 0.1 mm and rounded to the nearest 1.0 mm for graphing purposes. Each size represents a range of 1 mm (ex: 5 mm = 4.5 mm - 5.4 mm). Results are displayed by month.

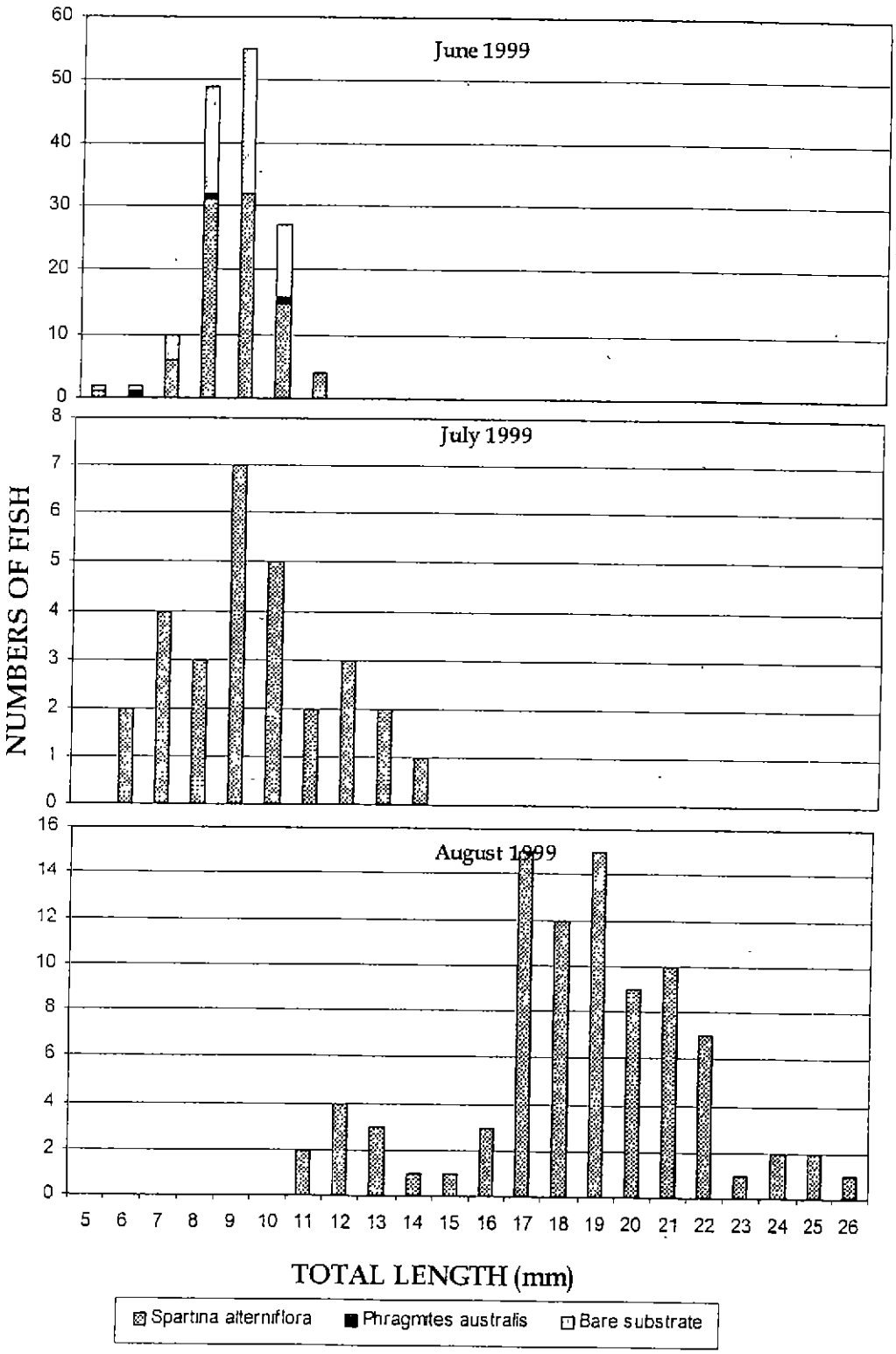
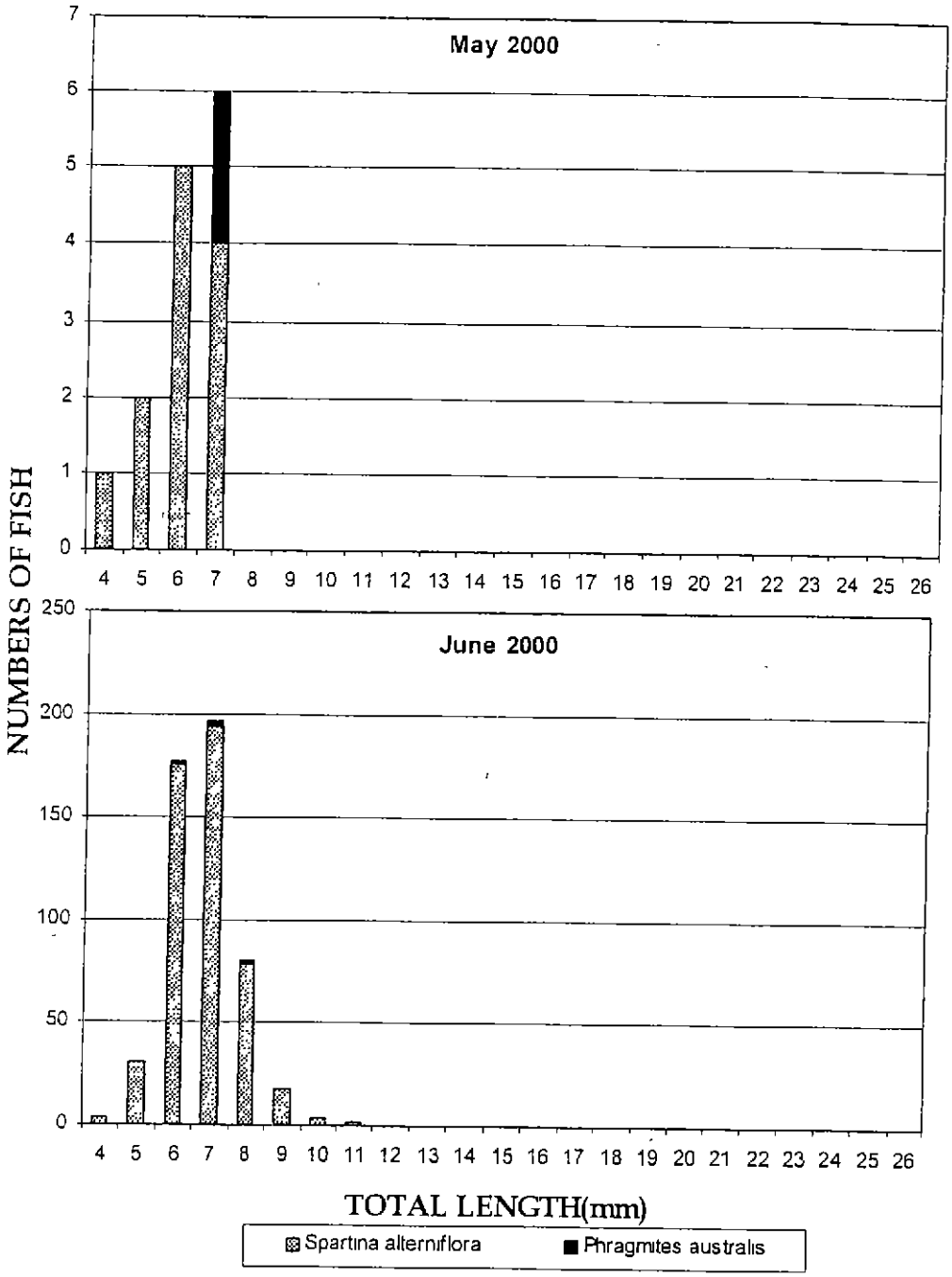

June 1999
July 1999
August 1999
NUMBERS OF FISH
TOTAL LENGTH (mm)
Spartina alterniflora
Phragmites australis
Bare substrate

Figure 7. Length frequency distribution of larval/small juvenile mummichog as collected by habitat at Mill Creek, NJ in 2000.

Total length was measured to the nearest 0.1 mm and rounded to the nearest 1.0 mm for graphing purposes. Each size represents a range of 1 mm (ex: 5 mm = 4.5 mm - 5.4 mm). Figure 7a shows the combined results for May and June. Figure 7b shows combined results for July and August.


