

Using winter flounder growth rates to assess habitat quality in Rhode Island's coastal lagoons

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ABSTRACT: We used growth rates of juvenile winter flounder *Pseudopleuronectes americanus*, to assess habitat quality in 3 of Rhode Island's coastal salt ponds that had differing levels of nutrients and human development. In each pond, 1 m² cages were placed in vegetated and unvegetated habitats and growth rates of individually marked fish were measured in three 10 to 15 d experiments from 4 June to 7 July 1997. Water temperature, salinity, dissolved oxygen, and benthic food were also measured. Stable isotopes of C and N were measured in experimental and wild fish. Growth rates were 0.06 to 0.76 mm d⁻¹ and decreased through the experiments. Growth rates of wild fish (0.19 mm d⁻¹ in Point Judith Pond and 0.21 in Ninigret Pond) were similar to the average of the 2nd and 3rd experiments (0.24 mm d⁻¹). Growth rates were the same in vegetated and unvegetated sites. They were also the same in Point Judith and Ninigret ponds but lower in Green Hill Pond. An ANCOVA suggested that Green Hill's lower rates were caused by its higher temperatures, particularly during the 3rd experiment. Benthic food was similar in the different ponds, different habitat types, and in cores taken inside and outside cages. Categories of food consumed by fish were not affected by the presence of vegetation in a cage, although food consumed did differ from pond to pond. Amphipods were the preferred food in all ponds; fish consumed proportionately more amphipods and fewer polychaetes in Ninigret Pond than in the other ponds. Values of $\delta^{15}\text{N}$ in the fish varied with the degree of development in the watershed but not with total nitrogen in the water column. The results of this study indicate that growth rates of fish can be used as indicators of habitat quality.

KEY WORDS: Fish habitat · Habitat quality · Estuaries · Fish growth · Stable isotopes

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INTRODUCTION

Estuaries provide high-quality nursery habitats for juvenile fishes with different life histories, life stages, and habitat needs (Deegan & Day 1984). Habitat quality varies depending upon anthropogenic and natural factors. Some habitats, such as shallow-water barrens and muddy bottoms, are economically and ecologically undervalued by humans and therefore vulnerable to human modification. Habitat types important to different species and life stages of fishes have been identified (Ayvazian et al. 1992, Baltz et al. 1993, Szedlmayer

& Able 1996, Meng & Powell 1999), but comparing the relative quality of habitats has been more problematic (Sogard 1992). Finding a way to assess quality of habitats may help prevent loss of areas essential to sustain fish populations and fish communities. In order to maintain populations, fishes need to quickly outgrow early life-history stages vulnerable to predation and environmental stress (Sissenwine 1984, Houde 1987, 1989). Presumably, fishes grow more quickly in higher quality habitats, which are rich in food and offer refuge from predation and the right set of environmental variables to promote growth. Therefore, fish growth rates may be a good way to assess habitat quality.

Vegetated areas are generally thought to be higher-quality habitats for juvenile fishes than unvegetated

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substrates. Vegetated areas are assumed to provide more food for juvenile fishes because of increased habitat heterogeneity and greater protection from predation because of increased cover. For example, eelgrass beds are known to be important habitats (e.g., Heck & Orth 1980, Bell & Steffe 1988, Heck et al. 1989, Ferrell & Bell 1991, Heck et al. 1997), as are marshes (e.g. Weinstein 1979, McIvor & Odum 1988, Kneib & Wagner 1994). However, work in Narragansett Bay and other estuaries has shown that other habitats are also important to juvenile fish development (e.g., Ayvazian et al. 1992, Baltz et al. 1993, Szedlmayer & Able 1996, Meng & Powell 1999), and some species, such as winter flounder *Pseudopleuronectes americanus*, are captured more frequently in unvegetated areas (Buckley 1989, Meng & Powell 1999). Sogard (1992) and Phelan et al. (2000) measured growth rates of juvenile fishes in 1 m² cages placed in vegetated (*Zostera* sp. or *Ulva* sp.) or unvegetated habitats. Sogard (1992) found that vegetation promoted growth of tautog *Tautoga onitis* but not winter flounder or naked goby *Gobiosoma boscii*. Phelan et al. (2000) found that vegetation did not affect growth.

Human activities can also affect habitat quality. Eutrophication alters food webs and changes sediment characteristics. In Rhode Island's coastal salt ponds, which are shallow and poorly flushed, eutrophication has increased the growth of macroalgae (Lee & Olsen 1985). Large masses of macroalgal detritus accumulate on the bottom, reducing dissolved oxygen concentrations and changing the dominant sediment type from sand to organic mud (Lee & Olsen 1985). This change in sediment characteristics can alter rates of nutrient recycling and worsen effects of increased nitrogen by more rapidly remineralizing inorganic nitrogen (Lee & Olsen 1985). Changes in sediment characteristics also alter benthic food webs. Boating damages eelgrass and macroalgal beds both directly via propeller damage (Clark 1995) and indirectly by releasing hydrocarbons into the water. Dredging, filling, and pier construction decrease sunlight available for aquatic plants and reduce the amount of shallow water (Able et al. 1999).

