Chapter 5

Occurrence and growth of the fish fauna of the Oyster Pond estuary

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Abstract

Fish were collected to evaluate distribution, growth rates, and tissue stable isotope signatures in the Oyster Pond estuarine system. The fish community was dominated by killifishes (*F. heteroclitus* and *F. majalis*). *F. majalis* was far more prevalent in the south end of Oyster Pond, and *F. heteroclitus* in the lagoon. This difference may be related to differences in bottom substrate at our sampling locations. The *F. heteroclitus* population included three age classes in the north end of Oyster Pond and four age classes in the lagoon. We found three age classes of *F. majalis* in each area of the estuary. Growth rates, measured by two methods, were similar throughout different areas of the system for both species. First year growth rates were higher than the growth rates found in other estuaries. Herbivorous fish have the lowest $\delta^{15}N$ (7.52‰). The carnivorous fishes have $\delta^{15}N$ values from 10‰ to 14‰. These differences represent the trophic position of the species. In *F. heteroclitus* and *F. majalis*, the $\delta^{15}N$ signature increased with body length, indicating that a jump in trophic level is associated with the growth of these fish. The $\delta^{15}N$ signatures of fishes in Oyster Pond were similar to signatures in other estuaries known to be impacted by wastewater nitrogen loads. While occurrence and growth rate of fish do not appear to be affected by nitrogen load at this time, elevated $\delta^{15}N$ signatures in fish tissue serve as an early indicator that wastewater nitrogen inputs are accelerating eutrophication in Oyster Pond.

Introduction

The Oyster Pond estuary system in Falmouth, MA has been subject to major ecological shifts in recent years, including substantial changes in the resident fish community (Emery 1997). This system is characterized not only by the typical salinity gradient (0-32‰), but also by considerable variation in nitrogen (N) loading derived from residential wastewater. The distribution and growth rates of fish fauna may be influenced by salinity and physical habitat variations, but this study offers an opportunity to investigate how differences in watershed derived nutrients may also alter these characteristics of the fish community.

Anthropogenic nitrogen inputs from coastal watersheds is a major mechanism for altering coastal habitats worldwide (GESAMP 1990, NAS 1994). Increased nitrogen supply to coastal waters generally results in increased primary productivity, which is indirectly linked to increased fish yield (Nixon 1988). These responses can be caused by a variety of factors, including changes in food types, food abundance, or altered physical or chemical habitat. When food abundance or quality increases, growth rates of fish may increase (Valiela, 1995), but, a study in nearby Waquoit Bay suggests that growth rates of some fish are not affected by this indirect linkage to nutrient load (Tober et al 2000).

Stable isotope analysis has been used as an indicator of wastewater nitrogen loads entering estuaries (McClelland et al. 1997). Stable isotope analysis can also be used to identify the trophic position of a group of organisms and to evaluate the effects of increased size that accompany growth in fishes (Griffin et al. 2001). The $\delta^{15}N$ isotope technique is based on metabolic processes that discriminate against the heavier nitrogen isotope, ^{15}N, and create fractionation that reveals changes in isotopic ratio among trophic levels (Griffin and Valiela 2001). Griffin and Valiela (2001) showed an increase in $\delta^{15}N$ signatures of the fish species *Fundulus heteroclitus* and *Menidia menidia* in Waquoit Bay estuaries with increased N-loads as well as an increase in signature with increased fish length. This tool provides a means to identify increasing N-loads to the food web before increased N availability alters the population and community structure of an estuary (McClelland and Valiela 1998, Valiela 1995).

The purpose of this study is to evaluate the impacts of anthropogenic nitrogen inputs on the distribution and growth of the fish community in the littoral zone of Oyster Pond. We used scale aging and cohort analysis to establish growth rates and applied $\delta^{15}N$ methods to evaluate the degree of linkage between fish and watersheds delivering nitrogen. We hypothesized that the distribution of fishes in Oyster Pond is driven by salinity and physical habitat differences rather than by N loading and that growth rates of fishes are not affected by differences in nitrogen inputs in Oyster Pond. We also hypothesized that the stable isotope ratio of fishes would become heavier with increasing trophic level, size, and can be used as an indicator of wastewater N load.

Methods

Study site

Fish were collected in Oyster Pond (Falmouth, Massachusetts). This estuary is oriented north-northwest and is composed of a pond, with the southern end connected to a shallow marsh lagoon through a culvert (Fig. 1). The lagoon is connected to Vineyard Sound by the Trunk River (Emery 1997).

Distribution of Fishes

We collected fish at 18 different sites within the estuary between October 4 and October 14, 2001. To collect fish we towed a five meter wide seine parallel to the shore for approximately 20 meters or set minnow traps (0.4 m x 0.2 m of diameter) in groups of four in the littoral zone. At each location, fish were identified, counted, and measured total length to the nearest 1 mm. To evaluate differences between these two methods of collection, we applied the G-test (Sokal and Rohlf 1981) on the size frequency distributions for *F. heteroclitus* and *F. majalis* collected by the two methods at the same sampling site. The goodness-of-fit test was also used to evaluate differences between size frequency distribution of these two species of fish collected from different regions of the estuary.

Growth Rates of F. heteroclitus and Fundulus majalis

We used two methods to measure growth rates of *F. majalis* and *F. heteroclitus*, the most commonly occurring fish in the littoral zone of Oyster Pond. First, we determined the age of 116 fish (62 *F. majalis* and 54 *F. heteroclitus*) of various length from different parts of the estuary (lagoon, north and south portions of Oyster Pond) by scales collected from behind the operculum. In the laboratory, the scales were washed with a solution of hydrogen peroxide (3% H_2O_2), dried, and pressed into acetate slides. The scale aging method is based on the patterns of circuli (bands of material deposited on scales) laid down over the course of a year (Diana 1995). We determined the age of each fish by counting annuli rings from the scale impressions on a screen projector (Fig. 2). We used a regression of the relationship between age and length based on the least square method (Neter et al. 1985) to estimate growth rate. To test for difference in growth rate of each species between locations we used the t test (Sokal and Rohlf 1981).

Second, we examined the cohorts of the fish collected. We used MIX 3.1.3. (Ichthus Data Systems 1998) to analyze size frequency distribution histograms and determine the mean length for modeled size classes at each site. To calculate growth rate from these cohorts, average length from one size class was subtracted from the average length of the preceding size class and divided by a 6 month growing season (Tober et al. 2000). To calculate growth rate of young of the year we subtracted 6 mm, which was the average length at hatch (Kneib 1993), and divided by 3 months, the average time that year 0 fish have to grow. We plotted the growth rates calculated by both methods to check for similarity between the two methods.

Stable Isotope Analysis

A small number of fish collected at each location in the estuary were brought back to the laboratory. The head, tail, and viscera were removed from each fish. The remaining body, predominantly consisting of white muscle, was washed with distilled water and dried at 60°C. Composite tissue samples were created from multiple individuals of similar species, size class and location. The dried samples were ground with a mortar and pestle and sent to University of California, Davis, Stable Isotope Facility, for $\delta^{15}N$ analysis.

We compared the $\delta^{15}N$ signatures of species from different trophic groups to demonstrate how trophic position affects this signature. To see if Oyster Pond advance in trophic position as they grow, we compared the signatures of different sized fish of the same species. We then compared $\delta^{15}N$ values for fishes found in Oyster Pond to values from various nearby estuaries with a wide range of N load rates.

Results and Discussion

Distribution of Fishes in the Littoral Zone

The fish community in the littoral zone of Oyster Pond is dominated by killifishes (Cyprinodotidae). The two most common species are *Fundulus majalis* (the striped killifish) and *Fundulus heteroclitus* (the common mummichog) (Table 1). A third cyprinodontid, *Cyprinidon variegatus* (the sheepshead minnow) is common in the lagoon, particularly in the Trunk River channel, but was not found in Oyster Pond.

American eel (*Anguilla rostrata*) and juvenile white perch (*Morone americana*) were caught throughout Oyster Pond and the lagoon. Four spine stickleback (*Apeltes quadracus*) and menhaden (*Brevoortia tyrannus*) were present in Oyster Pond but not in the lagoon. Atlantic silverside, *Menidia menidia*, was collected from sampling sites at the southern end of Oyster Pond, and in the lagoon as well as from Vineyard Sound, near the mouth of the Trunk River. Seine tows from Vineyard Sound also yielded several other species, which were not collected in Oyster Pond or the lagoon, including: striped anchovy (*Anchoa hepsetus*), cunner (*Tautogolabrus adsperus*), Northern pipefish (*Syngnathus fuscus*), sand lance (*Ammodytes americanus*) and one spotfin butterflyfish (*Chaetodon ocellatus*).

Similar numbers of both *F. heteroclitus and F. majalis* were collected in the north end of Oyster Pond, but *F. majalis* was far more prevalent in the south end of Oyster Pond. Far more *F. heteroclitus*, on the contrary, were collected in the lagoon. Both salinity and bottom substrate varied at each location (Table 1). Neither of these species is physiologically constrained by salinity differences (Weisberg 1986). The most common hypothesis to explain patterns of habitat use by intertidal fishes are: competitive refuge (Weisberg 1986), access to feeding areas (Rozas et al. 1988), higher food availability and anti-predator behavior (Kneib 1987, McIvor and Odum 1988). For example, Weisberg (1986) suggests that *F. heteroclitus* may be restricted to intertidal areas such as the lagoon to escape competition for food with *F. majalis*. However, *F. heteroclitus* has been found to vary in habitat usage with seasonal changes (Halpin 1997). Stronger swimming ability and its pointed snout allow *F. majalis* to force itself into substrate in order to feed more effectively on sandy bottoms (Werme 1981) such as those found in the south end of Oyster Pond. We believe that differences in bottom substrate at our sampling locations are largely responsible for the between site variation in the abundance ratios of these two species.

Growth Rates of Fundulus heteroclitus and F. majalis

Scale aging indicated that three age classes of *F. heteroclitus* were present in the north end of Oyster Pond and four age classes were present in the lagoon (Figure 3). Three age classes of *F. majalis* were found in the north and south end of the Oyster Pond, as well as in the lagoon (Fig. 4). T tests indicated that there were no differences between the growth rates in different locations of the pond for each species (Table 2). Therefore, data from all sites were pooled for each species and the regressions yielded average growth rates for all of Oyster Pond (Figs. 3 & 4).

The goodness-of-fit test of size frequency distributions indicated that the trap collection method and the seine collection method were significantly different ($\chi^2_{(0.05,6)}$= 146.408, p< 0.0001). We chose to combine our data from both types of collection methods and compile our data into the three following groups: North Oyster Pond, South Oyster Pond, and the lagoon. The goodness-of-fit test performed on the size frequency distributions for both species between Oyster Pond and the lagoon, as well as between the north and south ends of Oyster Pond indicated that the size frequency distributions between these locations were significantly different (Table 3). Size frequency distributions for all locations were pooled for cohort analyses of each species (Figs. 5 & 6). Three size classes were identified for *F. majalis* (see example, Fig. 7) and four size classes were identified for *F. heteroclitus*. Growth rates determined by cohort analysis were very similar to growth rates estimated by the regression from the age determination method (Figure 8). The growth rates calculated by cohort analysis for each species in each location are presented in Table 4. There is no apparent relationship between the wastewater N load at a specific location in the system and the growth rate of either species at that location.

