Effects of salinity and nutrient loading on species presence, growth, and food web position of fish in Oyster Pond and Salt Pond

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ABSTRACT

Changing land use increases nutrient loading into coastal environments. This nutrient loading can have harmful effects on fish populations (Justic et al., 2003). Salinity can also affect fish populations. Higher salinities may impede the spawning behaviors of anadromous fish (Limburg, 1998). We compared fish populations within Oyster Pond and the saltier, higher nutrient loaded, Salt Pond. We found some species exclusive to one pond while others were common in both. In *Alosa pseudoharengus* the growth rate of first year fish was similar between the two ponds. We found higher first year growth rates of *Fundulus heteroclitus* and *Menidia menidia* in the more saline pond. Our results suggest that salinity does not have a negative effect on growth of fish. Stable isotope analysis showed us that the fish of both ponds employed diverse feeding strategies, combining various degrees of herbivory and carnivory. Comparison of $\delta^{15}N$ values of the species that occurred in both ponds suggested that in Salt Pond, more nitrogen from waste water sources may be entering the food web. Finally, the $\delta^{13}C$ of the fish showed us the food webs of the ponds were based on two different sources of fixed carbon.

INTRODUCTION

Anthropogenic changes, such as changing land use, increase the amount of nutrient loading into coastal ecosystems. Estuary degradation on Cape Cod is well documented (McClelland et al., 1997; McClelland and Valiela, 1998a; McClelland and Valiela, 1998b). High nutrient loading can lead to algal blooms which in turn depletes oxygen levels. Depletion of oxygen levels leads to unfavorable living conditions for aerobic species. Oyster Pond in Falmouth, Massachusetts, is one estuary that has experienced a loss of quality because of human impacts. In the 1980s an increase of salt water entering Oyster Pond caused anoxia, loss of species, and water stratification (Howes and Hart, 1997). Currently a weir maintains an average salinity of 2-3 ppt in Oyster Pond (Bishop and Perret, personal communication). We chose to compare Oyster Pond to Salt Pond (Fig. 1) because Salt Pond receives higher nutrient loads than Oyster Pond (Bishop and Perret, personal communication).

Weisberg (1986) concluded certain fish species show preferences for specific ranges of salinity. The current management of Oyster Pond includes maintaining low salinities because of the belief that the growth of *A. pseudoharengus* juveniles is impeded by higher salinities, an idea that is based on untested observations and is not supported by the current literature (Rutecki, 2003). We compared Oyster Pond (average salinity 2-3 ppt) to Salt Pond (average salinity 25 ppt) because the salinities of the ponds differed, yet alewives were present in both ponds.

The breadth of resource partitioning determines how many species can be present in a community (Valiela, 1995). We studied the species presence in both ponds to determine which pond had more species.

Size of fish is a measure of how well their environment can support them. We compared the average lengths and growth rates of fish species in Oyster Pond and Salt Pond to see which of the ponds encouraged larger growth.

Stable isotope analysis can be used to characterize marine food webs. We compared the range of $\delta^{15}N$ values of the fish collected at both ponds to examine their feeding strategies. The $\delta^{15}N$ values also allowed us to estimate which of the two ponds was more influenced by the nitrogen inputs from wastewater. Additionally we used $\delta^{13}C$ to determine what type of primary producer provided the fixed carbon upon which the food web of each pond was based. The $\delta^{13}C$ values of the fish show us what type of producer fixes the carbon that enters the food web of each pond because consumers have $\delta^{13}C$ signatures very similar to the signatures of their food sources (Gannes et al. 1997).

To determine the number of species present at Salt Pond and Oyster Pond, we seined both ponds during the night and day. To calculate growth rates of fish we used cohort mean lengths. To examine the food web position of the fish we used stable isotopic analysis.

METHODS

We conducted our study in Oyster Pond and Salt Pond, two estuaries located in Falmouth, Massachusetts. Both of these bodies of water are connected to Vineyard Sound, the adjacent source of salt water. In both these ponds, we collected samples during October 2004.