We used growth rates of juvenile winter flounder to assess habitat quality in 3 of Rhode Island's coastal lagoons (known locally as salt ponds) that had differing levels of nutrients and human development. We placed 1 m² cages in vegetated and unvegetated habitats, grew winter flounder in each, and compared their growth rates. Based on nitrogen concentrations in the water column and human development, we

expected fish to grow fastest in Ninigret Pond, followed by Point Judith and Green Hill ponds. To determine other factors which influenced fish growth, we measured variables such as temperature, salinity, dissolved oxygen, plant density, prey density and prey-species composition. We also measured stable isotope ratios ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) in the fish. Previous work has shown that $\delta^{15}\text{N}$ ratios can be used as indicators of nutrient enrichment and that organisms from areas with high nitrogen loading will have greater $\delta^{15}\text{N}$ values (Yelenik et al. 1996, McClelland et al. 1997). $\delta^{15}\text{N}$ can also be used to estimate the number of levels in the food chain, with consumers showing an approx. 3‰ increase relative to their food source (e.g., Fry 1988, Hobson & Welch 1995, Wainwright et al. 1993, Keough et al. 1996, Vander Zanden et al. 1997). Finally, $\delta^{13}\text{C}$ can be used to identify sources of organic carbon to consumers (Fry & Sherr 1984, Wainwright et al. 1993). A food chain based on macroalgae and phytoplankton is expected to have $\delta^{13}\text{C}$ values lower than 1 based on macrophytes, such as eelgrass (Haines & Montague 1979, Stephenson et al. 1986, Keough et al. 1996).

METHODS

Study site. The 3 salt ponds were all in southern Rhode Island (Fig. 1). Point Judith and Ninigret ponds

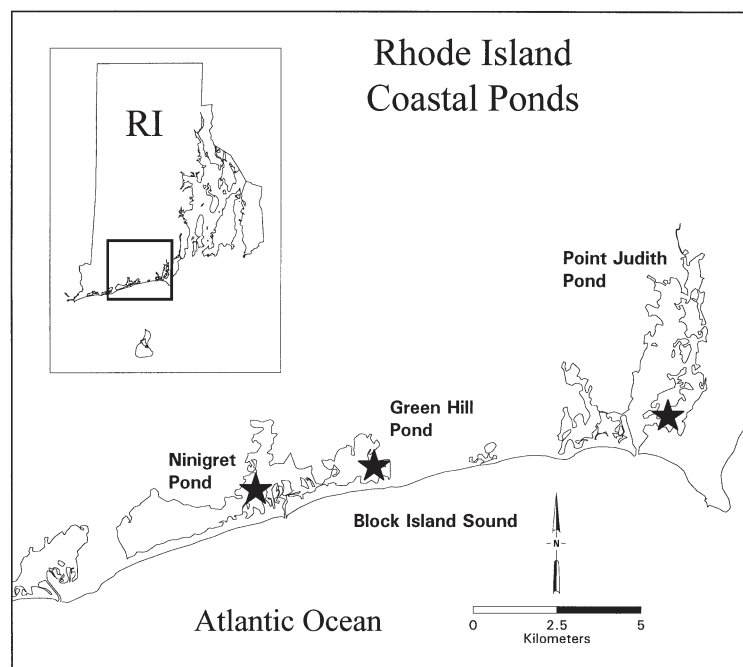


Fig. 1. Rhode Island coastal salt ponds. Experiments were conducted at starred locations in Point Judith, Ninigret, and Green Hill ponds

Table 1. Physical characteristics of 3 coastal ponds and caging sites used in winter flounder *Pseudopleuronectes americanus* growth experiments, Rhode Island, 1997. Measurements were taken at caging sites, except pond area, average depth, tidal range, inlet dimensions, watershed development (includes residential, industrial, and agricultural interests), and dissolved inorganic nitrogen concentrations (from Ernst 1996). Water temperature, salinity, and dissolved oxygen were taken at the bottom every 3 d during experiments from 4 June to 7 July 1997. Maximum flow was measured during spring tidal cycle. Turbidity, average depth, substrate, and vegetation measurements were collected at end of experiments. Numbers are averages unless noted otherwise

	Point Judith	Ninigret	Green Hill
Area $\times 10^6$ m ² ^a	7.85	6.45	1.55
Average depth (m) ^a	1.8	1.2	0.8
Tidal range (cm) ^a	44.5	13.7	3.7
Inlet dimensions (m) ^a	80 \times 4.6	34 \times 2	7 \times 1
Watershed development (%) ^a	38	21	33
Dissolved inorganic nitrogen concentration (mg l ⁻¹) ^b	1.1	2	3.8
Water temperature range (°C)	14.4–21.8	13.9–21.9	17.2–26.5
Salinity range (‰)	30–34	31–34	24–29
Dissolved oxygen range (mg l ⁻¹)	6.1–7.9	6.7–8.7	5.3–8.7
Maximum flow (cm s ⁻¹)	38	17	4
Turbidity (NTU)	3.6	1.1	2.5
Average depth at cage site (m)	1.0	0.66	0.58
Substrate	Sand	Mostly sand	Sand/silt mix
Area covered by vegetation in vegetated sites	100% eelgrass	100% eelgrass	50% eelgrass/widgeon grass
No. of plant stems m ⁻²	150	300	100