We found first year growth rates of both *F. heteroclitus* and *F. majalis* in Oyster Pond to be higher than to first year growth rates found in other studies in East coast estuaries (Table 5). The growth rates that we measured for subsequent years for both species in Oyster Pond were similar to studies from other estuaries. Such elevated growth rates in the first year of life could indicate that a higher quality or quantity of food is available to the young fish in Oyster Pond or that the success of this years age class was above average due to natural annual variability.

Stable Isotope Analysis

In Oyster Pond, $\delta^{15}N$ values increase with higher trophic levels (Fig. 9). Primary producers have the lowest $\delta^{15}N$ values ranging from 3‰ to 8‰. *Cyprinodon variegatus*, the only herbivore collected, had a $\delta^{15}N$ value of 7.52‰. All other fishes are carnivores and have $\delta^{15}N$ values from 10‰ to 14‰. These differences in $\delta^{15}N$ values are clearly related to the trophic position of the species. As nitrogen moves up the food web, the consumer $\delta^{15}N$ generally averages 3‰ to 5‰ heavier than its food source (Peterson and Fry 1987). A study in Waquoit Bay, Massachusetts by Griffin and Valiela (2001) found that the $\delta^{15}N$ signature *of F. heteroclitus* becomes heavier with increasing fish length. This change in $\delta^{15}N$ is due to the change in diet to larger prey as the fish grows. Table 6 indicates that the $\delta^{15}N$ values of *F. majalis* and *F. heteroclitus* in Oyster Pond increase with growth.

The $\delta^{15}N$ value of both *F. heteroclitus* and *F. majalis* in Oyster Pond fall within the range that has been found in studies of fish from nearby estuaries (Fig. 10). The $\delta^{15}N$ values of *F. heteroclitus* in Oyster Pond are similar to the values from that species in sub-estuaries of Waquoit Bay that are considerably impacted by wastewater derived nitrogen. McClelland et al. (1997) showed that larger relative contributions of wastewater in nitrogen loads caused heavier $\delta^{15}N$ values in water, primary producers and consumers in an estuary. This may make it possible to identify incipient wastewater-driven eutrophication before the profound changes in nearshore communities presently used as indicators of eutrophication become evident (McClelland et al. 1997). While no changes in occurrence or growth rates of fish in the littoral zone of Oyster Pond can currently be associated with nitrogen enrichment, elevated $\delta^{15}N$ values in the tissue of fish from the pond can be considered a warning sign that wastewater driven eutrophication is occurring.

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Table 1. Distribution of fishes in the Oyster Pond system. Salinity values are averaged for all of our sampling sites in each location (Burdick et al., unpublished data). Wastewater N-load is the average wastewater N-load from each sub-watershed discharging to that location, derived from the N-loading model (Al-Qatami et al., unpublished data).

Species	**Number of Fish by Location**			
	Oyster Pond (North)	**Oyster Pond (South)**	**Lagoon**	**Vinyard Sound**
Salinity (ppt)	**2.35**	**2.54**	**5.20**	**32.50**
Wastewater N-load (kg y^{-1})	**417.1**	**207.8**	**35.1**	**-**
Bottom substrate	**Mud**	**Sand**	**Mud**	**Sand**
Fundulus majalis (striped killifish)	560	1366	311	
Fundulus heteroclitus (mummichog)	469	36	822	
Cyprinodon variegatus (sheepshead minnow)			125	
Menidia menidia (Atlantic silverside)		39	25	17
Morone americana (white perch)	2	11	58	
Brevoortia tyrannus (menhaden)	10	1		
Apeltes quadracus (4-spine stickleback)	6	4		
Anguilla rostrata (American eel)	4	4	1	1
Anchoa hepsetus (striped anchovy)				14
Tautogolabrus adspersus (cunner)				2
Syngnathus fuscus (Northern pipefish)				2
Chaetodon ocellatus (spotfin butterflyfish)				1
Ammodytes americanus (sandlance)				3

Table 2. T-tests to compare slopes of ages vs total length of *Fundulus heteroclitus* and Fundulus majalis between different site in Oyster Pond.

	Source of variation	df	$t_{(0.05, df)}$	t_{obs}
F. heteroclitus	Lagoon vs North	50	2.008	0.073
F. majalis	Lagoon vs North	44	2.015	0.036
	Lagoon vs South	30	2.042	0.066
	North vs South	28	2.048	0.034

Table 3. Goodness-of-fit test for site comparisons for *Fundulus heteroclitus* and *Fundulus majalis*

Species	Site Comparisons	df within site	Chi-squared	P
Fundulus heteroclitus	Lagoon vs Oyster Pond	8	277.174	<0.0001
	Oyster Pond (North vs South)	8	41.575	<0.0001
Fundulus majalis	Lagoon vs Oyster Pond	8	176.600	<0.0001
	Oyster Pond (North vs South)	8	169.846	<0.0001

Table 4. Growth Rates of *F. heteroclitus* and *F. majalis* collected in Oyster Pond. Averages for all locations included for both species.

Species	Location	Wastewater N Load ($kg\ y^{-1}$)	Growth rate (cm/month)			
			Year 0	Year 1	Year 2	Year 3
Fundulus heteroclitus	Oyster Pond (North)	417	1.5	0.33	0.33	-
	Oyster Pond (South)	208	1.5	0.27	0.37	-
	Lagoon	35	1.5	0.3	0.28	0.17
	All Locations, average		1.5	0.28	0.25	0.23
Fundulus majalis	Oyster Pond (North)	417	1.5	0.25	0.22	-
	Oyster Pond (South)	208	1.5	0.27	0.23	-
	Lagoon	35	1.6	0.25	0.23	-
	All Locations, average		1.5	0.25	0.22	-

Table 5. Growth Rates of F. *heteroclitus* and *F. majalis* from various estuaries.

Species	Location	Growth rate (cm/month)				Reference
		Year 0	Year 1	Year 2	Year 3	
Fundulus heteroclitus	Oyster Pond (All locations)	1.5	0.28	0.25	0.23	This study
	Waquoit Bay	0.73	0.23	0.15	0.07	Tober et al. (2000)
	Great Sippewisset Marsh	0.84	-	-	-	Werme (1981)
	Great Sippewisset Marsh	-	0.24	0.16	0.18	Valiela et al. (1977)
	Lewes, DE	-	0.35	0.19	0.17	Meredith & Lotrich (1979)
Fundulus majalis	Oyster Pond (All locations)	1.5	0.25	0.22	-	This study
	Great Sippewisset Marsh	1.0	-	-	-	Werme (1981)

Table 6. $\delta^{15}N$ signatures for *F. majalis* and *F. heteroclitus* by location and size.

Location	Size (mm)		
	20-40	40-60	>60
F. majalis			
South Pond	11.1	11.32	11.91
North Pond	11.36	-	-
Lagoon	-	9.38	9.89
F. heteroclitus			
South Pond	11.4	-	-
North Pond	11.39	-	-
Lagoon	10.26	12.93	-

Figures

Figure 1. Oyster Pond, Cape Cod, Massachussets, USA. Sampling sites in the north end of the pond (NP), south end of the pond (SP), in the lagoon (LA) and in Vineyard Sound (VS). The grey area represents the body of water.

Figure 2. Scale of *F. heteroclitus* at age 3, 104 mm. Annuli 1 and 2 are the yearly rings. Circuli mark growth throughout each year.

Figure 3. Ages vs. total length for *F. heteroclitus*. Linear regression and R^2 value shown for the north end of Oyster Pond (y=51.23 + x20.61, R^2=0.804), the lagoon (y=49.73 + x18.59, R^2=0.603), and in the Oyster Pond system (y=50.82 + x18.95, R^2=0.687).

Figure 4. Ages vs. total length for *F. majalis* Linear regression and R^2 value shown for the south (y=53.27 + x13.95, R^2=0.722) and north end of Oyster Pond (y=56.73 + x15.01, R^2=0.754), the lagoon (y=44.02 +x15.74, R^2=0.487), and in the Oyster Pond system (y=53.3 + x12.64, R^2=0.516).

Figure 5. Size frequency of *F. heteroclitus* in different sites of the Oyster Pond and in the Oyster Pond system. Number of fish sampled per site indicated on graph.

Figure 6. Size frequency of *F. majalis* in different sites of the Oyster Pond and in the Oyster Pond system. Number of fish sampled per site indicated on graph.

Figure 7. Cohort analyis of *F. majalis* in Oyster Pond by Mix 3.1.3. Arrows indicate means for each size class.

Figure 8. Comparison of growth rates estimated using linear regression from age determination and cohort analysis.

Figure 9. $\delta^{15}N$ isotopes values by trophic level in the Oyster Pond system. Dashed lines represent mean values for each trophic level.

Figure 10. $\delta^{15}N$ isotopes values of consumers versus percent wastewater in total nitrogen load in Oyster Pond and Waquoit Bay. SL=Sage Lot Pond, QR= Quashnet River , CR= Childs River, and OP= Oyster Pond (Valiela et al. 1997).

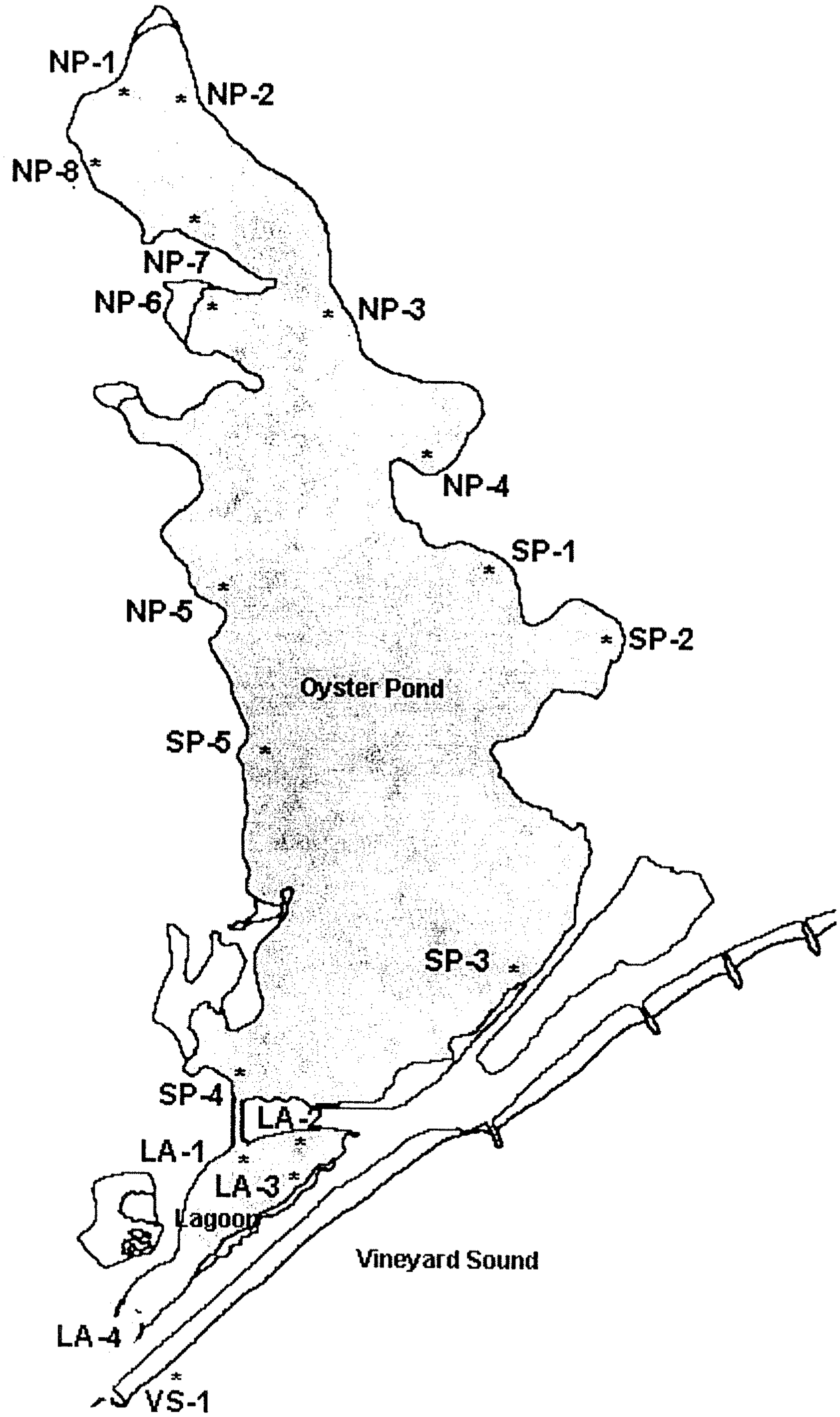

NP-1
NP-2
NP-8
NP-7
NP-6
NP-3
NP-4
SP-1
NP-5
SP-2
Oyster Pond
SP-5
SP-3
SP-4
LA-2
LA-1
LA-3
Lagoon
Vineyard Sound
LA-4
VS-1