May 2000
June 2000
NUMBERS OF FISH
TOTAL LENGTH(mm)
Spartina alterniflora
Phragmites australis

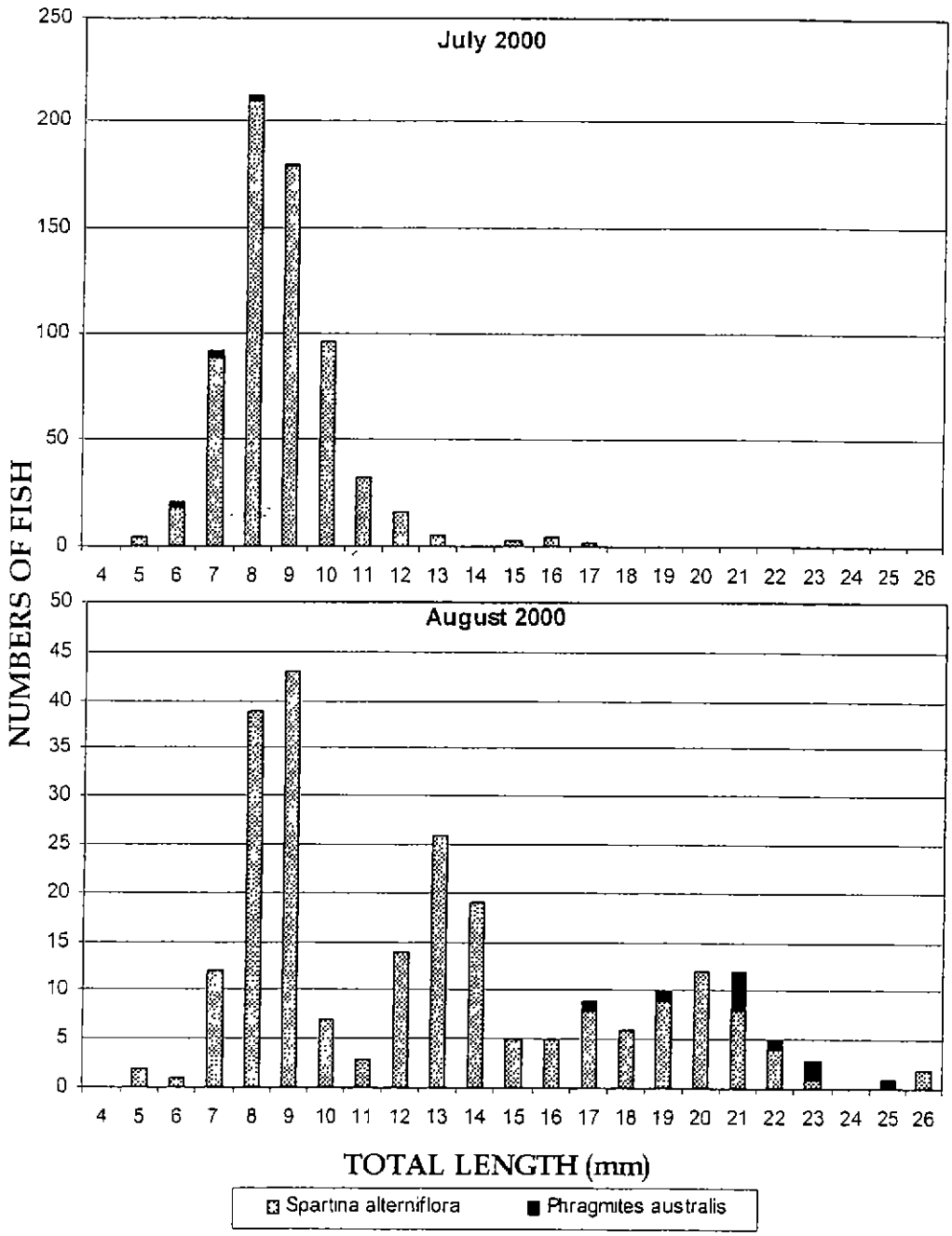

July 2000
August 2000
NUMBERS OF FISH
TOTAL LENGTH (mm)
Spartina alterniflora
Phragmites australis

Figure 8. Abundance (average catch per unit effort, CPUE) of larval/small juvenile mummichogs in *Phragmites* control plots vs. *Phragmites* treatment plots as collected by pit traps at Mill Creek, NJ in 2000.

Treatments involved creating a microtopography similar to that of *S. alterniflora* (i.e. more depressions and small pools) within *Phragmites*-dominated marsh. Each *Phragmites* treatment plot was established adjacent to a *Phragmites* control, separated by a distance of 2 - 10 m.

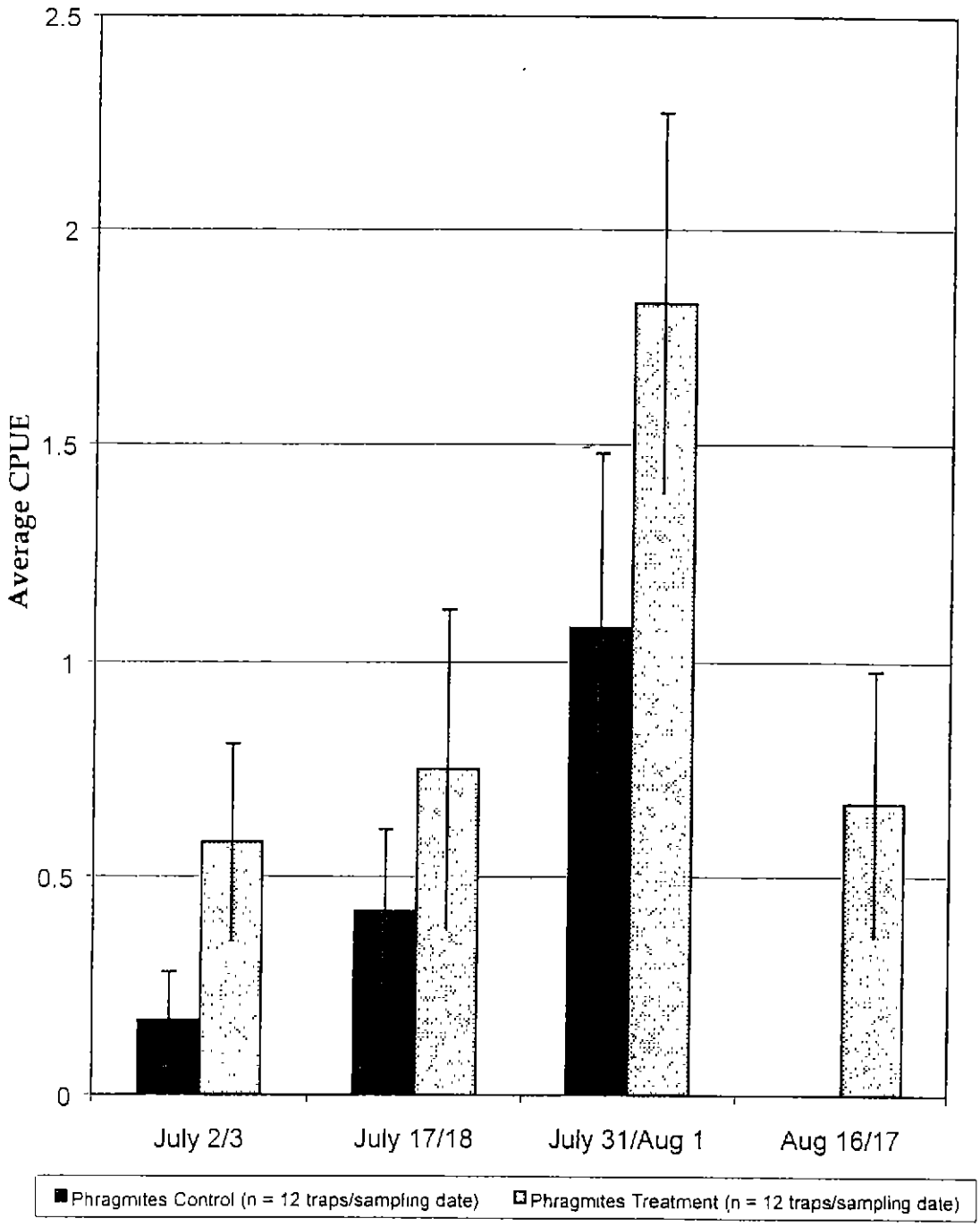

2.5
2
1.5
1
0.5
0
Average CPUE
July 2/3
July 17/18
July 31/Aug 1
Aug 16/17
Phragmites Control (n = 12 traps/sampling date)
Phragmites Treatment (n = 12 traps/sampling date)

Figure 9. A comparison of major invertebrate groups (taxa that comprise over 5% of the total organisms collected from all habitat types) collected by pit traps at Mill Creek, NJ in 1999 (a) and 2000 (b).