^aLee & Olsen (1985), ^bErnst (1996)

are connected to Block Island Sound by single, narrow, permanent, man-made breachways. Green Hill Pond has no direct opening to the sound, but is connected to Ninigret by a narrow channel. Point Judith and Ninigret ponds have similar temperatures, salinities, substrates, and flow rates (Table 1). Green Hill Pond is the smallest and has the highest temperatures and lowest salinities (Table 1). Tidal range and flow rates are lower in Green Hill (Table 1) resulting in lower flushing rates. We used data compiled in 1992 to assess nitrogen input and human development in the ponds (Ernst 1996). Point Judith's watershed is the most developed due to residential, industrial, and agricultural activities (Table 1), and harbors most of Rhode Island's fishing fleet. Green Hill has the highest housing density, highest nitrogen concentrations (Table 1), and is closed to shellfishing because of high fecal coliform bacteria concentrations from household septic systems. Ninigret is one of Rhode Island's cleanest ponds, and was considered a control. Within the ponds we chose sites that had eelgrass (Point Judith and Ninigret) or a mixture of eelgrass and widgeon grass (Green Hill) near unvegetated sandy or sandy-muddy areas.

Growth experiments. Winter flounder *Pseudopleuronectes americanus* were grown in 1 m² cages in the ponds. The cages were 70 cm tall and composed of wooden and welded-metal

frames covered with 0.3 mm plastic netting on the sides and top. Steel edges (17 cm wide) around the bottom allowed us to dig the cages into the substrate. To further secure the cages, we drove 70 cm stakes into the substrate through fittings at the lower corners of the cages. To allow access through removable tops, we placed the cages in water that was ~60 cm deep at low tide. We placed 6 cages in each pond, 3 each in vegetated and unvegetated areas. We ran 3 experiments of 10 to 15 d each in June and July 1997 (Table 2).

Experimental fish were seined from one site in Ninigret Pond (Fig. 1) and then weighed, measured (total length), and individually marked with Visible Implant Fluorescent Elastomer. To assess handling mortality, we held fish overnight in the field before placing them in cages. Dead fish (<1% of the total) were replaced with healthy fish. Before each experiment, cages were

Table 2. *Pseudopleuronectes americanus*. Experimental start dates, durations, and initial fish lengths. Growth rates are averages for the 3 ponds; 72 fish were measured (total length) for each experiment. Numbers in parentheses are standard deviations

	Experiment		
	1	2	3
Start	4 Jun 1997	18 Jun 1997	28 Jun 1997
End	18 Jun 1997	28 Jun 1997	7 Jul 1997
Duration	15	11	10
Average initial fish length (mm)	32.6 (2.3)	34.0 (2.1)	36.9 (2.1)
Average growth rate (mm d ⁻¹)	0.68 (0.13)	0.24 (0.12)	0.24 (0.12)

cleared of resident fish and decapods with bar seines and dip nets. Four fish were placed in each cage, a density comparable to juvenile winter flounder densities measured in the ponds by the Rhode Island Department of Environmental Management (RIDEM), Division of Fish and Wildlife (unpubl. data). We checked the cages every 3 d and brushed them to minimize fouling. At the end of each experiment, we removed fish from the cages with a mask, snorkel, and dip net and immediately weighed and measured them at the site.

At each caging site, we measured several variables related to habitat. We sampled the water near the bottom every 3 d and measured temperature and dissolved oxygen with a YSI meter and salinity with a hand-held refractometer. At the end of the experiments, we laid out a 30 m transect adjacent to each site. We then randomly generated 3 perpendicular transects and 3 points per transect, where we placed 1 m² quadrats and measured turbidity, depth, vegetation type (algae and vascular plants), and vegetation density. Substrate composition was estimated visually. To determine maximum flow rates at each caging site, we measured flows hourly with a Marsh-McBirney electronic flow meter over a spring tidal cycle.

Growth comparisons. Differences in fish growth among the 3 ponds and 2 habitats (vegetated and unvegetated) were assessed with 2-way analysis of variance using mean growth (mm d⁻¹) per cage as the tested variable. The effect of time was tested using experiment number as a blocking factor. A second analysis used temperature and initial fish length as covariates. To determine how closely growth rates inside the cages matched those outside, we compared our results for growth with the progression of standard lengths of juvenile winter flounder captured by RIDEM at fixed stations in Point Judith and Ninigret ponds. Their survey sampled 3 times a month from May to October with a 39.6 × 1.7 m, 6.4 mm stretched-mesh beach seine deployed from an outboard powered skiff. We estimated growth rates of free-ranging fish using linear regression on winter flounder lengths taken each 15 June to 31 July from 1994 to 1997. We chose this period to minimize effects of poor catches in May and early June and to correspond as closely as possible with the time our cages were in place.

Food. To assess prey availability, we took 3 core samples (5 cm diameter × 5 cm deep) inside and outside the cages at the end of the 3rd experiment. We used a 2-way multivariate analysis of variance to compare differences in food availability between vegetated and unvegetated habitats and inside and outside the cages. Variables used in the analysis were polychaetes, copepods, crustaceans, amphipods and other food organisms (these included cnidarians, worms, gastropods,

and bivalves), and total number of organisms and number of species. We also examined gut contents of all fish from the 3rd experiment. For the fish-stomach analysis, we added stomach fullness to the list of variables and dropped total number of organisms. We then used a 2-way multivariate analysis of variance to compare stomach contents for different ponds and for vegetated and unvegetated habitats. A univariate 2-way analysis of variance on food groups and ponds was used to see which food groups varied among ponds.