Figure 1

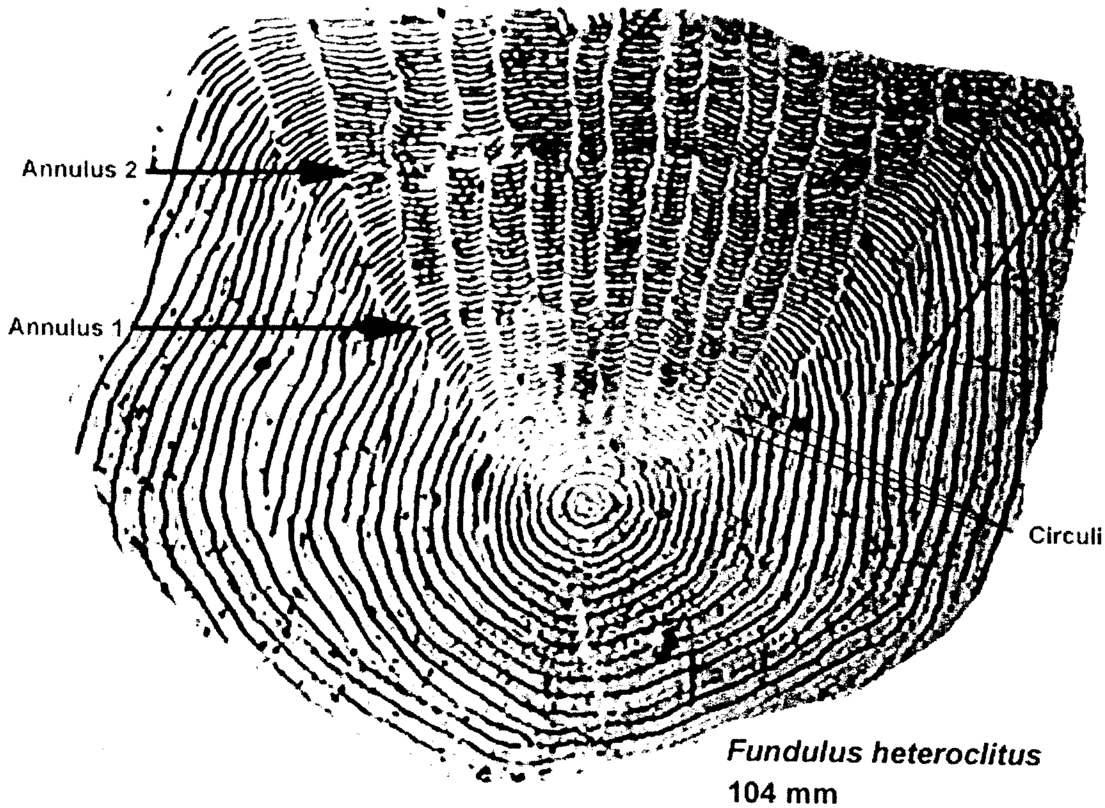


Figure 2

Figure 3

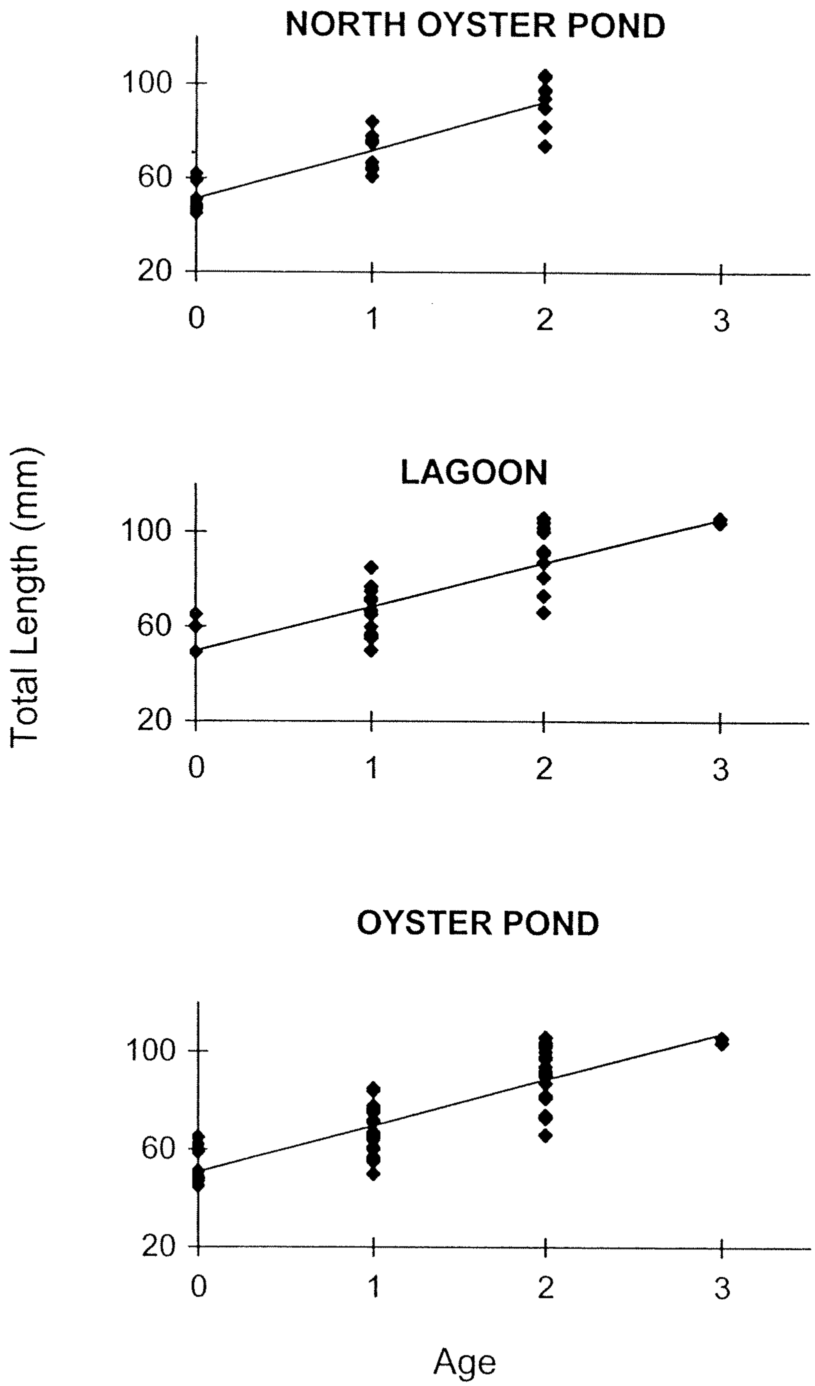
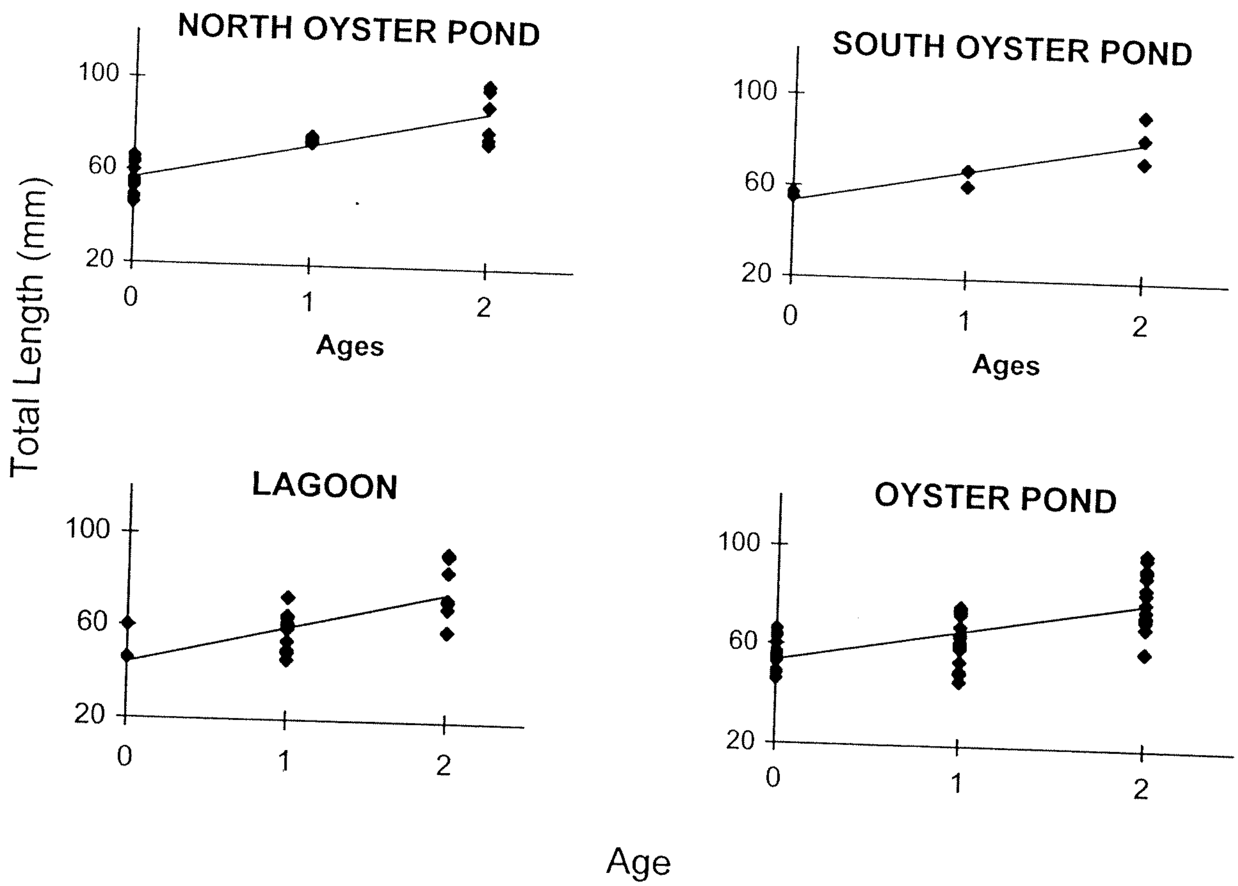
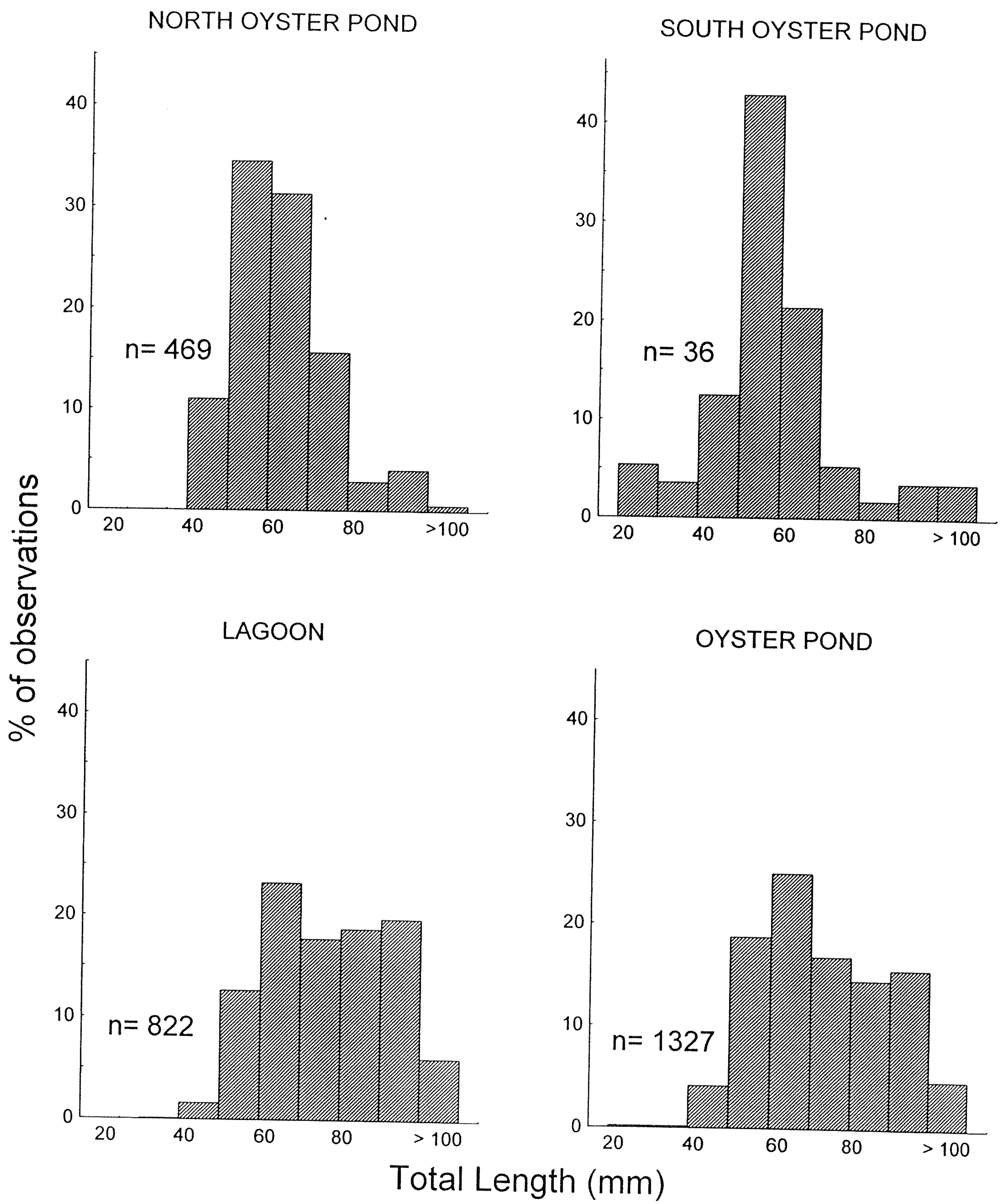