Seining

Fish samples were collected from both Oyster Pond and Salt Pond. We seined during the day and night to catch to catch both diurnal and nocturnal species. We recorded the species, standard length, and collection site of each fish caught.

Growth rate determination

By using MIX 3.1.3 software, we determined the number of cohorts present in each group of fish and the mean length of each cohort. We verified cohort ages by counting the number of annuli bands on fish scales. We removed six to ten scales from the head and body of five fish from each of the large, medium, and small size classes of each species from each location. To clean the scales we rinsed them in a 3% H_2O_2 solution, dried them, and placed them on glass slides. We viewed the scales under a compound microscope at 40x magnification. We determined the age of each fish by counting the number of annuli rings on a scale (Diana, 1995).

We calculated growth rates from the mean lengths of fish in each age class with values obtained in the cohort analyses. Growth rate in the first year was equal to the mean of the first cohort length because we assumed fish size at birth to be negligible. Growth rate of the second year cohorts was calculated by subtracting the mean length of the cohort from its mean length in the first year. If a three year age class was present, we subtracted mean length of the cohort at the second year from mean length of the cohort at the third year to determine the growth rate during the third year.

Isotopic analysis

We used stable isotope analysis to examine the food web position of the fish in this study. δ^{15} N analysis has been used to examine the trophic position of fish in aquatic food webs and to trace flow of wastewater derived nitrogen through estuarine food webs. (Griffin and Valiela, 2001; McClelland and Valiela, 1997; Minagawa and Wada, 1984). δ^{13}C isotopic analysis has been shown to be an indicator of which carbon source forms the base of the food web (McClelland and Valiela, 1998b).

We selected five small, medium and large individuals from each species for δ^{15}N and δ^{13}C isotopic analysis. We removed the head, fins, and viscera from each fish. We dried fish in a drying oven at 60°C for one to three days. Once the drying process was complete, we removed approximately 0.1g total of muscle, tissue, and bone from various parts of each fish. We ground all the removed mass from the group of fish to a fine powder with a mortar and pestle. We weighed out 1 mg samples of material from each group of fish. The Stable Isotope Facility of the University of California, Davis, conducted δ^{15} N analyses and δ^{13} C analyses.

RESULTS AND DISCUSSION

We found more species of fish species at Salt Pond than at Oyster Pond (Table 1). Of the 15 species of fish observed in this survey, only three were observed in both ponds. *Fundulus heteroclitus*, *Alosa pseudoharengus,* and *Menidia menidia* were abundant in both ponds.

A. pseudoharengus eggs and larvae must stay in the fresher parts of the Salt Pond estuary until juvenile development. Rutecki (2003) reviewed the current literature regarding *A. pseudoharengus* salinity tolerances and found that *A. pseudoharengus* eggs only exist in salinities from 0-3 ppt, larvae in 0-10 ppt, and juveniles in 0-32 ppt. In our study we found juvenile *A. pseudoharengus* of the same size in both ponds suggesting that higher salinities do not slow the growth rate of *A. pseudoharengus* (Table 2). The higher nutrient content and salinity of Salt Pond do not affect growth rate during the first year of development. *A. pseudoharengus* juveniles caught in Salt Pond were born in that estuary system because their δ^{13}C signature matched the signature of the main food source within that food web.

The average lengths of *F. heteroclitus* and *M. menidia* in Salt Pond were significantly higher for all age classes than those of their counterparts in Oyster Pond (Table 3). The annual growth of *F. heteroclitus* and *M. menidia* was also greater during their first year of growth at Salt Pond than at Oyster Pond, but growth rates for both ponds were similar in their second year of growth (Table 4). This indicates that after the first year of growth, salinity and nutrient loading did not affect growth rate of these two species.