Isotopic analysis. We measured stable isotope ratios ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) in the fish at the end of each experiment and from a subsample of fish collected at the beginning of each experiment (Day 0 fish). Whole fish from each replicate treatment were pooled and then dried, ground, and acid-washed. The same isotopes were measured in sediments from the caging sites. Isotopic analysis was conducted using a Fisons VG Optima Isotope Ratio Mass Spectrometer equipped with a Carlo Erba Elemental Analyzer coupled to a VG Isotech Continuous Flow Interface. Samples were combusted to 1020°C in an elemental analyzer, and the resulting gases (CO₂ and N₂) were compared to secondary high-purity gas standards whose isotopic ratio was calibrated to international standards. Instrument accuracy and precision was insured with certified reference materials and laboratory secondary standards. Isotopic ratios were expressed in standard δ notation, as the per mil (part per thousand) difference between the sample and the reference ratios, as follows: $\delta[\text{C}^{13}$ and $\text{N}^{15}] = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$, where $R = \text{C}^{13}/\text{C}^{12}$ or $\text{N}^{15}/\text{N}^{14}$. Instrumental precision was $\pm 0.15\text{‰}$ for $\delta^{13}\text{C}$ and $\pm 0.20\text{‰}$ for $\delta^{15}\text{N}$. Differences in isotopic ratios from the various treatments were analyzed with a 2-way ANOVA using experiment number as a blocking factor. Because isotopic ratios of fish from vegetated and unvegetated sites were not statistically different, replicates from both treatments were pooled and an ANOVA performed for differences among ponds in Expts 1 and 2 and between fish at the beginning and end of the experiments.

RESULTS

Growth comparisons

Growth rates of *Pseudopleuronectes americanus* ranged from 0.06 to 0.76 mm d⁻¹. These differences were attributed to temperature and starting times of the experiments (Fig. 2). There was a significant difference in growth among experiments (Table 3C, Fig. 2). Average growth rates across ponds were highest (0.68 mm d⁻¹) for the 1st experiment, and lower but similar (0.24 mm d⁻¹) for the 2nd and 3rd experiments

(Table 2). Growth rates were highest in Ninigret Pond and Point Judith Pond (0.43 and 0.42 mm d⁻¹, respectively) and lowest in Green Hill (0.32 mm d⁻¹) (Table 3A). Pairwise-mean comparisons indicated that Green Hill Pond's low growth rate differed significantly from the other 2 ($p = 0.03$). Vegetation did not significantly affect growth rates of flounder (Table 3C, Fig. 2), nor was the vegetation-pond interaction significant (Table 3C), suggesting that the contrast between vegetated and unvegetated sites was not dependent on the ponds. Similarly, vegetation was not significant in the covariate analysis ($p = 0.78$ both for vegetation and the vegetation-pond interaction). In the covariate analysis, temperature and ponds were significant ($p = 0.0001$ and $p = 0.02$, respectively), and growth rates were lower in Green Hill Pond due to the effect of temperature ($p = 0.04$) (Fig. 2). Differences in fish length at the beginning of the experiments was not a significant factor ($p = 0.76$).

Estimates of growth rates of free-ranging winter flounder were somewhat lower than those measured from fish in experimental cages (Table 3B). Regressions for 1997 were significant and were 0.19 mm d⁻¹ for Point Judith and 0.21 for Ninigret (Table 3B). These growth rates are similar to those from the second 2 experiments, 0.24 mm d⁻¹, averaged over the 3 ponds (Table 2).

Food

There were no significant differences between prey availability densities in vegetated and unvegetated cages, inside and outside cages, or for the interaction between vegetation and inside and outside cages (Table 4B). Although there were no significant differences among treatments, cores taken inside the cages generally had a greater number of food items than those outside (Fig. 3).

Gut contents of fish differed significantly among ponds (Table 4C). However, there was no difference attributable to the presence or absence of vegetation, nor was the vegetation by pond interaction significant (Table 4C). Gut contents did not differ for fullness, number of species eaten, copepods, crustaceans, or the 'other' food category among ponds or between vegetated and unvegetated sites (all $p > 0.05$). On the other hand, the number of polychaetes and amphipods consumed varied by pond ($p = 0.03$ and 0.01, respectively); this was caused by the high proportions of amphipods and low proportions of polychaetes eaten in Ninigret. In all 3 ponds, the proportion of amphipods eaten was considerably greater than the proportion available, but in Ninigret it was 50 times greater (Fig. 4). Conversely, the proportion of polychaetes eaten was about half of those available, except in Ninigret where it was ~10%.