NORTH OYSTER POND
LAGOON
OYSTER POND
Total Length (mm)
Age
100
60
20
0
1
2
3

Figure 4



NORTH OYSTER POND
SOUTH OYSTER POND
LAGOON
OYSTER POND
Total Length (mm)
100
60
20
0
1
2
Ages
Age

Figure 5



NORTH OYSTER POND
SOUTH OYSTER POND
LAGOON
OYSTER POND
n= 469
n= 36
n= 822
n= 1327
% of observations
Total Length (mm)
0
10
20
30
40
20
40
60
80
>100

Figure 6

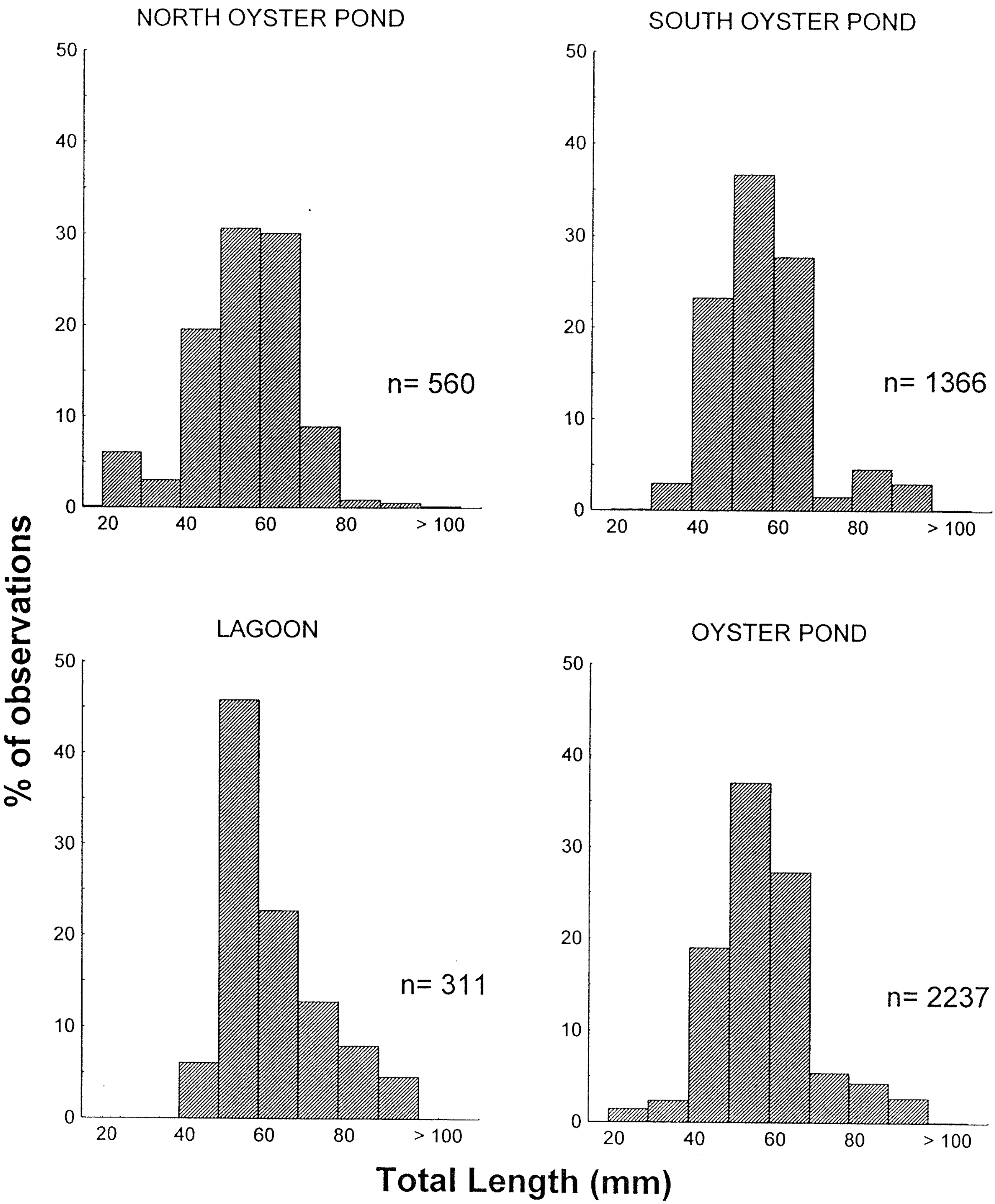
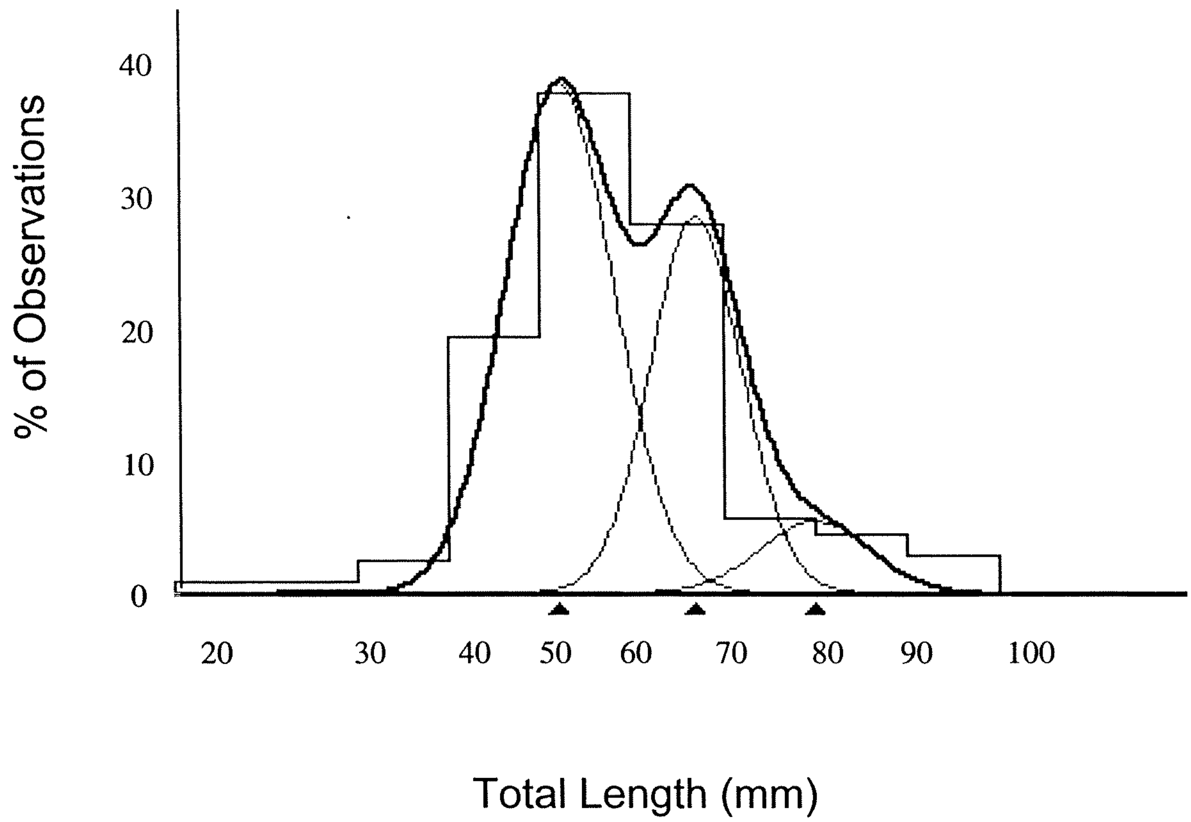

NORTH OYSTER POND
SOUTH OYSTER POND
LAGOON
OYSTER POND
n= 560
n= 1366
n= 311
n= 2237
50
40
30
20
10
0
20
40
60
80
> 100
% of observations
Total Length (mm)