In 1999, n = 36 samples/habitat type (*S. alterniflora, Phragmites,* and bare substrate). In 2000, n = 54 samples/marsh type (*S. alterniflora* and *Phragmites*). Ostracods are not displayed on the 1999 graph due to graphing scale constraints, but showed a similar pattern to the copepods with 4,821 individuals collected in *S. alterniflora*-dominated marsh, 636 individuals in *Phragmites*-dominated marsh and 139 individuals at bare substrate study sites.

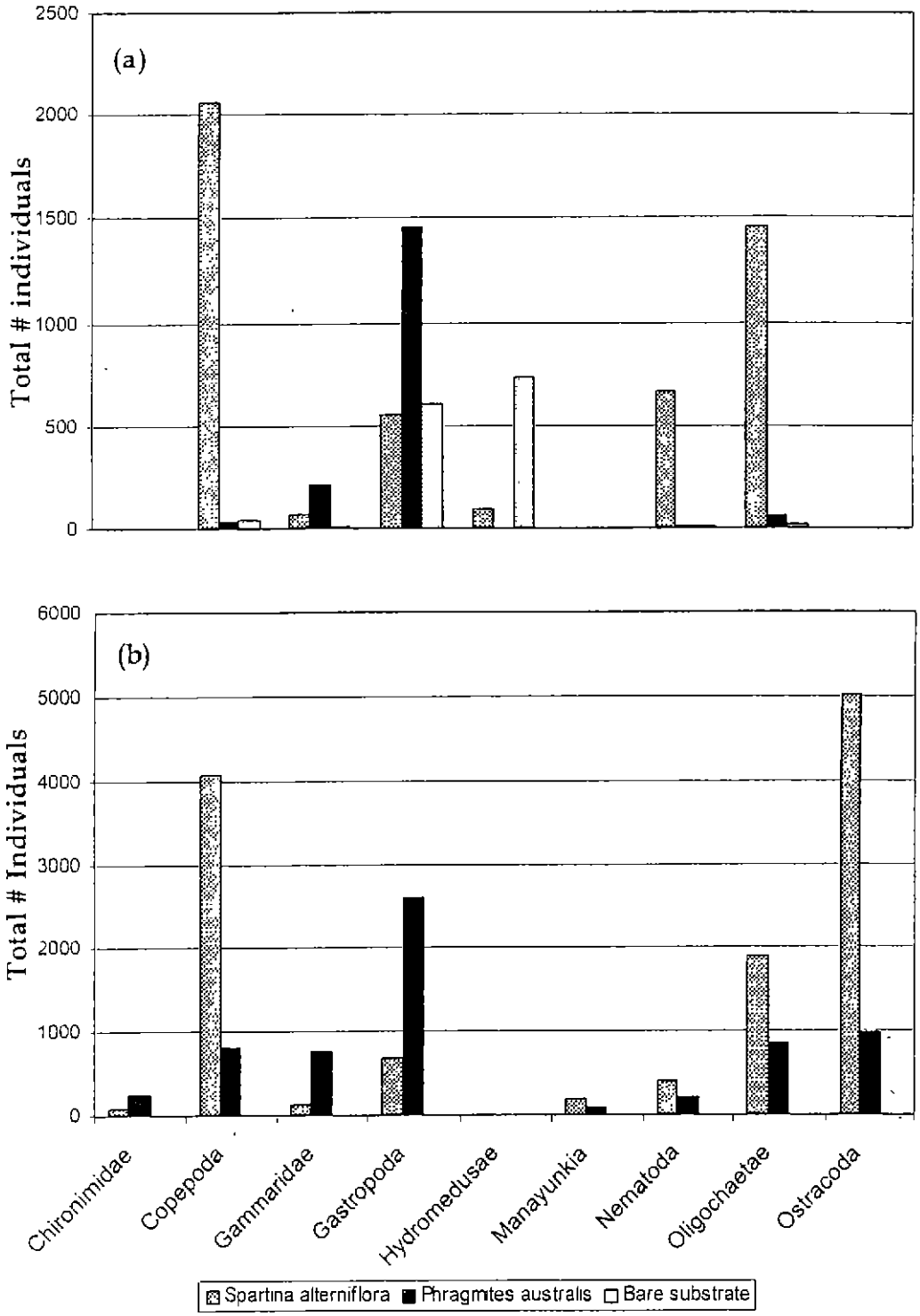
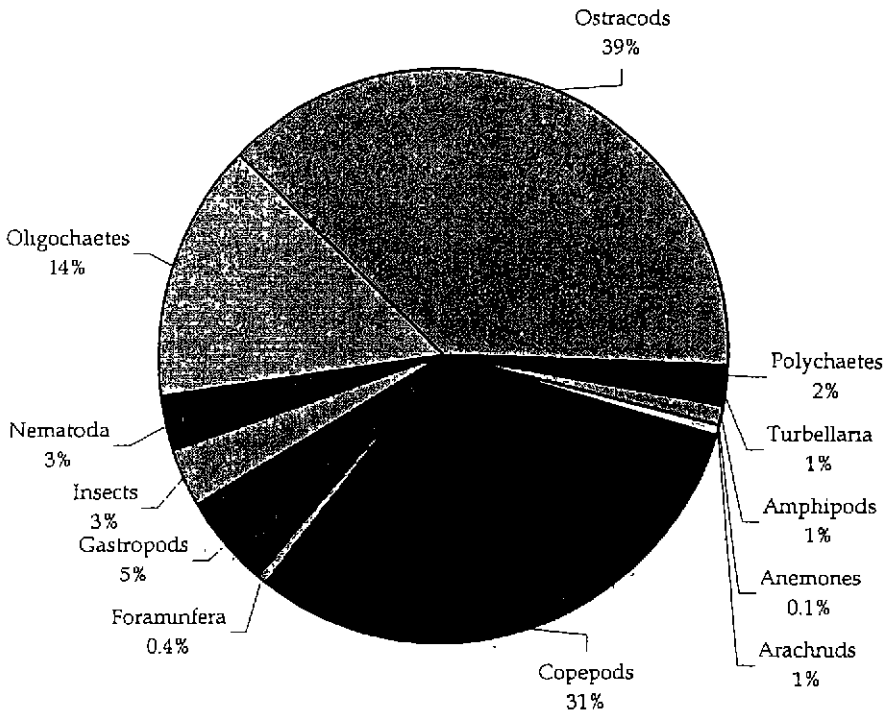

(a)
Total # individuals
2500
2000
1500
1000
500
0
(b)
Total # Individuals
6000
5000
4000
3000
2000
1000
0
Chironimidae
Copepoda
Gammaridae
Gastropoda
Hydromedusae
Manayunkia
Nematoda
Oligochaetae
Ostracoda
Spartina alterniflora
Phragmites australis
Bare substrate

Figure 10. Invertebrate assemblages at *Spartina alterniflora* (a) vs. *Phragmites* (b) dominated marshes as collected by pit traps (54 samples / marsh type) at Mill Creek, NJ in 2000.

The *S. alterniflora* collection (a) contained 13, 109 individuals and the *Phragmites* collection contained 7, 182 individuals.

(a)


Ostracods
39%
Oligochaetes
14%
Polychaetes
2%
Nematoda
3%
Turbellaria
1%
Insects
3%
Amphipods
1%
Gastropods
5%
Anemones
0.1%
Foramnifera
0.4%
Arachnids
1%
Copepods
31%

(b)