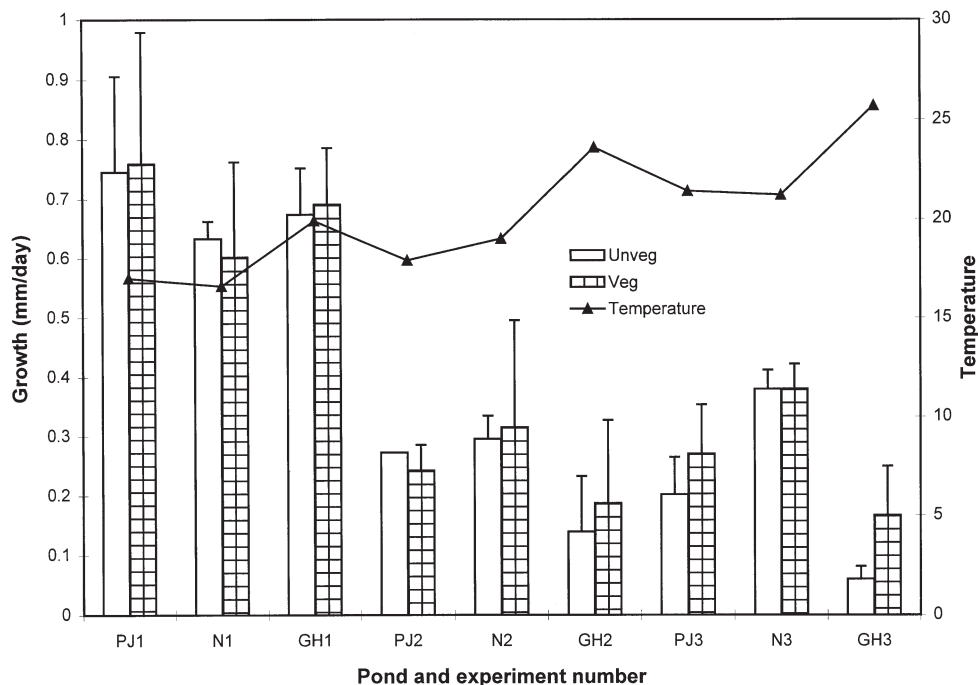


Fig. 2. *Pseudopleuronectes americanus*. Growth rates in vegetated and unvegetated habitats and average temperatures (°C) for each experiment at each site. Ponds and experiment number are denoted by letters and number; e.g., PJ1, N1, GH1 = Expt 1 in Point Judith, Ninigret, and Green Hill ponds, respectively. Error bars are 1 SD

Table 3. *Pseudopleuronectes americanus*. Mean growth rates from caging experiments (A) and from regression of standard lengths of juvenile winter flounder captured by Rhode Island Department of Environmental Management, Division of Fish and Wildlife (B). Numbers in parentheses are standard deviations. Significant regression results in **bold**. (C) Results of 2-way analysis of variance (ANOVA) on differences in growth among ponds and between vegetated and unvegetated sites using experiment number as blocking factor

(A) Caging experiment growth rates (mm d⁻¹)						
Vegetated?:	Point Judith		Ninigret		Green Hill	
	Yes	No	Yes	No	Yes	No
Expt 1	0.76 (0.22)	0.75 (0.16)	0.60 (0.16)	0.63 (0.03)	0.69 (0.09)	0.67 (0.08)
Expt 2	0.24 (0.04)	0.27 ^a	0.32 (0.18)	0.30 (0.04)	0.19 (0.14)	0.14 (0.09)
Expt 3	0.27 (0.08)	0.20 (0.06)	0.38 (0.04)	0.38 (0.03)	0.17 (0.08)	0.06 (0.02)
Mean	0.42	0.41	0.43	0.44	0.35	0.29

(B) Growth rates (b) from regression of field-captured winter flounder (mm d⁻¹), p = probability of a greater F value					
Year	Point Judith		Ninigret		Green Hill
	b	p	b	p	Not available
1994	0.22	0.43	0.28	0.003	
1995	0.22	0.54	0.14	0.27	
1996	0.11	0.63	0.37	0.07	
1997	0.19	0.04	0.21	0.02	
Average	0.19		0.21		

(C) ANOVA table using experiment number as blocking factor				
Source	df	MS	F	p
Vegetation	1	0.009	0.62	0.434
Pond	2	0.067	4.74	0.014
Vegetation × Pond	2	0.004	0.30	0.743
Expt no.	2	1.129	80.53	0.0001

^aBased on 1 replicate

None of the proportions of food types eaten by the fish were affected by presence of vegetation in the cages (all $p > 0.05$).

Isotopic analysis

$\delta^{13}\text{C}$ values differed significantly among experiments and ponds (Table 5B). $\delta^{15}\text{N}$ values differed significantly among ponds, but not among experiments (Table 5B). Mean $\delta^{13}\text{C}$ values in fish were similar for Ninigret and Green Hill, both of which were higher than those from Point Judith Pond ($p < 0.05$) (Table 5A). The values of $\delta^{15}\text{N}$ differed from pond to pond ($p < 0.05$), typically being highest in Point Judith and lowest in Ninigret (Table 5A, Fig. 5). In the 1st experiment only, the values of $\delta^{15}\text{N}$ for fish at Day 0 differed significantly from values at the end of the experiment ($p = 0.0001$). For the 1st and 2nd experiments in Point Judith Pond, values of $\delta^{13}\text{C}$ in fish at Day 0 differed from values at the end of the experiment ($p = 0.001$ and 0.002 , respectively). Isotopic values of the sediment were always more negative (depleted) than those of the caged fish (Table 5A).