Figure 7



40
30
20
10
0
% of Observations
20
30
40
50
60
70
80
90
100
Total Length (mm)

Figure 8

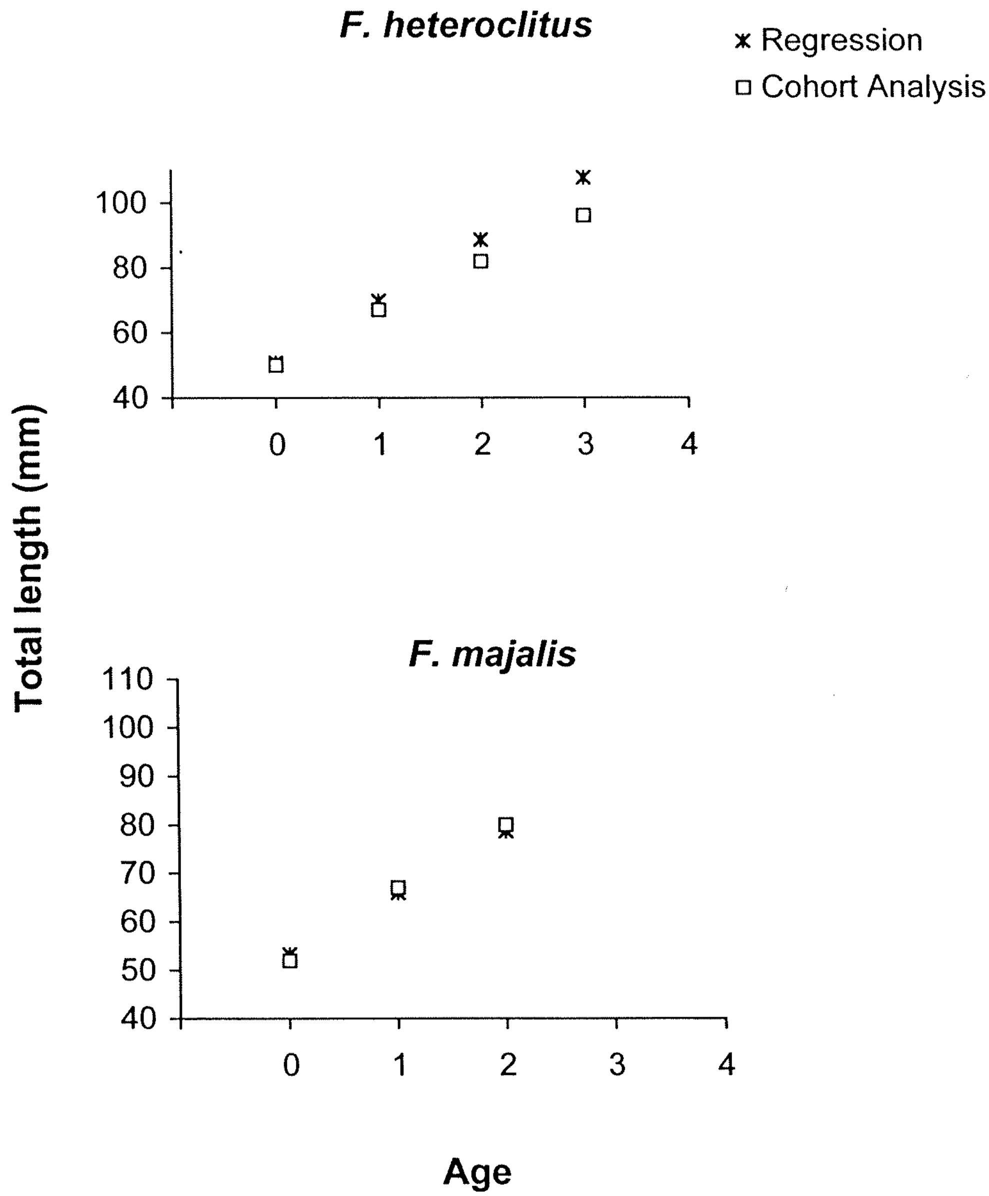
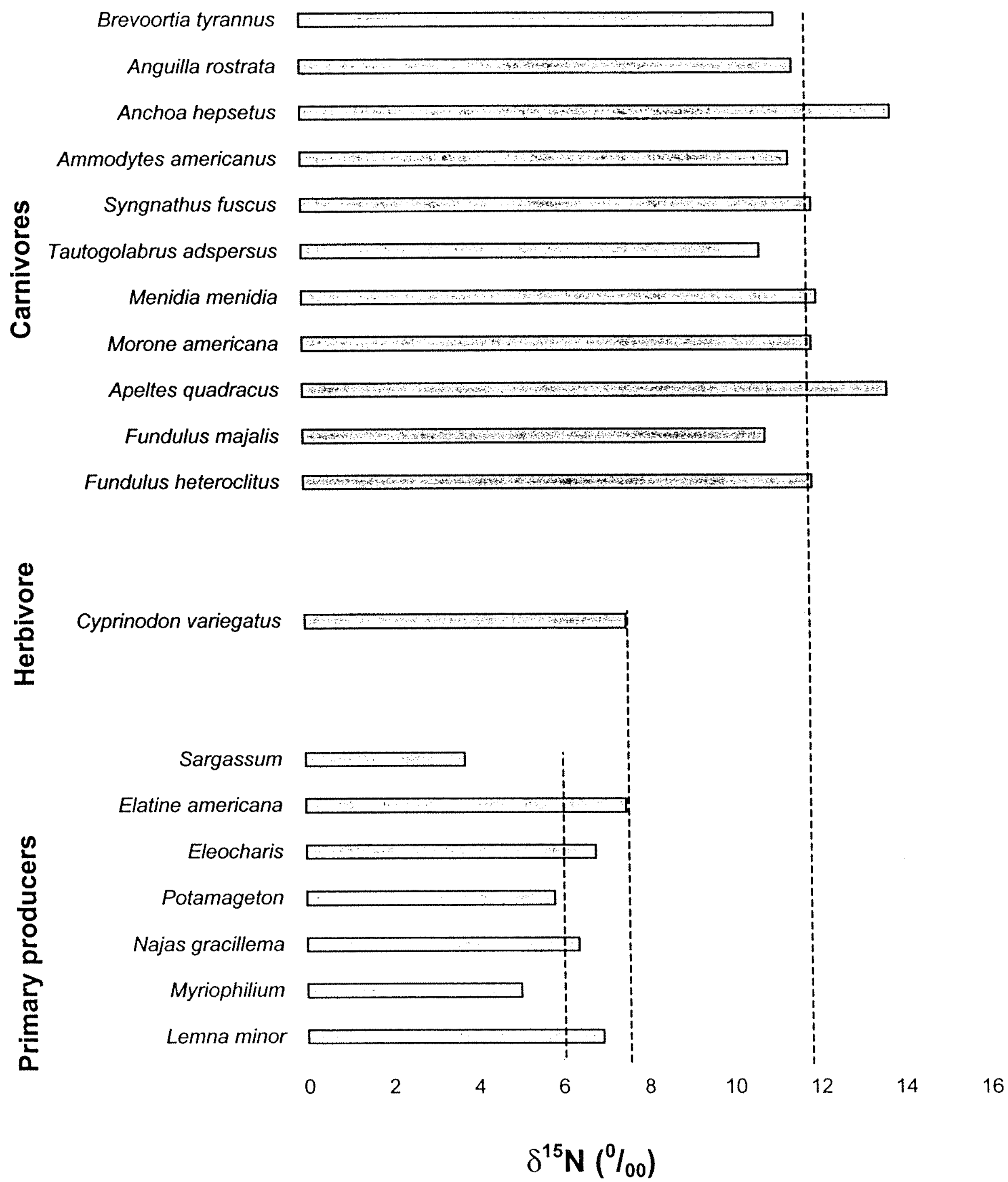
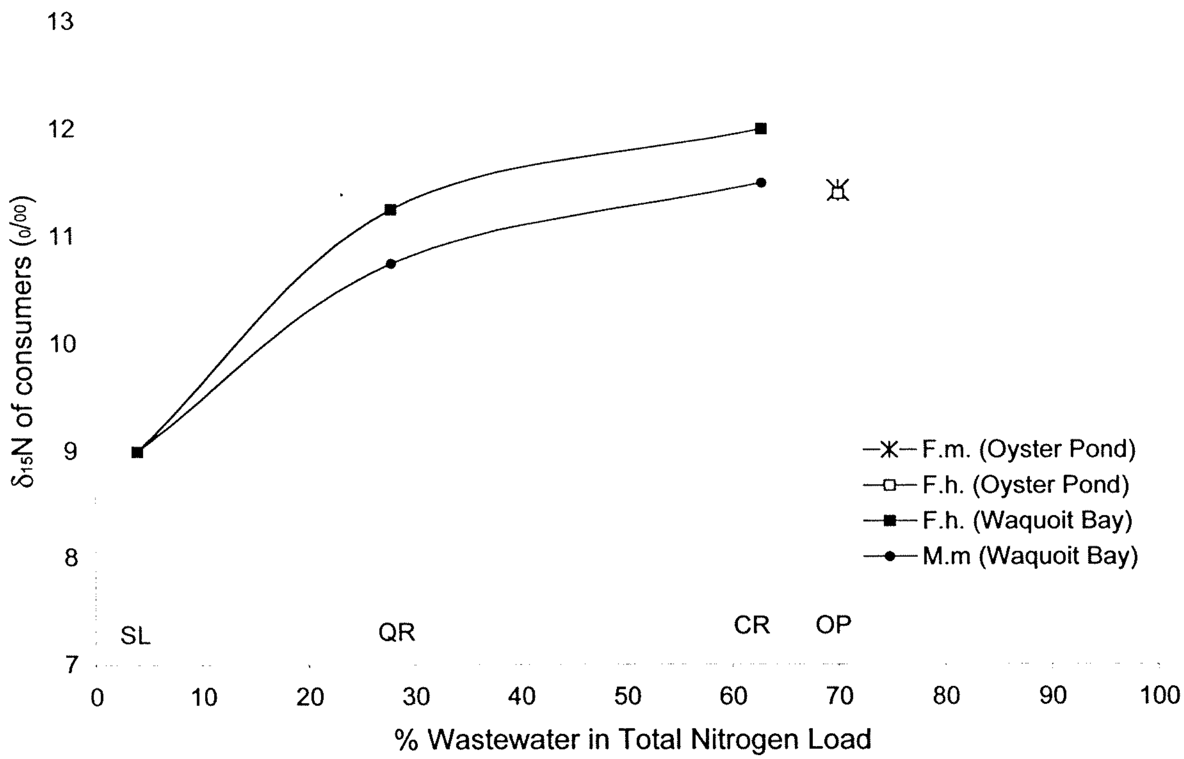

F. heteroclitus
Regression
Cohort Analysis
Total length (mm)
F. majalis
Age
100
80
60
40
0
1
2
3
4
110
90
70
50

Figure 9



Brevoortia tyrannus
Anguilla rostrata
Anchoa hepsetus
Ammodytes americanus
Syngnathus fuscus
Tautogolabrus adspersus
Menidia menidia
Morone americana
Apeltes quadracus
Fundulus majalis
Fundulus heteroclitus
Carnivores
Cyprinodon variegatus
Herbivore
Sargassum
Elatine americana
Eleocharis
Potamageton
Najas gracillema
Myriophilium
Lemna minor
Primary producers
0
2
4
6
8
10
12
14
16
δ15N (0/00)

Figure 10


13
12
11
10
9
8
7
δ15N of consumers (o/oo)
SL
QR
CR
OP
0
10
20
30
40
50
60
70
80
90
100
% Wastewater in Total Nitrogen Load
F.m. (Oyster Pond)
F.h. (Oyster Pond)
F.h. (Waquoit Bay)
M.m (Waquoit Bay)

Chapter 6

A primer on Oyster Pond ecology and possible research themes for junior high and high school students

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Section 1: To the Educator

Introduction

One of the most significant problems that faces ecologists, natural resource managers, educators, and citizens today is recognizing relationships in the complex system in which we live and work (Grant, 1998). It has been said (Worsely and Skrypiec, 1998) that environmental consciousness must become a prevalent part of life in the 1990s. The activities of humans are intertwined with the actions of other species and the health of their environment. This is a fact that must be recognized and understood as part of our education.