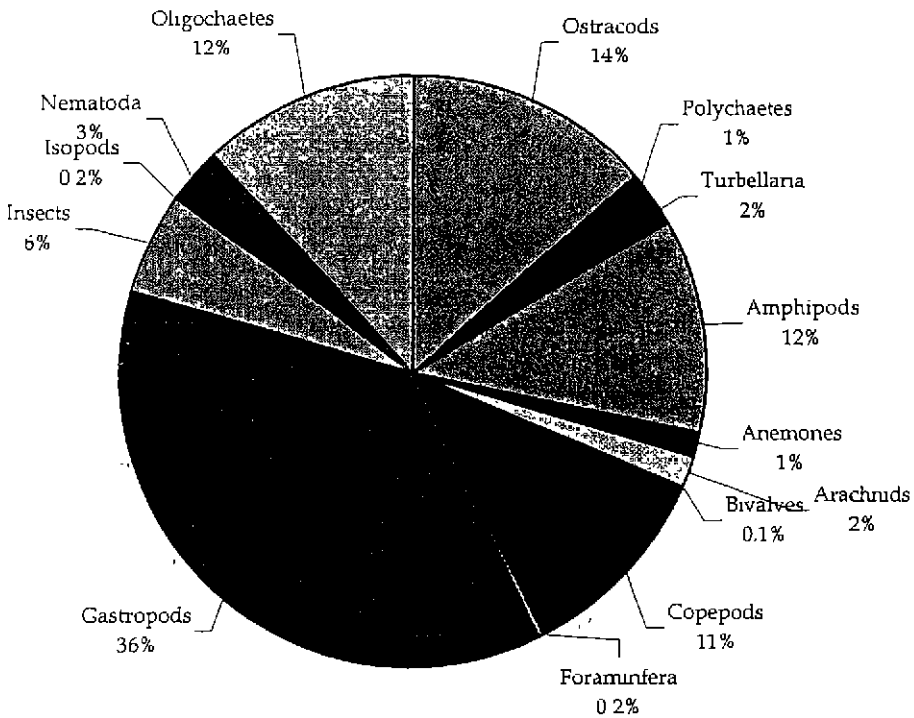

Oligochaetes
12%
Ostracods
14%
Nematoda
3%
Isopods
0 2%
Polychaetes
1%
Turbellaria
2%
Insects
6%
Amphipods
12%
Anemones
1%
Bivalves
0.1%
Arachnids
2%
Gastropods
36%
Copepods
11%
Foraminifera
0 2%

Figure 11. Abundance and composition of copepods collected in pit traps at *Spartina alterniflora* and *Phragmites* dominated marshes at Mill Creek, NJ in 2000. Individuals were collected from a total of 54 samples per marsh type.

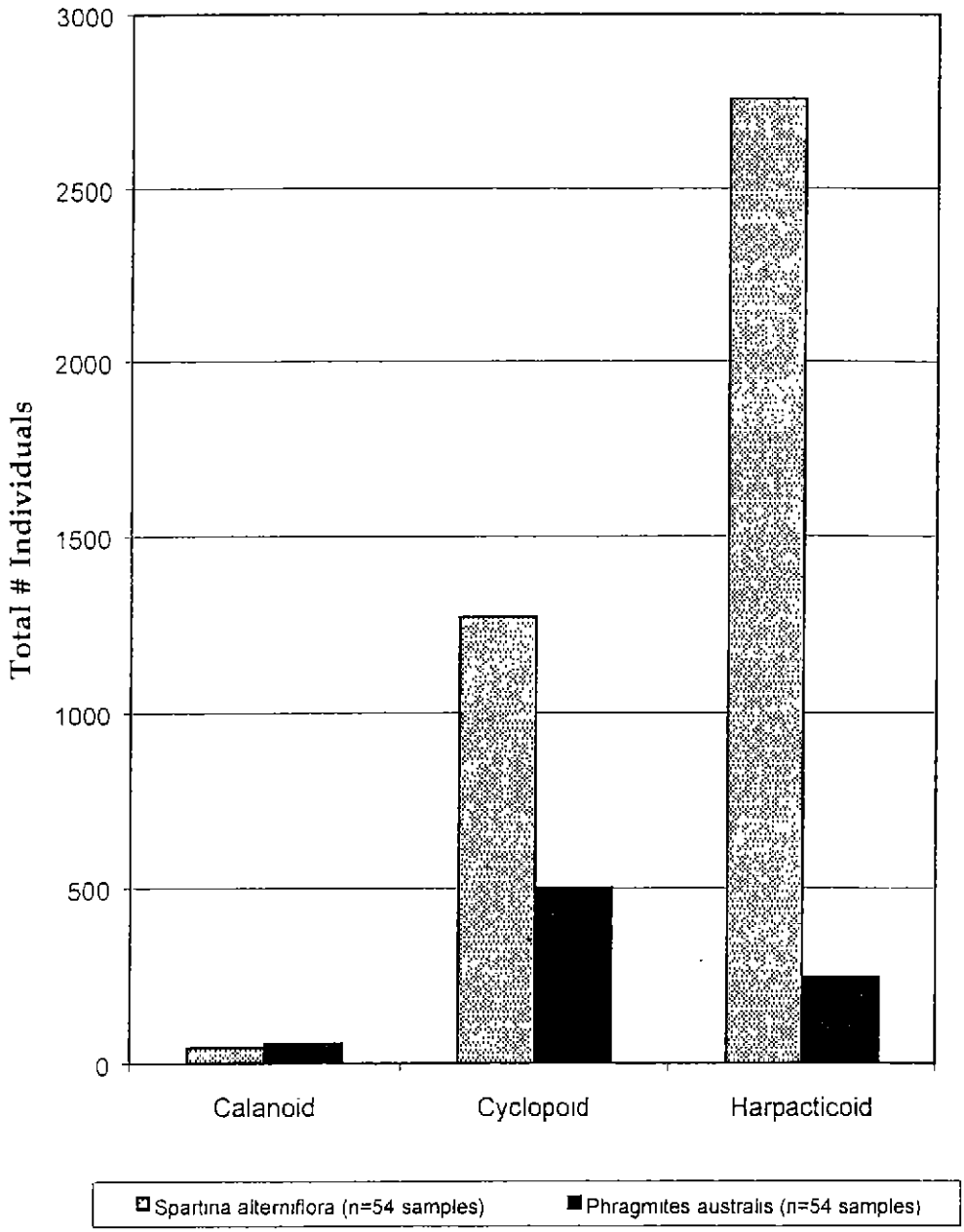
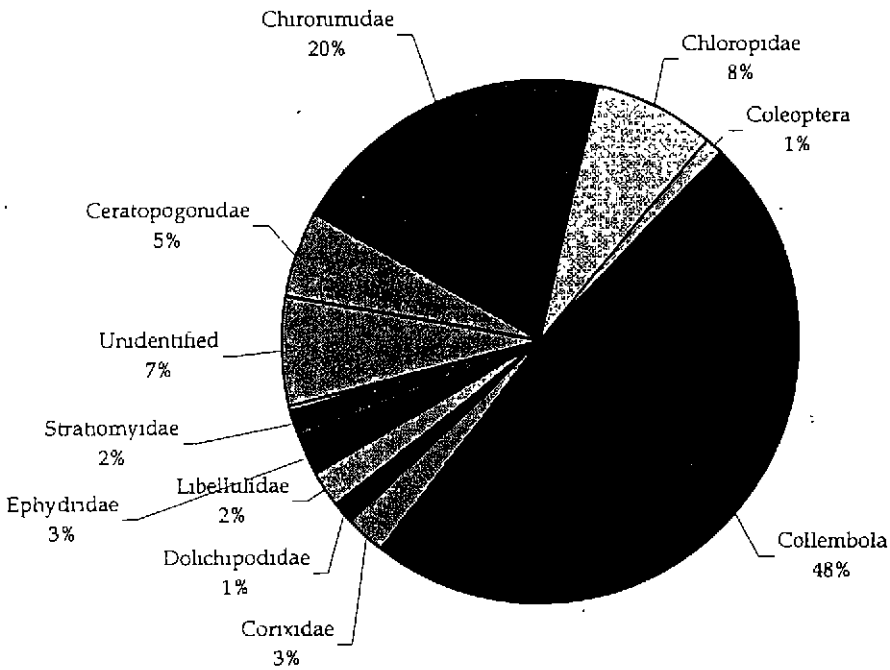

3000
2500
2000
1500
1000
500
0
Total # Individuals
Calanoid
Cyclopoid
Harpacticoid
Spartina alterniflora (n=54 samples)
Phragmites australis (n=54 samples)

Figure 12. Abundance and composition of insect larvae and nymphs collected in pit traps at *Spartina alterniflora* (a) and *Phragmites* (b) dominated marshes at Mill Creek, NJ in 2000.

A total of 428 individuals were collected from *S. alterniflora* and 398 individuals from *Phragmites*.