Fish collected from both ponds employ a variety of feeding strategies. The $\delta^{15}N$ values of the fish in Oyster Pond ranged from 9.37 ‰ to 13.18 ‰. The Salt Pond values ranged from 8.41‰ to 13.00 ‰ (Fig. 4). The δ^{15} N values of *Cyprinodon variegatus*, 8.41‰- 8.48‰, showed these fish were the most herbivorous. The δ^{15} N values of *Morone americana*, 11.94‰- 13.18‰, showed these fish were the most carnivorous (Fig. 3).

The δ^{15} N values of *A. pseudoharengus* and *F. heteroclitus,* but not *M. menidia,* were higher in Salt Pond than those of the same species in Oyster Pond (Fig. 4). Because nitrate that is derived from wastewater is enriched with ^{15}N relative to ^{14}N, the higher $\delta^{15}N$ values from the salt pond group of two of the three species common in both ponds suggest that there may be a greater input of nitrogen from wastewater sources in Salt Pond than in Oyster Pond.

The $\delta^{13}C$ values for Oyster Pond ranged from -18.91‰ to -26.34 ‰. The $\delta^{13}C$ values for Salt Pond ranged from -12.06 ‰ to -16.09 ‰ with no area of overlap. These values show that Oyster Pond is dominated by fish that feed on prey that derive their carbon from terrestrial plants and some aquatic plants. Similarly, Salt Pond is dominated by fish that feed on prey that derive their carbon from C_4 plants, such as the marsh grass, *Spartina alterniflora,* and some aquatic plants (Fig. 3). These findings show that the two ponds have different food webs.

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FIGURE LEGENDS

Figure 1. Map showing the relative proximity of Oyster Pond and Salt Pond. These ponds are located in Falmouth, Massachusetts.

Figure 2. Growth rates for two age classes of *F. heteroclitus* and *M. menidia* from Salt Pond and Oyster Pond. Y error bars indicate standard error.

Figure 3. $\delta^{13}C$ of Salt Pond and Oyster Pond fish plotted against their $\delta^{15}N$ values. Shaded areas indicate the $\delta^{13}C$ values of different primary producers. T = terrestrial plants, M = macroalgae, G = marsh grass (*Spartina alterniflora)*, E = eelgrass. The symbols for the fish species are: A = alewife (*A. pseudoharengus*), B = banded killifish (*F. diaphanus*), K = striped killifish (*F. majalis*), M = common mummichog (*F. heteroclitus*), S = silverside (*M. menidia*), Sm = sheepshead minnows (*C. variegatus*), and W = white perch (*M. americana*). Values for $\delta^{13}C$ of macroalgae and eel grass are from McClelland and Valiela (1998). Values for $\delta^{13}C$ of *Spartina* and terrestrial plants are from Fry and Sherr (1984).

Figure 4. $\delta^{15}N$ values for the three abundant species common to both ponds. The $\delta^{15}N$ values of the Salt Pond fish are plotted against the values of their conspecifics at Oyster Pond.

TABLES

Table 1. Abundant species collected and site where they were collected. (+) indicates species was present. (-) indicates species was not present.

Species	Oyster Pond	Salt Pond
Morone americana	+	-
Anguilla rostrata	+	-
Fundulus diaphanus	+	-
Fundulus heteroclitus	+	+
Alosa pseudoharengus	+	+
Menidia menidia	+	+
Fundulus majalis	-	+
Cyprinodon variegatus	-	+
Total number of species	7	11

Table 2. Growth rate (mm y^{-1}) (mean ± s.e.) of A. pseudoharengus in their first year of growth. Asterisks indicate that there is no significant difference between these growth rates (student's t-test, p= 0.91, df = 9).

Growth rate (mm y-1) (mean ± s.e.)	Oyster Pond	Salt Pond
early cohort	72 ± 1	--
late cohort	63 ± 0	--
total	64 ± 0 *	63 ± 5 *
Sample size	714	10

Table 3. Lengths(mm) (mean ± s.e.) of the three abundant species of fish common to Oyster Pond and Salt Pond. Asterisks indicate significance (student's t-test).