DISCUSSION

Our finding that growth rates of *Pseudopleuronectes americanus* were unaffected by vegetation in the cages agreed with previous caging studies (Sogard 1992, Heck et al. 1997, Phelan et al. 2000). For example, although Sogard (1992) collected meiofauna directly from blades of eelgrass and *Ulva* sp. fronds and found more potential prey than over sediment, winter flounder grew just as fast in unvegetated sites. Although we did not sample vegetation for food, prey were probably more abundant in vegetated cages, especially the favored amphipod *Microdeutopus gryllotalpa*, which is often associated with vegetation (Bousfield 1973). Our results are corroborated by field data which indicate that juvenile winter flounder are captured more often in unvegetated areas with substrates of sand and silt (Buckley 1989, Meng & Powell 1999) or mud and shell hash (Howell et al. 1999).

Vegetated sites may protect juvenile fish from predation (Orth et al. 1984, Gotceitas & Colgan 1989, Gotceitas et al. 1997). In field surveys and subsequent laboratory studies, Gotceitas et al. found that juvenile cod *Gadus morhua* moved into eelgrass beds in the pres-

Table 4. *Pseudopleuronectes americanus*. (A) Benthic organisms found in 5 cm core samples and stomach contents of winter flounder. Core samples (taken inside and outside cages) and stomach contents were assessed after 3rd experiment. Numbers are averages per cage for benthic samples and averages per fish for stomach samples, with standard deviations in parentheses. Multivariate analysis of variance (MANOVA) tables for (B) benthic organisms in cores and (C) food items in winter flounder stomachs

(A) Benthic organisms in cores and food items in stomachs				
	Point Judith	Ninigret	Green Hill	
Benthic organisms in 5 cm core samples				
Polychaetes	81 (79)	99 (52)	61 (26)	
Copepods	40 (38)	213 (160)	35 (22)	
Crustaceans	1 (1)	1 (1)	6 (6)	
Amphipods	1 (1)	6 (7)	10 (14)	
Other	50 (38)	27 (13)	69 (47)	
Total	174 (137)	346 (148)	180 (85)	
No. of species	17 (7)	23 (3)	25 (4)	
Food items in winter flounder stomachs				
Stomach fullness	63 (33)	80 (25)	58 (25)	
Polychaetes	1.8 (1.5)	0.4 (0.7)	1.3 (1.5)	
Copepods	1.8 (2.5)	0.1 (0.4)	0.7 (1.9)	
Crustaceans	1.2 (1.7)	1.0 (2.2)	0.3 (0.9)	
Amphipods	0.4 (0.7)	9.9 (9.5)	3.7 (4.2)	
Other	1.3 (2.4)	0.2 (0.7)	0.6 (0.6)	
No. of species	3.4 (2.2)	2.0 (1.0)	3.3 (1.6)	
(B) MANOVA table for benthic organisms in cores				
Source	df	Wilks' lambda	F	p
Vegetation	6	0.013	12.78	0.21
In/out	6	0.007	23.26	0.16
Vegetation × In/out	6	0.034	4.81	0.34
(C) MANOVA table for stomach contents				
Vegetation	7	0.245	2.64	0.13
Pond	14	0.042	3.32	0.02
Vegetation × Pond	14	0.271	0.79	0.67

ence of a predator. In Sogard's study (1992), naked goby were most abundant in eelgrass beds, which supported the lowest growth rates. Presumably, naked gobies traded off foraging quality for increased protection from predation. In our study, we found it extremely difficult to capture winter flounder juveniles with dip nets in the vegetated cages. When chased by a dip net, winter flounder swam vertically into the eelgrass blades and hid at the base of the plant. This was an effective escape from a human dip-netter, but perhaps not as effective from fish predators, as the winter flounder's more typical escape response is to bury themselves in the sediment. Winter flounder may also have experienced poorer foraging rates in the more complex vegetated habitats, which offset the greater food resources. It is possible, however, that juvenile winter flounder, like cod, use unvegetated margins near eelgrass beds and move into beds in the presence of a predator.

Growth rates appeared to be negatively influenced by high temperatures or some factor related to temperature in our study. Growth was lowest in Green Hill in the 3rd experiment, when temperatures exceeded 25°C. Green Hill differed from the other ponds in size, flushing rate, and salinity, but it is likely that the high temperatures affected growth. Winter flounder are adapted to spawn in early spring in temperatures ranging from 1 to 10°C, with the optimum occurring at 3 to 4°C (Martin & Drewry 1978). For juveniles, temperatures between 20 and 29°C produce sublethal effects such as inhibition of feeding (Casterlin & Reynolds 1982). Avoidance responses start at or below 27°C (Casterlin & Reynolds 1982). Phelan et al. (2000) also found that growth rates decreased with time, but they attributed it to significant differences in the initial sizes of the fish, with smaller winter flounder growing faster than larger ones. In all 3 of our experiments, however, fish were initially the same size, and effects of time or