(a)


Chironomidae
20%
Chloropidae
8%
Coleoptera
1%
Ceratopogonidae
5%
Unidentified
7%
Stratiomyidae
2%
Libellulidae
2%
Ephydridae
3%
Dolichopodidae
1%
Corixidae
3%
Collembola
48%

(b)

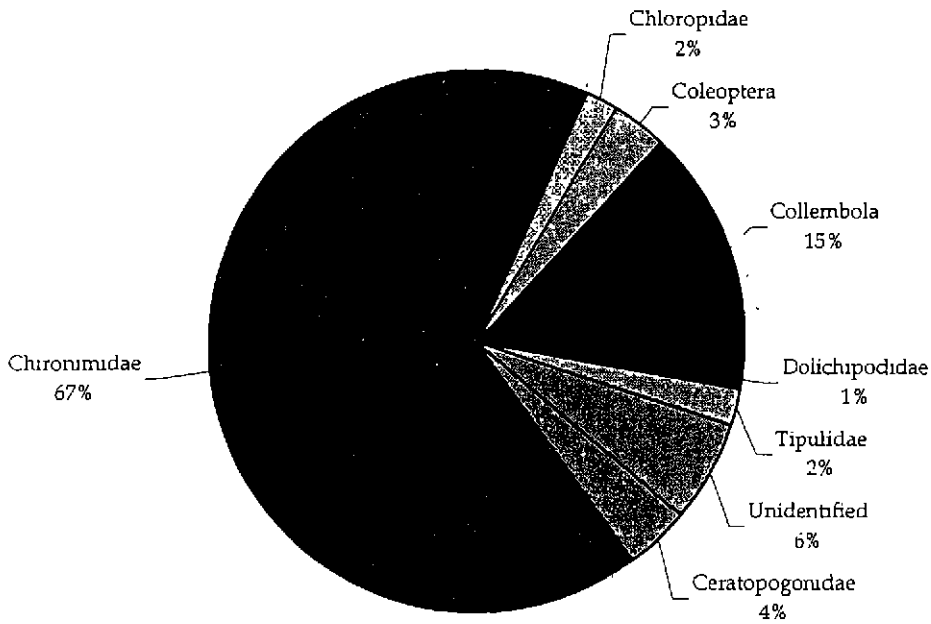
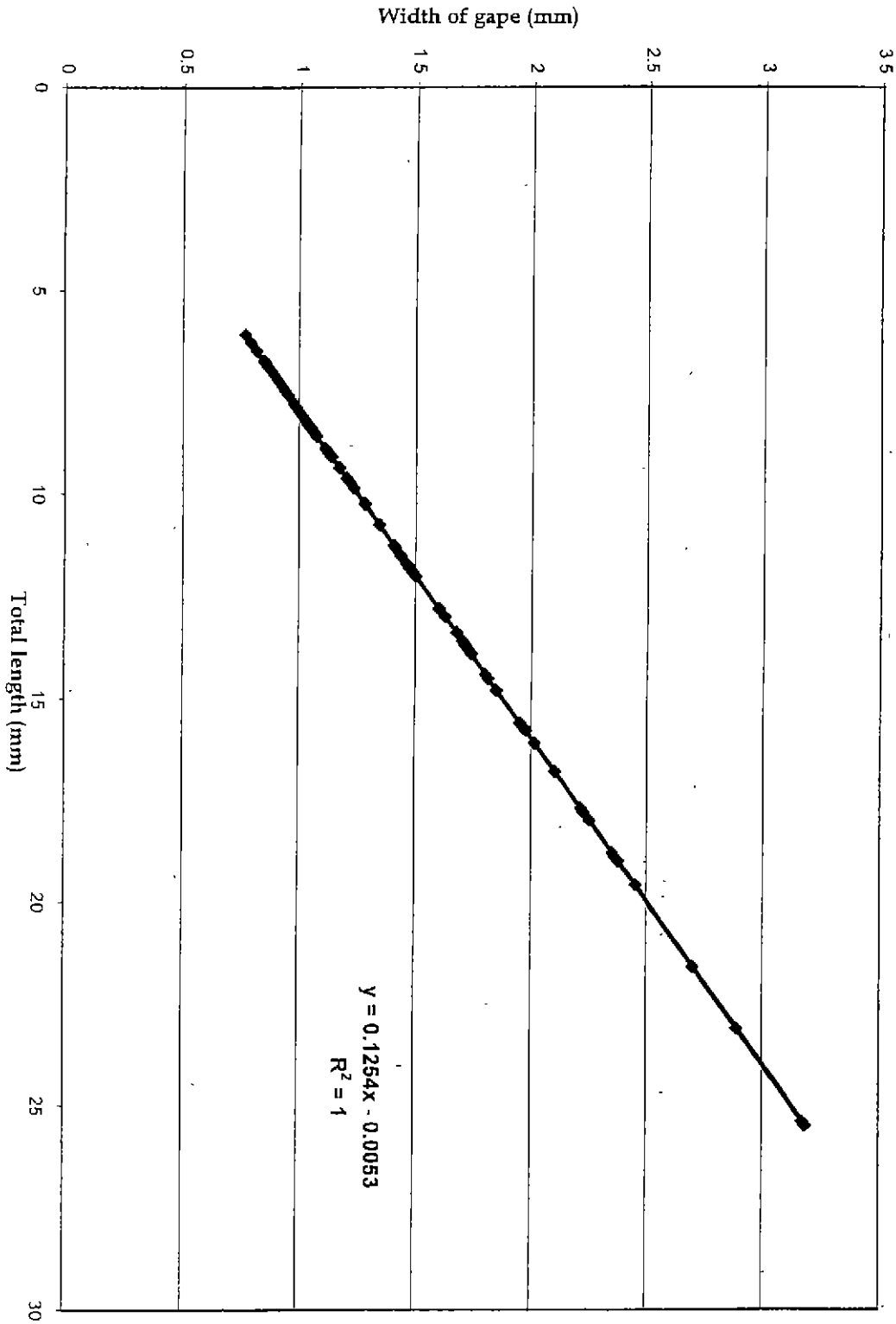

Chloropidae
2%
Coleoptera
3%
Collembola
15%
Dolichipodidae
1%
Tipulidae
2%
Unidentified
6%
Ceratopogonidae
4%
Chironimidae
67%

Figure 13. The relationship between total length and width of gape for mummichog (n = 98).


Width of gape (mm)
0
0.5
1
1.5
2
2.5
3
3.5
Total length (mm)
0
5
10
15
20
25
30
y = 0.1254x - 0.0053
R² = 1

IV. DISCUSSION

The results of this study suggest that *Phragmites*-dominated marshes may not be providing the habitat necessary for mummichog larvae and small juveniles based on their low abundances in contrast to *S. alterniflora* in both 1999 and 2000. These results corroborate earlier comparisons between these marsh types in the Mullica River, NJ (Able and Hagan 2000). On the other hand, the abundance and distribution of the larger juveniles and adults in Mill Creek seems to indicate that these size classes are utilizing the two marsh types similarly. These results correspond to findings in the Connecticut River (Fell *et al.* 1998, Rilling *et al.* 1998), the Chesapeake Bay (Meyer *et al.* in press) and the Mullica River, NJ (Able and Hagan 2000). Study results demonstrating that larger individuals are similarly abundant in *Phragmites*-dominated and "*Phragmites*-free" marshes should be interpreted with caution. In each of the aforementioned studies, *Phragmites* sampling sites were in close proximity to *Spartina* sampling sites, which may have been serving as larval habitat and hence a major source for the populations in *Phragmites*. Once the young fish are large enough to migrate on and off of the marsh surface (≈ 15 - 20 mm standard length as per Kneib 1986), they may then use both marsh types similarly. This study is not suggesting that *Spartina* marsh is the only habitat available for the early life history stages of mummichog, but rather that *Phragmites* monocultures may not be providing adequate habitat to sustain abundant populations of this species.

It is not yet clear what factors are contributing to the dramatic differences in larval and small juvenile mummichog abundances within *Phragmites* and *S. alterniflora* dominated marshes. Although physical features such as elevation and flood depth affect fish utilization of the marsh surface, these potentially confounding factors were kept similar between marsh types and thus cannot be responsible for the differences in abundance between the two habitats. A lack of larval microhabitats on the marsh surface, altered hydrology, scarcity of egg deposition sites, as well as reduced availability of larval prey items are all possible reasons for the apparent unsuitability of habitat in *Phragmites*-dominated marshes.

It is well established that small depressions and pools on the marsh surface are important larval refuges at low tide (Taylor *et al.* 1979, Talbot and Able 1984, Yozzo *et al.* 1994, Kneib 1997). The creation of microhabitats (i.e. increasing rugosity and amount of standing water) on the *Phragmites* marsh surface appeared to improve larval habitat in terms of abundance but, based on limited data, cannot be concluded as the only important feature. There are hydrologic features that antecede the issue of microtopography in terms of larval fish habitat. Since mean flow speed over the marsh surface has an inverse relationship with plant density (Leonard and Luther 1995) it would follow that the conversion of a *Spartina*-dominated marsh to the significantly lower basal

area coverage of a *Phragmites*-dominated marsh would alter this hydrologic feature. Angradi *et al.* (in press) estimated water velocity across the marsh surface from mass loss (g d -1) of plaster of Paris standards placed on the surface of both *Phragmites* and *Spartina* dominated marsh. They determined that velocity, in combination with inundation, was higher in *Phragmites* marshes based on mass loss. In addition, the influence plant morphology has on deposition and erosion patterns in tidal marshes (Gray 1992) is also an important consideration in the resulting spatial distribution of velocity (i.e. small creeks and rivulets in *Spartina* marsh vs. "sheet flow" in *Phragmites* marsh). A higher mean flow speed coupled with a more uniform flow may greatly affect larval habitat and survivorship late in the tide.