During childhood, we are most open to new ideas and concepts. It is during this period that our opinions take shape and our interests formed. Teaching environmental concerns in this time period is critical to children acquiring basic concepts of life structure and function. These teachings promote the care and social responsibility for the planet and ecosystem, ensuring the future health of the environment. Buiatti (1995) said that environmental teachings should be based as much as possible on the study and solution of real problems and avoid where possible "the construction of all- explanatory models". Giving students a personal experience promotes a greater awareness and understanding (House, 1999).

This paper provides basic terms, illustrative principles, and identifies areas of possible research for projects to be undertaken by junior and high school students. It uses Cape Cod ponds and estuaries as field sites, giving students the opportunity to gain experience in environmental science, learn basic scientific methods and begin to realize the guiding principles behind scientific research itself, rewarding both to the individual and to the community itself.

Modules

Topics are broken up into modules dealing with the pond's hydrographic properties, watershed region, nutrient input, vegetation, and fish. In each module, basic information is presented, and then feasible research objectives are posed. Specific projects, highlighted in boxes, are described within the module itself. Each module in this primer may be used independently or sequentially. Projects of varying skill levels are included to emphasize the concepts, and questions to promote discussion are included where relevant as well as additional resources for future study.

Section 2: Student Modules

Module 1

Hydrography: How water changes in natural environments

In the natural world, water occurs in a variety of environments: streams, pond, oceans, lakes, and rivers. The physical properties of each environment vary as well. This results in different characteristics of water that are specific to each environment. The two types of water bodies examined in this module are freshwater ponds and estuaries.

Freshwater Ponds

In Cape Cod, as in many other places, there is a layer of sediment below the ground that is saturated with water. This layer is called the aquifer, and the water that moves through it is referred to as groundwater (Figure 1). Freshwater ponds are places where the land surface dips down to the top layer of water in the aquifer, called the water table (Figure 2). Although it may not seem so at first glance, the water in a pond is not the same throughout: it has many properties that lead to different conditions. What does that mean to us? It turns out that these properties influence the way we use and enjoy ponds. One important property to study is water temperature.

In the summer, sun warms the upper layer of pond water, while the water at the bottom of the pond remains cool. The density of water changes in the topmost layer: as the water warms, it becomes lighter (less dense). The cold water remains heavy (more dense). Because of the different densities in between the upper and lower layers, they remain separate and do not mix together (Figure 3). The same effect can be seen when oil and water are combined. This separation effect is called "stratification". In a stratified pond, only the upper layer of the pond can be stirred and mixed by the wind.

As fall comes the top layer of water becomes cooler, because the temperature of the air is colder than it is in the summer. At some point, the temperature of the top layer is the same as the bottom. Then any wind action may stir the entire vertical extent of the pond. This is called the fall "overturn" because the water from the bottom of the pond mixes with the water from the surface (Figure 3).

When winter comes, the air may be cold enough to freeze the top layer of water and form a layer of ice. The bottom layer of water is not exposed to the air, so it does not freeze, and the pond again becomes stratified. In the spring, the air warms up and the ice melts. The pond's temperature becomes uniform (the same), and the spring takes place. Then the summer stratification begins, and the cycle repeats itself.

You may wonder why any of this is important. Physical characteristics are important because they determine what things can live in a pond as well as how we may use it. By understanding what physical changes occur in a pond from season to season, we gain insight into natural processes, their effect on the environment, and the value of natural resources.

General Question: Do ponds have different vertical temperature profiles (temperature measurements at different depths) during different seasons?

Project:

Measure the temperature of the pond at different depths during the summer. Then, measure temperature at the same depths during the fall and compare the temperature profiles between seasons.

Methods:

Obtain a water sampling device that can be used a various depths. Decide what locations are appropriate to sample based on the size of the pond. At these sites, sample the water at various depths and measure the temperature of samples. Chart your results on a graph, comparing temperature to depth.

Discussion

What do you notice? Does stratification or overturn occur? During which season(s) are these situations occurring?

Estuaries

Oyster Pond, located in Woods Hole, is not really a pond. It is an estuary: a place where fresh water and salt water mix. Estuaries undergo the same temperature changes that ponds experience, but the salt water creates an additional complication. Tides from the ocean force salty seawater into the estuary during flooding tide periods. This salt water has a greater density (it is heavier) than fresh. Instead of mixing with fresh water, the salt water tends to sink and create a salty bottom layer of water (like with warm and cold water or oil and water). The combination of a salty bottom layer and a fresh top layer give estuaries unique properties.

General Question: What is the result of fresh and salt water mixing in Oyster Pond?

Projects:

A. How does tidal flow influence the vertical profile of an estuary?

Methods:

Measure a vertical profile of temperature, salinity, and dissolved oxygen for the estuary at high tide and low tide. Choose one site at the north and south ends of the pond, the weir, in the lagoon and in the ocean. Using a water-sampling device, take samples of the site once every meter from the top of the pond to the bottom. Use a thermometer, refractometer and dissolved oxygen measuring device to obtain these measurements.

B. How do seasonal temperature changes affect water mixing in an estuary?

Methods:

Measure a vertical profile of temperature, salinity, and dissolved oxygen for the estuary at different times of the year. Follow the same procedure as used in project A, but take measurements twice: once in the summer and once in the fall.

Water flow through an estuary

General Question: How does water move in an estuarine system?

Fresh water occurs at the top of the estuary (Oyster Pond) and flows through the system to Vineyard Sound (Figure 4). Freshwater enters the system primarily through groundwater (Strahler, 1966). Water from the sound travels into the pond via the lagoon and the weir. The flow of salt water in and out of the estuarine system is referred to as the salt wedge (Figure 5), because as it flows in, it forms a "wedge" underneath the fresh water, rather than mixing with it. There are several factors that affect "water residence" (how long water remains inside the system). These factors include mixing, water input and outflow (how much water comes in and how much leaves during a tidal cycle).

Question: How does the horizonal tidal component influence water movement in an estuary?

Projects:

A. How does seawater come in to the estuary at high tide and how does it leave?

Methods:

To determine how water flows through the estuary system, create a horizontal profile:

1. At slack low tide, deploy numbered oranges that will float just below the surface and can follow the path of water as it moves around the estuary.
2. Monitor floats over a time period, noting their location after 1, 5, 10, 20, 30 etc. days, collecting at slack high tide.

3. Map out the path that the oranges follow as they travel through system.

Vocabulary Section:

Salinity: Salinity is the amount of dissolved salts in a sample of water. Seawater has a salinity of about 35 ppt (parts per thousand: a measure of how many parts salt are present in a sample of 1,000 parts water) and fresh water has a salinity of 0 ppt. Salinity varies throughout an estuary, the saltiest part being where ocean water enters the system. Salt water is denser than fresh water, so it sinks and forms a separate layer when the two are combined, as occurs in an estuary.

Temperature: Water temperature varies with depth and with season. Water at the top of a water body is subject to more drastic change due to the heightened effect of the sun. When a water body has is stratified by layers of different temperature, the water cannot mix. (See "overturn" and "stratification")

Dissolved Oxygen: Oxygen in water is called "dissolved". Oxygen enters the water through photosynthesis by aquatic plants and from the atmosphere. Water that experiences mixing has a higher level of dissolved oxygen. The ability of oxygen to dissolve in water decreases with increased temperature and salinity.

Stratification: a separation effect that occurs when materials having different densities are mixed together, like with oil and water. Layers that are separated will not mix together. In a water body, stratification occurs when the top layer of water changes in temperature with the seasons and cannot mix with the bottom layer.

Overturn: When a the top layer of water in a stratified water body becomes the same temperature of the rest of the water body, mixing can occur between the two layers. This mixing is called overturn.

Aquifer: a layer of sediment below the ground that is saturated with water (see Figure 1)

Groundwater: water flowing through the aquifer (see Figure 1)

Water table: the top layer of water in the aquifer (see Figure 1)

Estuary: a coastal water system where fresh water meets salty ocean water.

Vertical Profile: a series of measurements taken at different depths

Further Readings:

1.) A Coastal Pond Studied by Oceanographic Methods
K.O. Emery, 1969
Available from the Oyster Pond Environmental Trust (Woods Hole, MA)

2.) Oyster Pond- Three Decades of Change
Howes, B. L. and S. R. Hart, 1997
Oyster Pond Environmental Trust (Woods Hole, MA)

2.) A Drop of Water: A book of science and water
W. Wick, 1997
School and Library Binding

3.) A Geologists View of Cape Cod
A. N. Strahler, 1966
Parnassus Printing, Boston, MA

Module 2

Watersheds and Water Quality

General Question: How you discover where water entering a water body comes from?

A watershed is a geographic area in which all sources of water including lakes, rivers, estuaries, wetlands and streams, as well as groundwater, drain to a common water body. All the precipitation (water in the form of rain, snow, etc.) that falls on a watershed drains to the same receiving water body. Most watersheds are part of a greater system where the water eventually drains to the ocean. Areas of higher elevation separate watersheds from one another. Runoff (the surface flow of water from higher to lower ground) occurs, allowing water to move through the system. Cape Cod is unusual, in that runoff is not the primary source of freshwater for ponds, lakes and streams, though it is in most other places. Freshwater here is primarily in the form of groundwater (Emery, 1997).

Watershed regions can be determined using a water table map. A water table map shows the height of the water table (the top layer of the aquifer) across an area (Figure 6) allowing scientists to determine how groundwater flows through the system.

Question: What is the watershed for Oyster Pond?

Projects:

A.) Using a water table map for the Falmouth/ Woods Hole area, draw the Oyster Pond watershed on a separate map. Water table maps for this area can be obtained from the Town of Falmouth Natural Resources Division (508- 457- 2536). Compare your map to Figure 7.

B.) Draw arrows on the map to indicate the flow of water through the Oyster Pond estuarine system.

Nutrient input to ponds and estuaries

Question: How can we monitor what enters a watershed?

Land use in a watershed affects the water resources it contains. Water quality is a term used to describe the chemical, physical and biological characteristics of a water body. Good water quality indicates a low level of pollution. There are two forms of pollution. Point- source pollution occurs when a specific source, such as a pipe or septic system, can be identified. When the pollution enters the system through runoff or drainage and an exact source cannot be identified, it is referred to as non- point source pollution. Nutrient input to Oyster Pond travels via both forms of pollution.