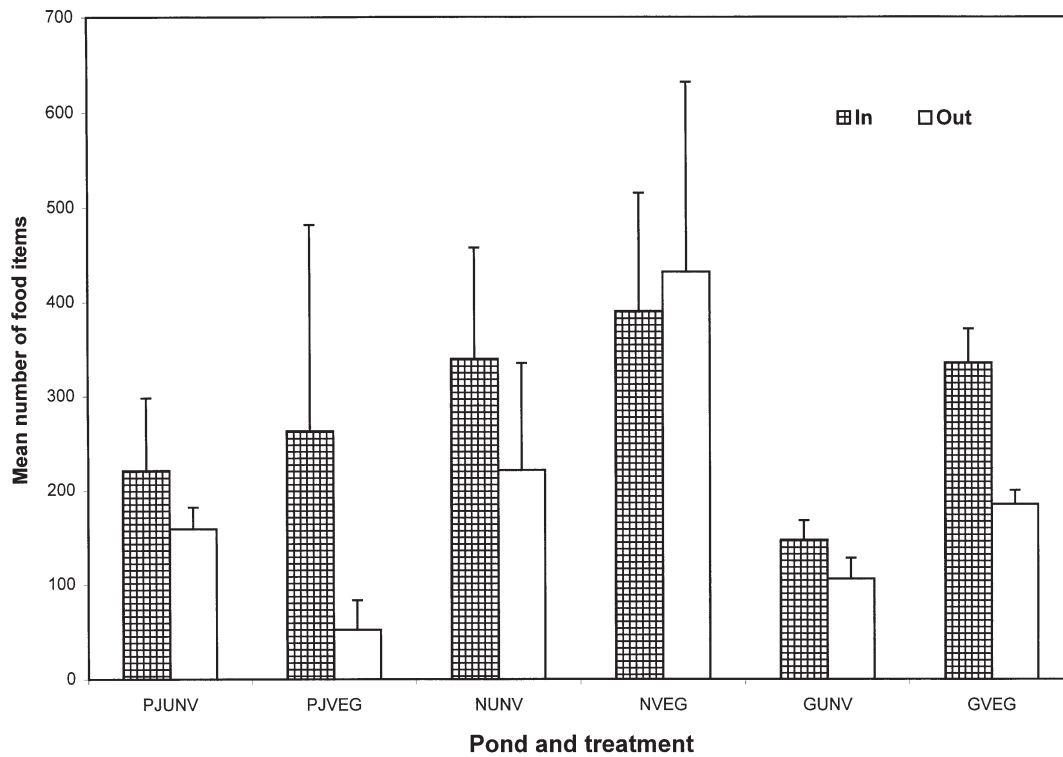


Fig. 3. Number of benthic food items inside and outside experimental cages collected in 5 cm core samples. PJVEG = Point Judith vegetated, PJUNV = Point Judith unvegetated, NVEG = Ninigret vegetated, NUNV = Ninigret unvegetated, GHVEG = Green Hill vegetated, GHUNV = Green Hill unvegetated. Error bars are +1 SD

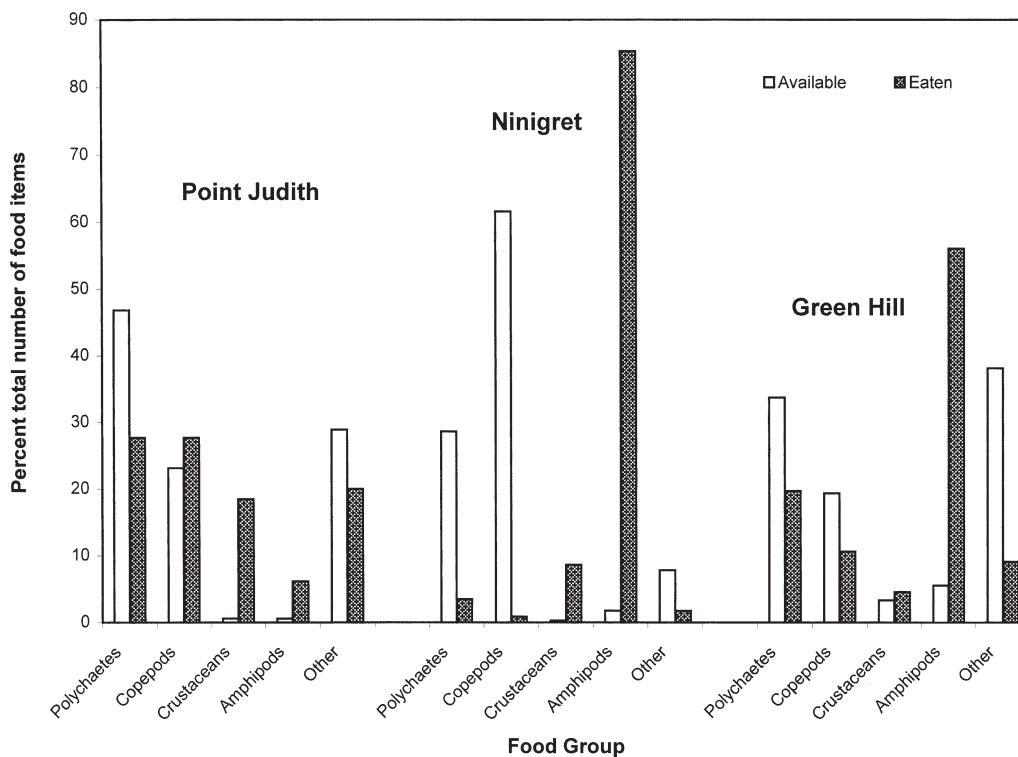


Fig. 4. Food groups available compared to groups eaten by *Pseudopleuronectes americanus* in experimental cages. Data are percent total number of food items in stomach or core sample