Egg deposition sites available in *S. alterniflora* marshes (i.e. the interstice formed by the first axil of the plant) are lacking in *Phragmites* marshes. Eggs have been observed within the broken culms of *Phragmites* short enough to be submerged at high tide, with the number of eggs positively correlating to stem diameter (Able and Hagan unpublished data). In addition, the results of the spawning substrate trial in this study showed that these fish will spawn within *Phragmites* marshes, given adequate substrate. Further investigation is necessary to determine if broken culms are the only sites available for spawning. It is interesting to note that eggs were collected only from the *Phragmites* plots with creeks adjacent to them. This finding alludes to the potential importance of the amount of creeks

and rivulets on the marsh surface (i.e. drainage density) as access points for spawning and feeding (Rozas *et al.* 1988, Kneib 1997). These topographic features are reduced as a result of *Phragmites* establishment (Windham and Lathrop 1999, Weinstein and Balletto 1999, Rooth and Stevenson 2000) and may, in turn, influence marsh fish accessibility and hence abundance over the long-term.

The results of the invertebrate sampling with pit traps suggest that availability of larval fish prey items may be greater in *S. alterniflora*-dominated marsh in comparison to *Phragmites*-dominated. Harpacticoid copepods, nematodes, *Manayunkia aestuarina*, and ostracods, all demonstrated to be mummichog larval prey items (Kneib and Stiven 1978, Smith *et al.* 2000), were significantly more available in the *S. alterniflora*-dominated marshes than in *Phragmites*-dominated marshes. The relationship between invertebrate size and gape width of mummichogs indicates that these organisms are available to the smallest size classes. The taxa found to be dominant in the *Phragmites*-dominated marshes (i.e. amphipods and gastropods) are known to be prey of larger individuals (Kneib and Stiven 1978, Fell *et al.* 1998, Rilling *et al.* 1998, Smith *et al.* 2000). These prey size differences might contribute to the fish size class differences between marsh types in this study.

The pit traps sampled the invertebrates suspended in the water column and those associated with habitats on or just above the marsh surface and thus are the

organisms that would be available as prey for the mummichog and should not be compared with study results of differing sampling methodologies (e.g. benthic cores). The greater amount of benthic taxa such as nematodes, *Manayunkia aestuarina*, and oligochaetes in *S. alterniflora* pit trap collections could possibly be attributed to a greater amount of suspended sediments in these marshes (personal observation). In addition, the low numbers of copepods in *Phragmites* marshes (in contrast with numbers found in *S. alterniflora* marshes) may be due to the decrease in light penetration to the marsh surface as a result of dense aerial production. This decrease in light would influence diatom production (Thurman 1991) and thus limit a food resource for the copepods, which in turn are an important prey for the mummichog.

Based on both measured and personal and observations, future studies should investigate *Phragmites* marshes for 1) alterations in hydrodynamic features and the subsequent influence on larval marsh fish habitat and survivorship, 2) the availability of spawning substrate for marsh resident fishes, and 3) prey availability for larval and small juvenile marsh fishes.

V. CONCLUSIONS

In general, the physical and hydrological changes associated with the conversion of a *S. alterniflora*-dominated marsh to a *Phragmites*-dominated marsh may influence the fauna closely associated with the habitats on or just below the marsh surface. As a result, these alterations may have adverse effects on the habitat of marsh resident fish such as the mummichog, an abundant and important component of Atlantic coast tidal marshes. Because the mummichog occurs frequently in the diets of many estuarine species, it would follow that a population size reduction could lead to negative effects on the estuarine food web structure and the transfer of energy from the marsh surface to the adjacent subtidal waters.

Based on recent studies, it is apparent that the larger size classes of the mummichog are able to access and feed within *Phragmites*-dominated marshes as well as in "*Phragmites*-free" marshes (Rilling *et al.* 1998, Fell *et al.* 1998, Able and Hagan 2000, Meyer *et al.* in press). However, the results of this study and findings in the Mullica River, NJ (Able and Hagan 2000) indicate *Phragmites* may not be providing the habitat necessary for the early life history stages. A combination of factors that include altered flows over the marsh surface and subsequent lack of larval refuges (i.e. depressions and pools on the marsh surface), scarcity of egg deposition sites, and reduced prey availability may

contribute to the low abundance of larvae found in a *Phragmites*-dominated marsh.

Management implications

Although the establishment of *Phragmites* is frequently perceived in a negative light, it does provide some beneficial services. Due to its very high aerial production, *Phragmites* is capable of incorporating a large portion of the available nitrogen and phosphorus into its biomass (Templer *et al.* 1998, Meyerson *et al.* 1999), which would be beneficial in eutrophic systems. In addition, because *Phragmites* is able to colonize in recently deposited dredge materials, it can effectively detoxify these active acid sulfate soils (Fanning and Fanning 1989). In cases where shoreline erosion is occurring, *Phragmites* may improve sediment retention and accumulation (Rice *et al.* 2000, Rooth and Stevenson 2000). Often the first plant to colonize disturbed altered areas, it is also the first plant to offer wildlife habitat. Bird species such as marsh wrens, red-winged blackbirds, common yellowthroats, swamp sparrows, and Virginia rails will nest in and utilize its cover (Benoit and Askins 1999, personal observation). Also, muskrats tunnel in and utilize *Phragmites* in the construction of their dens (personal observation). In addition, during the course of this study, many marsh crab (*Rhitropanopeus harrisii, Uca spp.*) burrows were observed along *Phragmites*-dominated marsh banks. The effects of *Phragmites* establishment on estuarine

fauna, in general, are still in the process of being unraveled by the scientific community.

On the other hand, *Phragmites* excludes many salt marsh obligate species. Bird species such as seaside sparrows, clapper rails, willets, and salt marsh sharp-tailed sparrows, which rely on salt marsh grasses as nesting sites are negatively affected by its domination (Benoit and Askins 1999). In addition, the dense aerial growth typical of *Phragmites* may inhibit shorebird feeding. This study's results suggest that habitat for the early life history stages of marsh resident fishes is adversely affected by *Phragmites* dominance and the presence of *Spartina* marshes may be necessary to serve as habitat for recruitment.

Although biocontrol measures are currently being suggested for the eradication of *Phragmites* (Blossey and McCauley 2000), there are limited ecological studies to confirm that such a measure is warranted. Some argue that there are beneficial aspects to *Phragmites* establishment and that many desirable ecosystem functions are being maintained at a similar level as uninvaded marshes (Rooth and Windham 2000). This study's findings illustrate the complexity of interpreting the limited information on marsh resident fish response to *Phragmites*. Further studies are necessary to elucidate faunal response to this habitat alteration.

In a restoration or mitigation design, it is essential that the benefits and disadvantages of *Phragmites* presence be dealt with explicitly. Complete removal of this plant may not be necessary or desirable. However, the invasive character of *Phragmites* necessitates cautious design and management.

VI. BIBLIOGRAPHY

Able, K. W. and S. M. Hagan. 2000. Effects of common reed (*Phragmites australis*) invasion on marsh surface macrofauna: Response of fishes and decapod crustaceans. Estuaries.

Able, K. W. and M. P. Fahay. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press, New Brunswick, New Jersey.

Able, K. W. and D. Hata. 1984. Reproductive behavior in the *Fundulus heteroclitus-F. grandis* complex. Copeia (4): 820-825.

Able, K. W. 1984. Variation in spawning site selection of the mummichog *Fundulus heteroclitus*. Copeia (2):522-525.

Able, K. W. and M. Castagna. 1975. Aspects of an undescribed reproductive behavior in *Fundulus heteroclitus* (Pices: Cyprinodontidae) from Virginia. Chesapeake Science. 16: 282-284.

Angradi, T. R., S. M. Hagan, and K. W. Able. In press. Vegetation type and the intertidal macroinvertebrate fauna of a brackish marsh: *Phragmites* vs. *Spartina*. Wetlands.

Armstrong, P. B. and J. S. Child. 1965. Stages in the normal development of *Fundulus heteroclitus*. Biological Bulletin. 128(2): 143-168.

Benoit, L. K. and R. A. Askins. 1999. Impact of the spread of *Phragmites australis* on the distribution of birds in Connecticut tidal marshes. Wetlands. 19(1): 194-208.

Blossey, B. and J. McCauley. 2000. A plan for developing biological control for *Phragmites australis* in North America. Wetland Journal. 12(1): 23-28.