Species	Oyster Pond	Salt Pond	p-value	df
A. pseudoharengus	64 ± 0	63 ± 5	0.911	9
F. heteroclitus	26 ± 1	68 ± 2	<0.001*	48
M. menidia	48 ± 0	62 ± 1	<0.001*	382

Table 4. Number of age classes, cohorts per age class, and length (mean ± s.e.) for the three species present in abundance in both ponds. Values were obtained from MIX 3.1.3. as described in methods section.

Species	Location	Annual age classes	Cohorts per annual age class	Length (mm) (mean ± s.e)	Annual growth (mm y^{-1}) (mean ± s.e.)
A. pseudoharengus	Oyster	1	2	63 ± 0	63 ± 0
				72 ± 1	72 ± 1
F. heteroclitus	Oyster	2	1	28 ± 0	28 ± 0
				63 ± 3	35 ± 5
F. heteroclitus	Salt	2	1	59 ± 5	59 ± 5
				84 ± 4	25 ± 6
M. menidia	Oyster	2	1	43 ± 1	43 ± 1
				48 ± 0	5 ± 1
M. menidia	Salt	2	1	57 ± 0	57 ± 0
				67 ± 2	10 ± 2

FIGURES

Figure 1.

Figure 2.

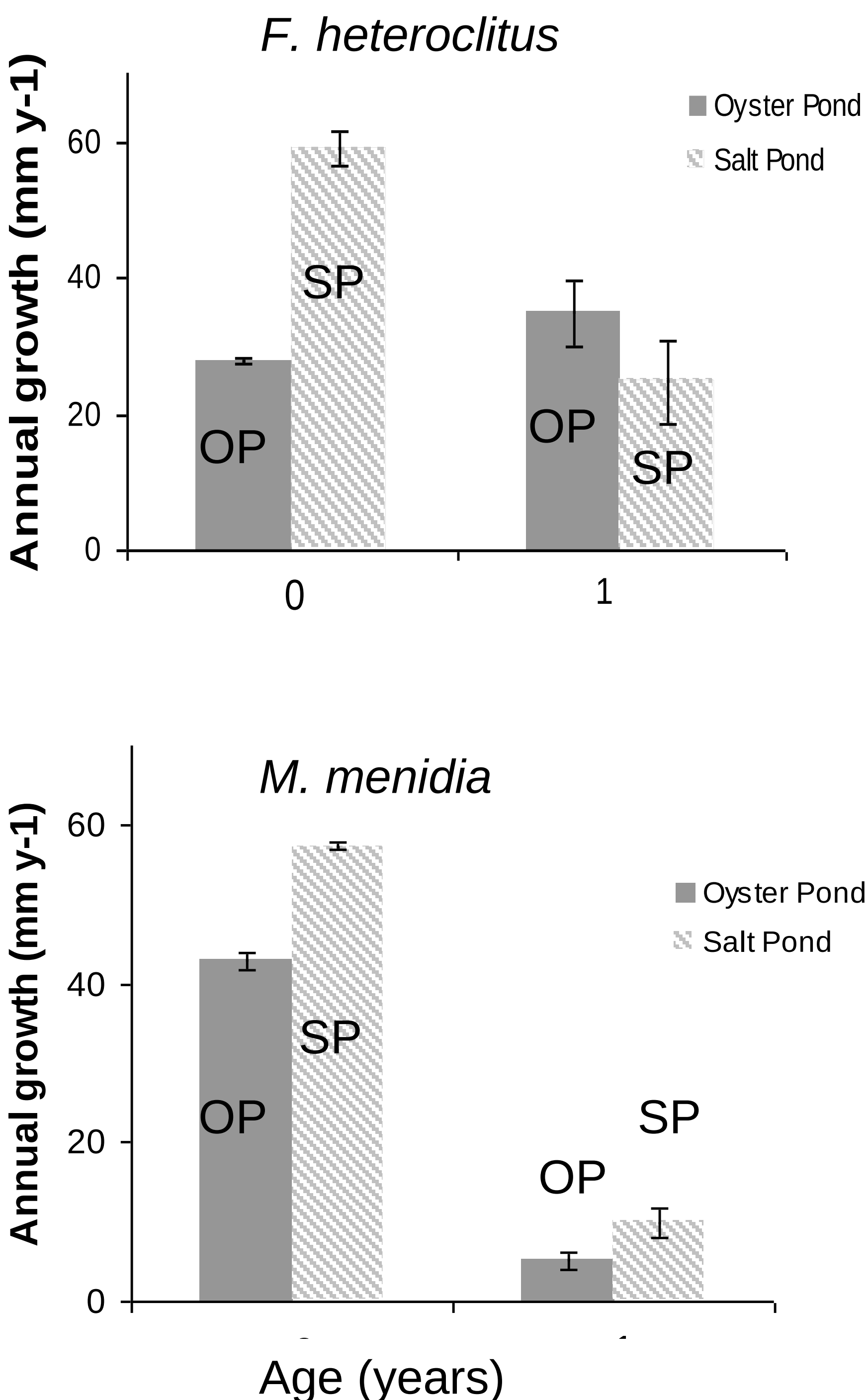
F. heteroclitus
Annual growth (mm y-1)
Oyster Pond
Salt Pond
0
20
40
60
OP
SP
OP
SP
0
1
M. menidia
Annual growth (mm y-1)
Oyster Pond
Salt Pond
0
20
40
60
OP
SP
OP
SP
Age (years)