Nutrients, pesticides, and pathogens from wastewater affect water quality. When excess amounts enter a system, organisms living in the water may not be able to survive. In Cape Cod, nutrients affects on water quality are a major cause of concern. Nutrients from fertilizers, septic systems, and the atmospheric deposition encourage the growth of algae in water. Excessive algal growth can prevent light from passing through the water. When the algae die, the decaying process uses up oxygen in the water, leaving little or none in the water for other organisms. A low concentration of oxygen in the water is termed "hypoxic", and a pond with no oxygen in the water is called "anoxic" (without oxygen). It is very hard for organisms to survive in a hypoxic pond, making swimming, fishing and other activities less enjoyable.

Question: Does Oyster Pond have any hypoxic or anoxic areas?

Projects:

A. What do the results of the dissolved oxygen measurements from your earlier study tell you about oxygen levels in the pond?

Vocabulary Section:

Watershed: A watershed is a geographic area in which all sources of water including lakes, rivers, estuaries, wetlands and streams, as well as groundwater, drain to a common water body

Runoff: the flow of surface water from areas of higher elevation to lower areas

Point- source pollution: pollution originating from an identifiable source

Non point- source pollution: pollution that cannot be traced to a specific source

Hyperoxic: water with a low concentration of dissolved oxygen

Anoxic: water with no dissolved oxygen

Atmospheric Deposition: occurs chemicals from the atmosphere are brought down to interact with terrestrial environments.

Future Readings:

1.) A Coastal Pond Studied by Oceanographic Methods
K.O. Emery, 1969
Available from the Oyster Pond Environmental Trust (Woods Hole, MA)

2.) Watersheds: A practical handbook for healthy water
G. G. Beck and C. Dobson, 1999
Firefly Books, New York NY

3.) The Estuary's Gift: an Atlantic Coast Cultural Biography
D. Griffish, 1999
Pennsylvania State University Printing, Pittsburg, PA

4.) Integrated Watershed Management: Principles and Practice
I.W. Heathcote, 1998
John Wiley and Sons, New York NY

Module 3

Nutrient Loading

General Question: Why do phytoplankton blooms occur?

Plants need several basic things: light, water, oxygen and food. Plants use nutrients, such as nitrogen and phosphate, for food. Tiny organisms called phytoplankton live in the water, and function in a similar way. Thought they are not plants, phytoplankton require many of these same things, and like plants, they change energy from the sun into food using oxygen and nutrients present in the water in a process called photosynthesis. Organisms that photosynthesize are referred to as primary producers, because they form the bottom of the food pyramid. In the aquatic food chain, phytoplankton function as a major primary producer. Many other organisms depend on phytoplankton as their main food source.

Even though phytoplankton play a very important role in creating healthy aquatic ecosystems, too much of them can become a problem. The more nutrients that enter the system, the more phytoplankton will grow. The amount of nutrients that enter a water body is called the "nutrient load". To prevent phytoplankton blooms from occurring, we have to regulate nutrient loads for watershed regions. Excess nutrients from fertilizers and from wastewater (water that has passed through a septic system) are the main cause of phytoplankton blooms in Oyster Pond (Emery, 1969). Through understanding their causes and monitoring nutrient input, we can prevent phytoplankton blooms.

Question: What factors play a role in phytoplankton blooms?

Projects:

A. What effect does the addition of nutrients have on phytoplankton?

B. What effect does light have on phytoplankton growth

Methods:

A. Take 10 water samples from Oyster Pond. To five samples, add increasing amounts of nitrogen (starting from no nitrogen added). The bottle with no nitrogen added is called a "control". Controls are used to ensure that the evidence you gather has a real effect, and that other factors are not influencing your results. Repeat this procedure using phosphate and the other five samples. Record which jars show the most phytoplankton growth.

B. Using six more sample of Oyster Pod water, add the same amount of nitrogen to three samples. Put one in complete darkness, one in constant light, and one in light for twelve hours and dark for twelve hours. What is the "control" for this experiment? Repeat this procedure for the using phosphate. Record under what light conditions the most growth occurs.

Discussion:

How can you be sure that the effects you noticed are not due to other factors? By performing "replicate" studies, that is, having two or more sets of the same experiment running at the same time. Like controls, using replicates is an essential part of carrying out an accurate scientific experiment. Remember to perform the above experiments using replicate studies.

Vocabulary Section:

Phytoplankton: Through the process of photosynthesis these microscopic, single-celled plants nourish the entire food web of aquatic ecosystems. They are not actually plants, but algae.

Phytoplankton Bloom: when excess nutrients enter an aquatic system, phytoplankton undergo a period of excess growth, referred to as a "bloom".

Nutrient Load: the amount of nutrients entering a water body from its watershed.

Further Readings:

1.) A Coastal Pond Studied by Oceanographic Methods
K.O. Emery, 1969
Available from the Oyster Pond Environmental Trust (Woods Hole, MA)

2.) Stream, Lake, Estuary and Ocean Pollution
N.L. Nemerow, 1985
John Wiley and Sons, New York NY

3.) Esuarine Science: A synthetic approach to research and practice
J.E. Hobbie (Ed.), 2000
Island Press, New York NY

4.) Eutrophication Processes in coastal systems: Origin and succession of plankton blooms on secondary production
R.J. Livingston, 2000
Lewis Publishers, Inc., Pittsburg, PA

Module 4

Vegetation in an estuary system

General Question: How do vegetation patterns change across the Oyster Pond system?

If a cross section of the Oyster Pond estuary was made, it would show plants growing along the shore and wherever light could reach, even under several meters of water! As you examined this cross section, you would notice that the plants appeared very different. This pattern of growth is called zonation. Each habitat in the estuary has characteristics that limit what plants can grow there. Two basic categories of plants are emergent, and submerged. The plants within each category share some basic growth requirements, which limit them to grow within certain kinds of places (Figure 8). Shoreline vegetation consists of plants that like to have wet roots, but can tolerate periods of dryness or flooding. Emergent plants have their root systems and part of their stems submerged in water. Submerged plants grow entirely under water, rooted in bottom mud.

Additionally, plant growth may be limited by factors such as light, salinity, oxygen, amount of water, or soil type. In an estuarine system, salinity plays an important role in where plant species can grow. Plants that are specifically adapted to grow in salty conditions are called "halophytes". Their adaptations include methods to eliminate excess salt and prevent "desiccation" (drying out). A common halophyte is *Spartina alterniaflora*, or salt marsh cordgrass (Figure 9), which grows in the southern end of the Oyster Pond estuarine system. It is important to know which species are present in the Oyster Pond plant community, because changes in its composition can indicate changes occurring in the environment.

Question: What controls the presence of different plant species in the Oyster Pond Estuary?

Projects:

A. Examine vegetation samples obtained from three sites: Oyster Pond, the lagoon, and Vineyard Sound. Do plant samples from the same site appear to share certain characteristics?

B. Identify some of the samples from each area using a plant field guide such as "Coastal Plants from Cape Cod to Cape Canaveral" by I.H. Stuckey and L.L. Gould. After identifying a sample, learn about the habitat that it is usually found in. Is that where your sample was found? If not, consider what characteristics of the Oyster Pond estuary system could cause a plant to be found in an unusual habitat.

Vocabulary Section:

Zonation: changes in habitat conditions reflected by vegetative growth

Emergent Vegetation: plants that prefer to grow with their roots wet, but can endure flooded or dry conditions.

Submerged Vegetation: plants grow with their roots and part of their stems underwater

Halophytes: plants that grow in salty conditions

Desiccation: periods of drying out experienced by estuarine plants and organisms that occur between tides as the water level changes

Further Readings:

1.) A Coastal Pond Studied by Oceanographic Methods
K.O. Emery, 1969
Available from the Oyster Pond Environmental Trust (Woods Hole, MA)

2.) Coastal Plants from Cape Cod to Cape Canavral
I.H. Stuckey and L.L. Gould, 2001
University of North Carolina Press, Chapel Hill NC

3.) Salt Tide: cycles and currents of life along the mid- coast.
C. J. Badjer, 1999
Countryman Press, Woodstock VT

Module 5

Fish of the Oyster Pond estuary

An important characteristic of any water body is its fish population. Oyster Pond is no exception; it is home to a large variety of fish species that play essential roles in maintaining the pond's health and diversity. Estuarine systems in general are valuable as places for fish to spawn and for young fish (called "fry") to grow up. The fish in Oyster Pond are primarily fresh or brackish (part salty/ part fresh) water species such as yellow perch and killifish. A large number of fish that live in the ocean and come to estuaries to spawn (andromenus fish) are temporary inhabitants. These fish are often economically valuable and include herring, alewives, and salmon. Eels, which live in fresh water all their lives but spawn in the ocean (catadromenus), can also be found in Oyster Pond. In order to understand how to preserve the Oyster Pond fish community we must first understand how different factors could alter future abundance.

One important factor is salinity. Some species of fish can tolerate a wide variety of salinities, while others survive only in a certain range. For example: white perch, primarily a freshwater species, populated the pond during the 1980's. When the Trunk River was dredged, the pond's salinity increased (Howes and Hart, 1997). Soon after, the white perch population began to decline because the perch do not reproduce in salty water. For some time, only adults of the species were observed and from 1989- 1990 this species was not observed in the pond (Emery, 1969). After completion of the weir, less salty water entered the pond, and the water became brackish. Adult white perch were observed in the pond during 1992 and juveniles were observed in 1994, indicating that white perch have returned to the Oyster Pond system. This example illustrates the effect of environmental change and the important role factors like salinity can play in determining species composition. It also shows that human actions can markedly change an environment and consequently, the species within it.

Another factor that affects Oyster Pond's fish community is pollution, which can occur in many different forms. One type of pollution that may occur is the input of excess nutrients such as nitrogen or phosphate to the system, resulting in algal "blooms". The layer of algae across the top of the pond becomes so thick that light cannot pass through it. Bacteria trying to decompose this excess matter use up the available oxygen, creating anoxic conditions. Fish and other organisms under the water cannot survive. By measuring the abundance, distribution, and species in Oyster Pond, we can get an idea of how fish in a water body are affected by changes caused by humans.

Question: How is the fish community structured in Oyster Pond and how has this structure changed over the years.

Projects:

A. Set minnow traps at a variety of locations within the Oyster Pond estuarine system. If possible, obtain information from local fishermen about what species they have recently caught in the pond.

B. Record the lengths and species of trapped fish, as well as the habitat type in which they were caught.

C. Take salinity and dissolved oxygen measurements at each trap site.

D. Compare your findings with data gathered by BU students or by OPET. Have the species present changed? If they have, why do you think the change occurred? Is there a greater abundance in any one area of the pond? What does that indicate about this location? Why are salinity and dissolved oxygen levels important?

Vocabulary Section:

Fry: another name for fish young

Andromenus: a species of fish that spends its adult life in the ocean but returns to estuaries or fresh water to spawn.

Catadromenus: species of fish that spend adult life in fresh water but return to salt water to spawn.