Brower, J. E., J. H. Zar, and C. N. von Ende. 1990. Field and Laboratory Methods for General Ecology. Third Edition. Wm. C. Brown Publishers, Dubuque IA.

CH2MHILL 1995a. Design alternatives analysis, Brown's Run site. Draft report to Public Service Electric and Gas Company, November 7. PSE&G, Newark, NJ.

CH2MHILL. 1995b. Design alternatives analysis, Green Swamp site. Draft report to Public Service Electric and Gas Company, November 7. PSE&G, Newark, NJ.

Cadigan, K. M. and P. E. Fell. 1985. Reproduction, growth and feeding habits of *Menidia menidia* (Atherinidae) in a tidal marsh-estuarine system in southern New England. Copeia. 21-6.

Chambers, R. M., L.A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into Tidal Wetlands of North America. Aquatic Botany. 64: 261-273.

Coorey, D. N., K. W. Able, and J. K. Shisler. 1985. Life History and food habits of the inland silversides, *Menidia beryllina*, in a New Jersey salt marsh. Bulletin of the New Jersey Academy of Science. 30 (1): 29-38.

Cross, D. H. and K. L. Fleming. 1989. Control of *Phragmites* or common reed. U.S. Fish and Wildlife Service, Office of Information Transfer, Fort Collins, FWS/OIT - 13.4.12:1-15.

Cross, R. E. and A. E. Stiven. 1999. Size-dependent interactions in salt marsh fish (*Fundulus heteroclitus* Linnaeus) and shrimp (*Palaemonetes pugio* Holthuis). Journal of Experimental Marine Biology and Ecology. 242: 179-199.

Deegan, L. A 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. Canadian Journal of Fisheries and Aquatic Sciences. 50: 74-79.

Fanning, D. S. and M. B. Fanning. 1989. Soil morphology, Genesis, and Classification. John Wiley & Sons. New York, NY, USA.

Fell, P. E., S. P. Weissbach, D. A. Jones, M. A. Fallon, J. A. Zeppieri, E. K. Faison, K. A. Lennon, K. J. Newberry, L. K. Reddington. 1998. Does invasion of oligohaline tidal marshes by reed grass, *Phragmites australis* (Cav.) Trin. ex Steud., affect the availability of prey resources for the mummichog, *Fundulus heteroclitus* L.? Journal of Experimental Marine Biology and Ecology. 222: 59-77.

Gray, A. J. 1992. Saltmarsh plant ecology: Zonation and succession revisited, p. 63-79. *In*: J. R. L. Allen and K. Pye (eds.), Saltmarshes, morphodynamics, conservation and engineering significance. Cambridge.

Hardy, J. D., Jr. 1978. Development of fishes of the mid-Atlantic Bight. An Atlas of Egg, Larval and Juvenile Stages. Vol. II. U.S. Fish and Wildlife Service Publication FWS/OBS-78/12. Pp 162 - 178.

Haslam, S. M. 1971a. Community regulation in *Phragmites communis* Trin. I. Monodominant stands. Journal of Ecology. 59: 65-73.

Hettler, Jr., W. F. 1989. Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. Marine Ecology Progress Series. Vol. 56: 111-118.

Hackensack Meadowlands Development Commission. February 2000. Internal report for the National Academy of Sciences Meadowlands Mitigation Project Summary.

Hollander, M. and D. A. Wolfe. 1973. Nonparametric Statistical Methods. John Wiley & Sons, Inc., NY.

Horton, D. B. 1966. A study of population behavior, homing orientation and movement in the comon mummichog, *Fundulus heteroclitus*. Ph.D. Diss., University of Rhode Island.

Kneib, R. T and A. E. Stiven. 1978. Growth, reproduction and feeding of *Fundulus heteroclitus* (L.) on a North Carolina salt marsh. Journal of Experimental Marine Biology and Ecology. 31: 121-140.

Kneib, R. T. 1984. Patterns in the utilization of the intertidal salt marsh by larvae and juveniles of *Fundulus heteroclitus* (Linnaeus) and *Fundulus luciae* (Baird). Journal of Experimental Marine Biology and Ecology. 83: 41-51.

Kneib, R. T. 1986. The role of *Fundulus heteroclitus* in salt marsh trophic dynamics. American Zoologist. 26: 259-269.

Kneib, R. T. and S. L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series. 106: 227-238.

Kneib, R. T. March 1997. Early life stages of resident nekton in intertidal marshes. Estuaries. Vol. 20 (1): 214-230.

Kneib, R. T. 1997. The role of tidal marshes in the ecology of estuarine nekton. Oceanography and Marine Biology: an Annual Review. 35:163-220.

Kneib, R. T. Predation risk and use of intertidal habitats by young fishes and shrimp. Ecology. 68(2): 379-386.

Krebs, C. J. 1989 Ecological Methodology. Harper & Row Publishers, NY.

Leonard, L. A., and M. E. Luther. 1995. Flow hydrodynamics in tidal marsh canopies Limnology and Oceanography. 40(8): 1474-1484.

Marks, M., B. Lapin, and J. Randall. 1994. Element Stewardship Abstract for *Phragmites australis*. The Nature Conservancy, Arlington, VA.

McIvor C. C. and W. E. Odum. 1988. Food, predation risk, and microhabitat selection in a marsh fish assemblage. Ecology. 69(5) : 1341-1351.

Meredith, W. H. and V. A. Lotrich. 1979. Production dynamics of a tidal creek population of *Fundulus heteroclitus* (Linnaeus). Estuarine and Coastal Marine Science. 8: 99-118.

Merritt R. W. and K. W. Cummins. 1978. An Introduction to the Aquatic Insects of North America. Second Edition. Edited by R.W. Merritt and K.W. Cummins. Kendall/Hunt Publishing Company. Dubuque, Iowa.

Meyer, D. L., J. M Johnson, and J. W. Gill. In press. A comparison of nekton use of *Phragmites australis* and *Spartina alterniflora* marshes in the Chesapeake Bay, USA. Marine Ecology Progress Series.

Meyerson, L. A., K. A. Vogt, and R. M. Chambers. 1999. The effects of *Phragmites* removal on nutrient pools in a freshwater tidal marsh ecosystem. Biological Invasions. 1:129-136.

Minello, T J., R. J. Zimmerman, and R. Medina. 1994. The importance of edge for natant macrofauna in a created salt marsh. Wetlands. 14(3): 184-198.

Minello, T J. and J. W. Webb, Jr. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Marine Ecology Progress Series. 151: 165-179.

Pollock, L. W. 1998. A Practical Guide to the Marine Animals of Northeastern North America. Rutgers University Press, New Brunswick, NJ.

Prinslow, T. E., I. Valiela, and J M. Teal. 1974. The effect of detritus and ration size on the growth of *Fundulus heteroclitus* (L.). Journal of Experimental Marine Biology and Ecology. 16: 1-10.

Quinn, J. R. 1997. Fields of Sun and Grass: An Artists Journal of the New Jersey Meadowlands. Rutgers University Press, New Brunswick, NJ.

Rice, D. M. 1996. Determining the distribution and expansion rate of *Phragmites australis* in six Chesapeake Bay area marshes. M. S. Thesis. University of Maryland.

Rice, D., J. Rooth, and J. C. Stevenson. 2000. Colonization and expansion of *Phragmites australis* in upper Chesapeake Bay tidal marshes. Wetlands. 20(2): 280-299.

Rilling, G. C., P E. Fell, and R. S. Warren. March 26, 1998. Fish use of brackish high marsh areas in the lower Connecticut River: a comparison of a *Phragmites australis*-dominated vs. a restored marsh. Final report for Connecticut Department of Environmental Protection. Office of Long Island Sound Programs, Hartford, CT.

Rooth, J E. and L. Windham. 2000. Phragmites on death row: Is biocontrol really warranted? Wetland Journal. 12(1): 29-37.

Rooth, J. E. and J. C. Stevenson. 2000. Sediment deposition patterns in *Phragmites australis* communities: implications for coastal areas threatened by rising sea-level. Wetlands Ecology and Management.

Rosza, R. 1995. Human impacts on tidal wetlands: History and regulations. *In*: Dreyer, G.D., Niering, W.A. (eds.), Tidal marshes of Long Island Sound: Ecology, History, and Restoration. Connecticut College Arboretum. Bulletin No. 34: 42-50.

Rozas, L. P. 1995. Hydroperiod and its influence on nekton use of the salt marsh: A pulsing ecosystem. Estuaries. 18(4): 579-590.

Rozas, L. P. and D. J. Reed. 1993. Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence. Marine Ecology Progress Series. 96: 147-157.