Figure 3.

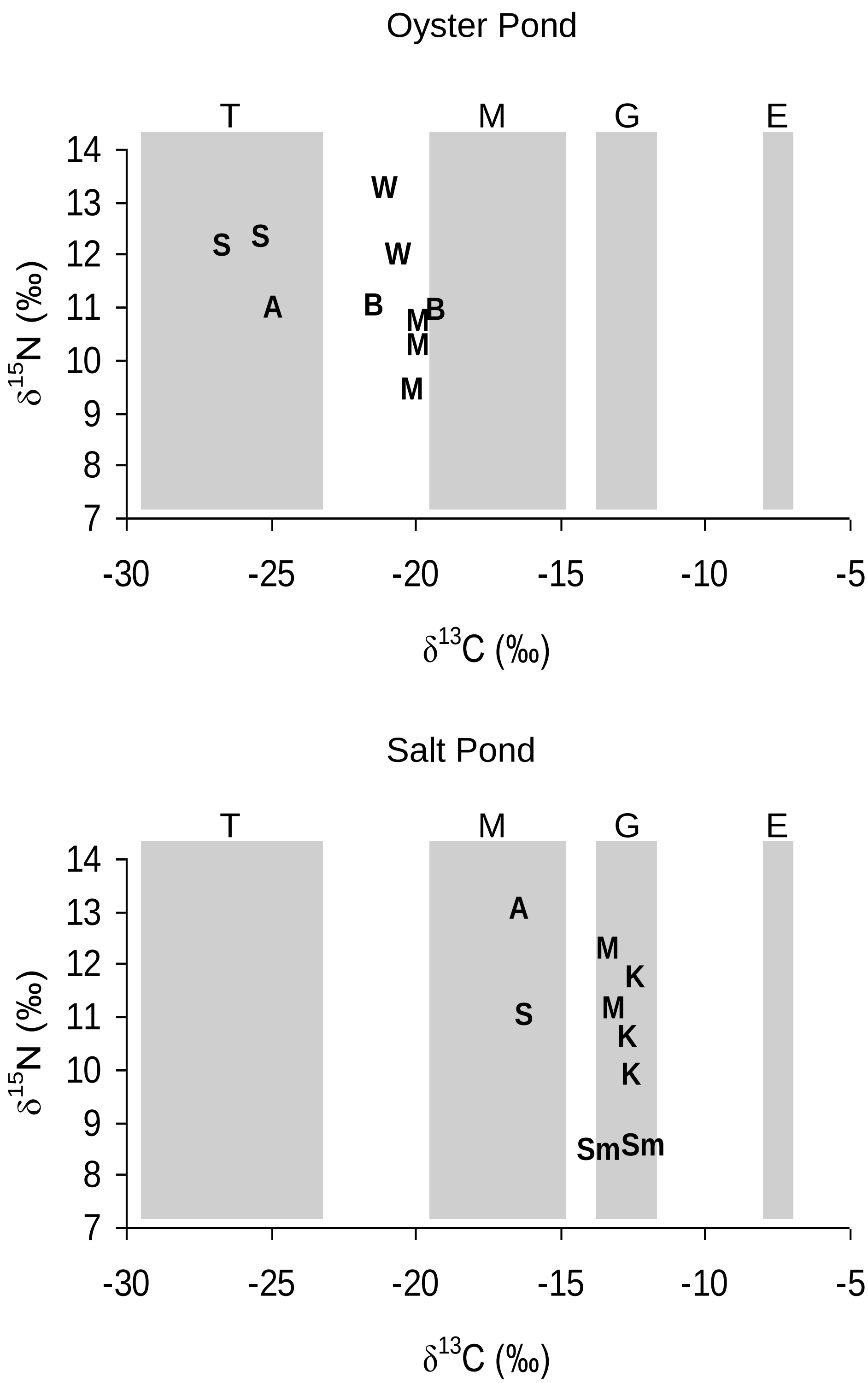
Oyster Pond
T
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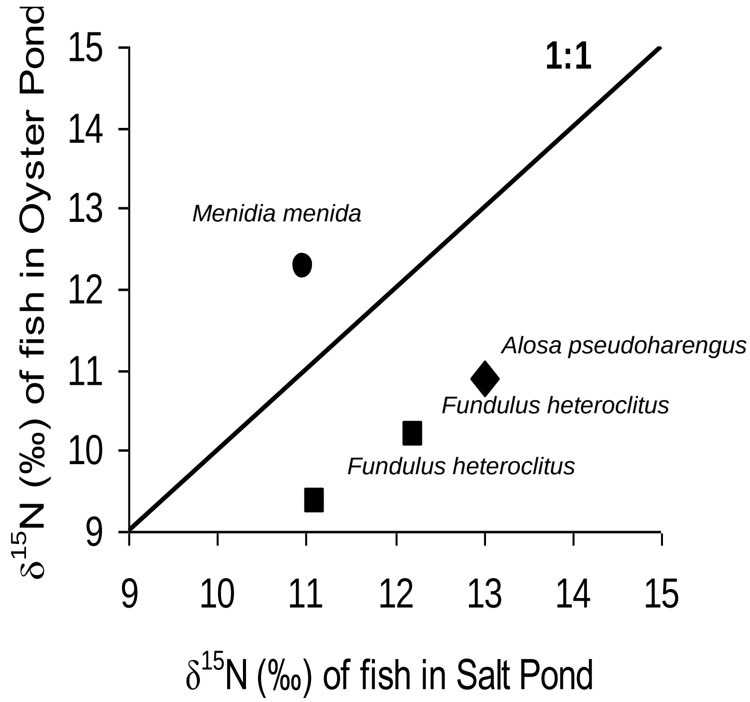
Figure 4.



1:1
Menidia menida
Alosa pseudoharengus
Fundulus heteroclitus
Fundulus heteroclitus
9
10
11
12
13
14
15
δ15N (‰) of fish in Oyster Pond
δ15N (‰) of fish in Salt Pond