Brackish: water of an intermediate salt concentration

Year Class: a group of fish born in a given year

Age Frequency: the number of fish in each year class

Further Readings:

1.) A Coastal Pond Studied by Oceanographic Methods
K.O. Emery, 1969
Available from the Oyster Pond Environmental Trust (Woods Hole, MA)

2.) A field guide to Atlantic Coast fishes
C. Richard Robbins, 1986
Houghton Mifflin Company,

3.) A field guide to freshwater fishes: North America north of Mexico
L.M. Brooks et al., 1998
Houghton Mifflin Company, New York, NY

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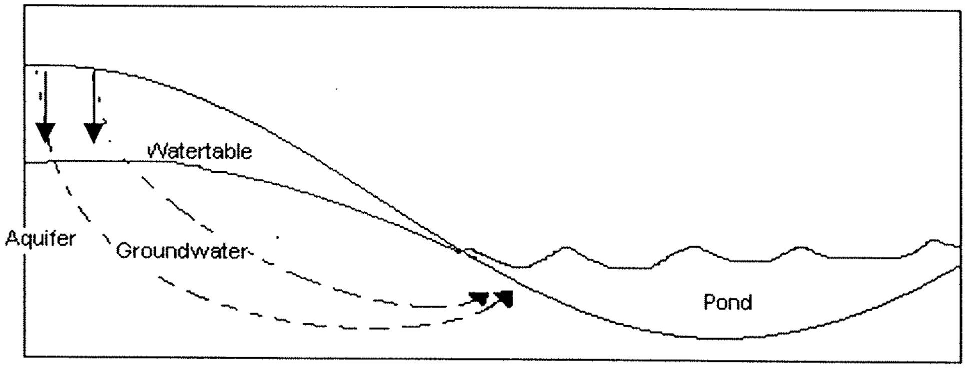
House, M. 1999. Citizen Participation in Water Management Water Science Technology 40: 125- 130.

Worsely, A. and G. Skrypiec. 1998. Environmental Attitudes of Senior Secondary School Students in S. Australia Global Environmental Change 8: 209- 225.



Fiqure 1: Groundwater flow through the aquifer

Water passes through the ground until it reaches the aquifer. When it enters the aquifer, it is called groundwater. Ground water flows into streams, lakes and ponds when the level of the ground is lower than that of the watertable (top layer of water in the aquifer).

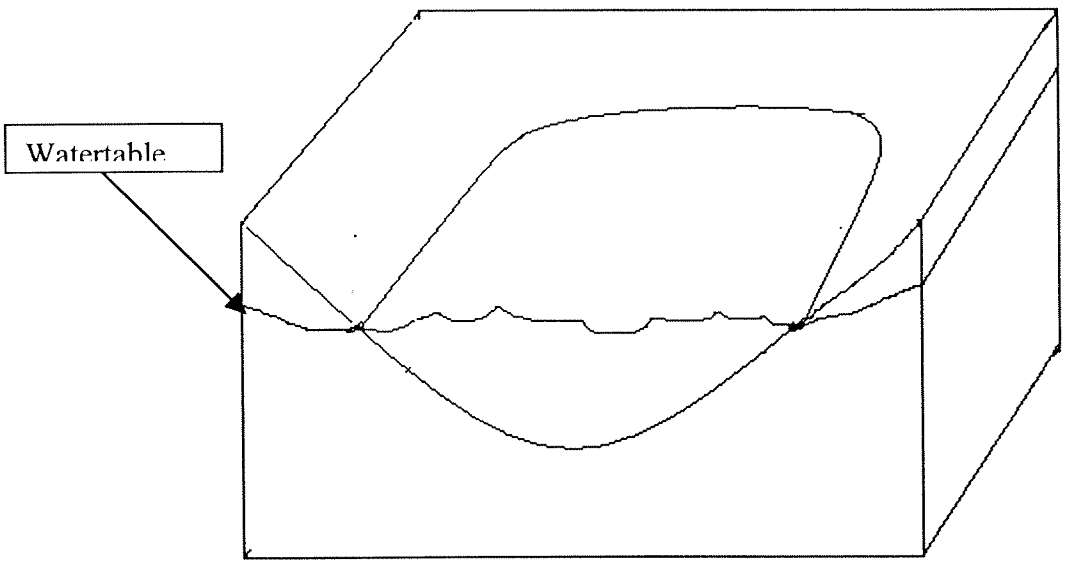


Figure 2: Ponds in relation to the watertable

A pond is an indent into the sediment, formed thousands of years ago from chunks of ice left behind by a glacier. Water fills the depression because it goes below the level of the water table.

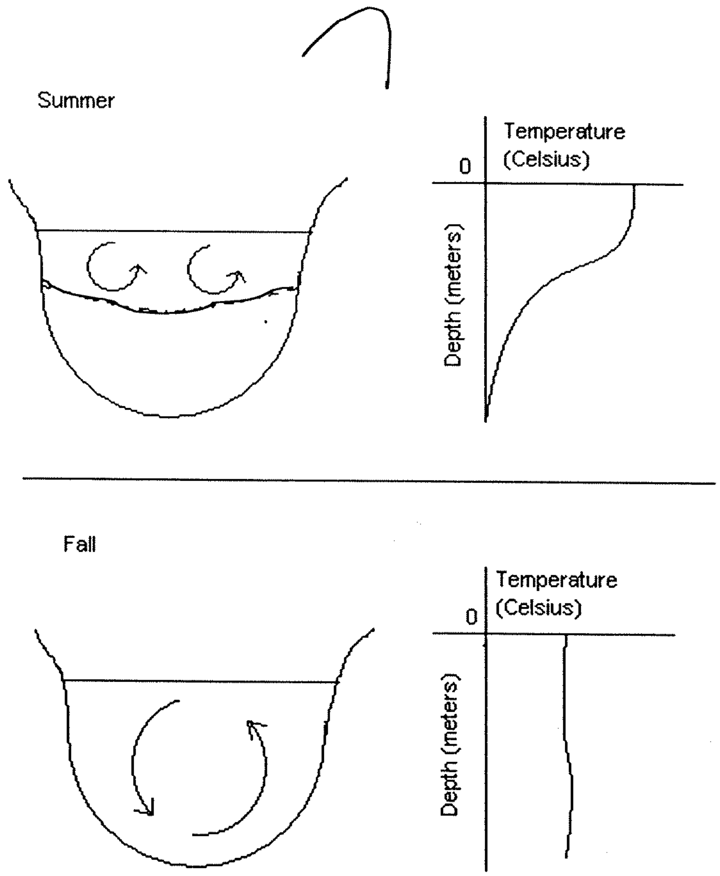


Figure 3: Seasonal Changes in Pond Stratification

In the summer, the top layer of water in a pond warms, while the bottom layer remains cold. Warm and cold water have different densities, and cannot mix together. This separation is called stratification. The graphs on the right show how the temperature changes in the pond from top to bottom. Notice that in summer there is a difference in temperature, while in fall the temperature remains approximately the same throughout. In the fall, the pond does not have layers, and can mix. This mixing is called "overturn".

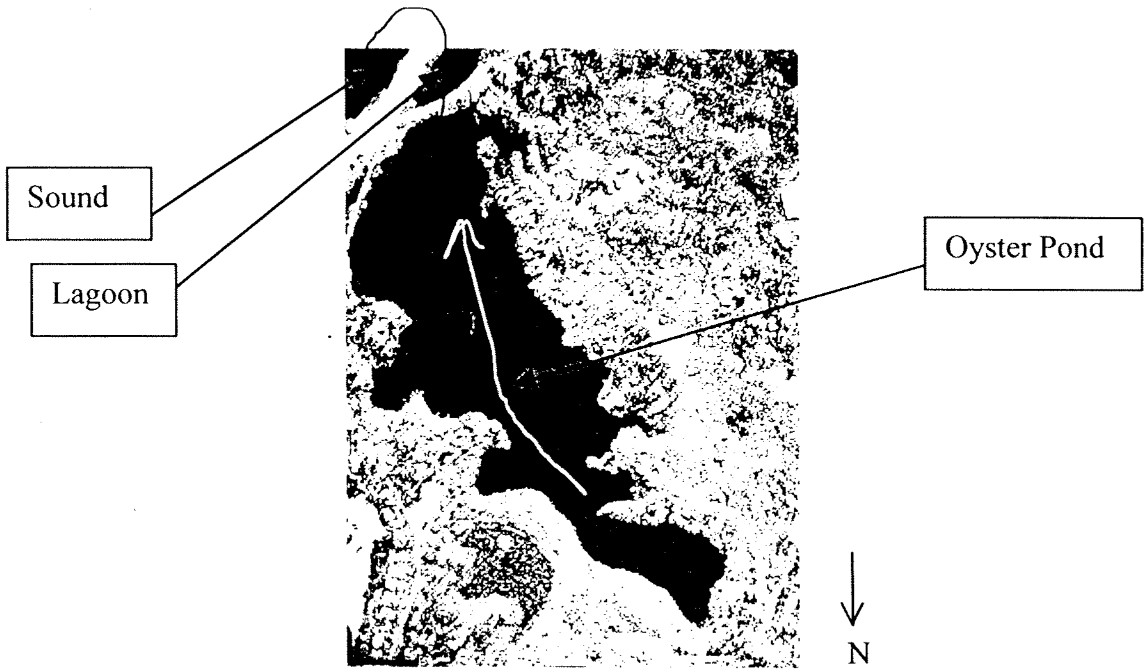


Figure 4: The Oyster Pond System

Freshwater enters the system in the form of groundwater. Salty water from the sound is pushed through the lagoon and into the pond during high tides. In this diagram, arrows indicate the path water travels. The light arrow represents freshwater flow, and the dark arrow represents salt-water flow.

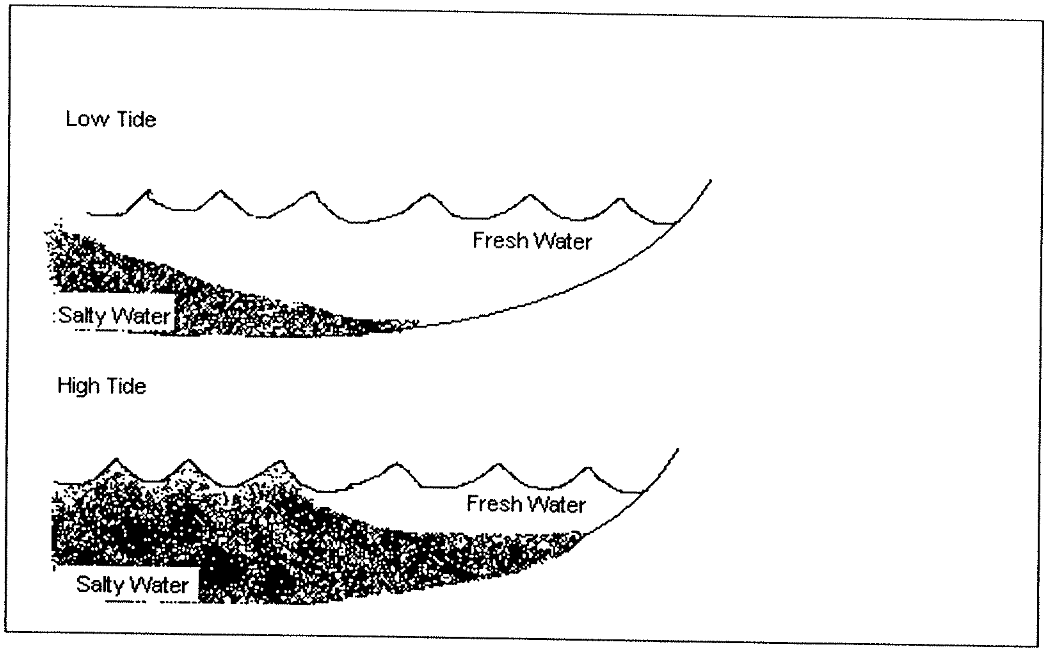


Figure 5: The Salt Wedge

When salt water enters an estuary, it meets fresh water. Salt water is heavier than fresh, so it sinks to the bottom. The two types of water do not mix (like oil and water). When the tide comes in, it pushes salt water higher into the estuary. When the tide goes out, the layer of salt water no longer is forced into the estuary, and it moves back out to sea. The salt-water layer is also called the salt wedge, because as the tide turns, the layer wedges underneath the fresh water layer.