Rozas, L. P., C. C. McIvor, and W. E. Odum. 1988. Intertidal rivulets and creekbanks: corridors between tidal creeks and marshes. Marine Ecology Progress Series. 47: 303-307.

Ruiz, G. M., A. H. Hines, and M. H. Posey. 1993. Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. Marine Ecology Progress Series. 99: 1-16.

Sipple, W. 1971. The past and present flora and vegetation of the Hackensack Meadows, NJ, and suggestions for management. Master of Regional Planning thesis. University of Pennsylvania.

Smith, K. J., and K. W. Able. 1994. Salt-marsh tide pools as winter refuges for the mummichog, *Fundulus heteroclitus*, in New Jersey. Estuaries. 17(1B): 226-234.

Smith, K. J., G. L. Taghon, and K. W. Able. 2000. Trophic linkages in marshes: Ontogenetic changes in diet for young-of-the-year mummichog, *Fundulus heteroclitus*. *In*: M. P. Weinstein and D. A. Kreeger (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers.

Sogard, S. M. and K. W. Able. 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. Estuarine, Coastal and Shelf Science. 33: 501-519.

Talbot, C W. and K. W. Able. December 1984. Composition and distribution of larval fishes in New Jersey high marshes. Estuaries. 7(4A): 434-443.

Taylor, M. H., L. Di Michele and G. J. Leach. 1977. Egg stranding in the life cycle of the mummichog, *Fundulus heteroclitus*. Copeia. 2: 397-399.

Taylor, M. H. and L. H. DiMichele. 1983. Spawning site utilization in a Delaware population of *Fundulus heteroclitus* (Pisces: Cyprinodontidae) Copeia: 719-725.

Taylor, M. H., G. J. Leach, L. H. DiMichele, W. M. Levian, and W. F. Jacob. 1979. Lunar spawning in the mummichog, *Fundulus heteroclitus* (Pisces: Cyprinodonntidae). Copeia: 291-297.

Templer, P., S. Findlay, and C. Wigand 1998. Sediment chemistry associated with native and non-native emergent macrophytes of a Hudson River marsh ecosystem. Wetlands. 18:70-78.

Valiela, I. J. E. Wright, J. M. Teal, and S. B. Volkmann. 1977. Growth, production and energy transformations in the salt marsh killifish *Fundulus heteroclitus*. Marine Biology. 40: 135-144.

Wainright, S. C., M. P. Weinstein, K. W. Able, and C. A. Currin. 2000. Relative importance of benthic microalgae, phytoplankton and the detritus of smooth cordgrass (*Spartina*) and the common reed (*Phragmites*) to brackish marsh food webs. Marine Ecology Progress Series.

Wang, J. C. S., and R. J. Kernehan. 1979. Fishes of the Delaware Estuaries - A guide to the early life histories. EA Communications, Ecological Analysts, Inc., Towson, Maryland. Pp. 125-138.

Warren, R. S. and P. E. Fell. 1996. *Phragmites australis* on the lower Connecticut River: Impacts on emergent wetlands and estuarine waters. Final report to the CT DEP Office of Long Island Sound Programs, Hartford, CT.

Weinstein, M. P., S. Y. Litvin, K. L. Bosley, C. M. Fuller, and S. C. Wainright. 2000. The role of tidal marsh as an energy source for marine transient and resident finfishes: A stable isotope approach. Transactions of the American Fisheries Society.

Weinstein, M. P., and J. H. Balletto. 1999. Does the common reed, *Phragmites australis*, affect essential fish habitat? Estuaries. 22(3B):793-802.

Weisberg, S. B. and V. A. Lotrich. 1982. The importance of an infrequently flooded intertidal marsh surface as an energy source for the mummichog *Fundulus heteroclitus*. An experimental approach. Marine Biology. 66:307-310.

Weiss, H. M. 1995. Marine Animals of Southern New England and New York. State Geological and Natural History Survey of Connecticut Department of Environmental Protection. Bulletin 115. ISBN 0-942081-06-4.

Windham, L. and R. Lathrop. 1999. Effects of *Phragmites australis* (common reed) invasion on aboveground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. Estuaries 22(4):927-935.

Yozzo, D. J , A. Manning, and D. E. Smith. 1994. Midsummer abundance of resident sub-adult marsh nekton at the Virginia Coast Reserve. Virginia Journal of Science. 45:21-30.

Ye, Z. H., A. J. M. Baker, and M. H. Wong. 1997. Zinc, lead and cadmium tolerance, uptake and accumulation by the common reed, *Phragmites australis* (Cav.) Trin ex Steudel. Annals of Botany. 80: 363-370.

Appendix A. Invertebrate Taxa List from Pit Trap Collections in 2000

Phylum Nematoda
Phylum: Arthropoda
- Class: Crustacea
  - Subclass: Copepoda
    - Group. Calanoid
    - Group: Cyclopoid
    - Group: Harpacticoid
  - Subclass: Ostracoda
  - Subclass Cirripedia
  - Order: Amphipoda
    - Family: Gammaridae
    - Family. Talitridae
    - Family. Corophidae
  - Order: Isopoda
    - Family: Anthuridae
      - Genus: *Cyathura polita*
    - Family: Oniscidae
      - Genus: *Philoscia vittata*
- Class: Arachnida
  - Order: Acarina
  - Order: Pseudoscorpiones
- Class: Insecta
  - Order: Coleoptera
    - Family: Hydrophilidae
  - Order Diptera
    - Family Ephydridae
    - Family Tipulidae
    - Family: Ceratopogonidae
    - Family: Chironimidae
    - Family: Dolichipodidae
    - Family: Stratiomyidae
    - Family: Chloropidae
  - Order: Hemiptera
    - Family: Corixidae
  - Order: Odonata
    - Family: Libellulidae
      - Genus: *Erythrodiplax berenice*
  - Order: Collembola

Phylum: Mollusca
- Class. Bivalvia
  - Genus: *Macoma baltica*
- Class. Gastropoda
  - Family: Hydrobidiidae
  - Family: Succineidae
    - Genus: *Succinea wilsonii*
  - Family: Melampodidae

Genus: *Melampus bidentata*

Phylum Annelida
Class: Oligochaetae
Class. Polychaetae
Family: Sabellidae
Genus: *Manayunkia aestuarina*
Family: Ampharetidae
Family. Spionidae
Phylum: Cnidaria
Class: Anthozoa

Phylum Sarcomastigophora
Order: Foraminiferida
Phylum: Platyhelminthes
Class: Turbellaria

Appendix B. Taxa abundance in *Phragmites* and *S. alterniflora*-dominated marshes as collected by pit traps (n = 54 samples per marsh type).

The seasonal totals of all individuals are reported by taxa, according to the marsh type they were collected in.

Scientific name	Common name	Total individuals collected in *Phragmites*	Total individuals collected in *S alterniflora*
Acarina	mite	83	67
Ampharetidae	Spaghetti-mouth worm	5	1
Anthozoa	anemones	89	11
Capitellidae	threadworms	3	0
Ceratopogonidae	Biting midge	15	23
Chironimidae	midge	266	87
Chloropidae	Grass fly	8	33
Collembola	Springtail	60	207
Copepoda	Calanoid copepod	58	46
" "	Cyclopoid copepod	501	1,275
" "	Harpacticoid copepod	243	2,756
" "	Fish louse	1	22
Corixidae	Water boatman	0	11
Corophium spp.	Slender tube makers	3	3
Cyathura polita	Slender isopod	2	1
Dolichipodidae	Long-legged fly	3	6
Ephydridae	Shore fly	0	11
Erythrodiplax berenice	Salt marsh dragonlet	0	9
Fundulus heteroclitus	mummichog	29	1,440
Foraminifera	Foram	14	39
Gammaridae	Gammarid	771	130
Hydrobia	Swamp snail	2,600	688
Hydrophilidae	Water scavenger beetle	13	4
Macoma baltica	Baltic macoma	5	0
Manayunkia aestuarina		82	196
Melampus bidentata	Eastern melampus	1	0
Nematoda	Nematode	219	403
Oligochaetae	Oligochaete	850	1,899
Ostracoda	Ostracod	982	5,018
Palaemonetes spp.	Grass shrimp	0	2
Philoscia vittata	Sow bug	6	0
Pseudoscorpiones	Pseudoscorpion	7	0

Rhithropanopeus harrisii	White-finger mud crab	1	0
Spionidae	Mud worm	0	1
Stratiomyidae	Soldier fly	0	7
Succinea wilsonii	Amber snail	29	18
Talitridae	Talitrid	74	2
Tipulidae	Crane fly	9	1
Turbellaria	Flatworm	125	104
Unidentified insects	----------	24	29
Unidentified arachnids	----------	30	3