Table 5. *Pseudopleuronectes americanus*. (A) Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (‰) \pm SD for caged fish, a subsample of fish collected before each experiment (Day 0) fish, and sediments from caging sites. Day 0 fish were captured in Ninigret Pond. Numbers in parentheses are sample sizes. (B) Results of 2-way analysis of variance (ANOVA) on differences in $\delta^{13}\text{C}/\delta^{15}\text{N}$ in fish tissue among ponds and between vegetated and unvegetated sites, using experiment number as blocking factor

(A) Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$									
	Day 0 fish		Point Judith		Ninigret		Green Hill		
	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	
Expt 1 fish	-11.10 ± 0.64 (3)	9.23 ± 0.32 (3)	-13.29 ± 0.99 (6)	11.28 ± 0.26 (6)	-11.72 ± 0.92 (6)	10.57 ± 0.62 (6)	-11.23 ± 0.75 (6)	10.95 ± 0.58 (6)	
Expt 2 fish	-11.22 ± 0.37 (3)	9.98 ± 0.47 (3)	-12.91 ± 0.56 (3)	11.28 ± 0.26 (3)	-11.97 ± 0.47 (6)	10.36 ± 0.55 (6)	-11.41 ± 0.36 (6)	10.80 ± 0.61 (6)	
Expt 3 fish	-13.23 (1)	10.54 (1)	-13.65 ± 0.83 (6)	11.41 ± 0.39 (6)	-12.69 ± 0.57 (6)	10.66 ± 0.23 (6)	-12.90 ± 1.07 (6)	10.83 ± 0.26 (6)	
Sediment			-18.75 ± 0.81 (6)	5.66 ± 0.77 (6)	-20.06 ± 1.45 (6)	4.25 ± 1.00 (6)	-19.14 ± 1.5 (6)	3.57 ± 0.97 (6)	

(B) ANOVA table using experiment as blocking factor ($\delta^{13}\text{C}/\delta^{15}\text{N}$)				
Source	df	MS	F	p
Vegetation	1	0.91/0.24	1.46/1.43	0.23/0.24
Pond	2	8.43/1.88	13.50/11.24	0.0001/0.0002
Vegetation \times Pond	2	0.20/0.18	0.31/1.07	0.73/0.35
Expt	2	4.11/0.17	6.58/1.01	0.004/0.37

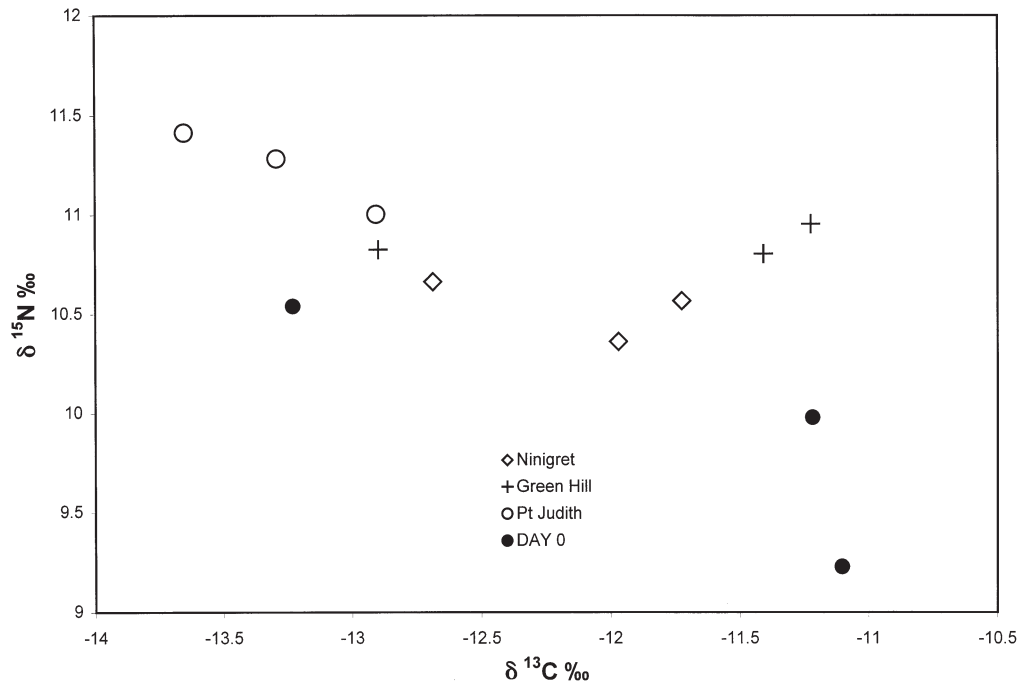


Fig. 5. Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope values (‰) in winter flounder collected at end of experiments and in subsample of fish collected at beginning of experiments (Day 0)

experiment number were significant. Unfortunately, because temperature increased with experiment number, it was difficult to determine whether time or temperature decreased growth rates.

Other factors related to temperature or experiment length may have affected growth rates. Benthic communities which supplied food for the fish may have changed in species composition and nutrient value

with increasing temperature and time. It is also likely that metabolic rates increased with temperature, which would increase the fish's demand for food. Results from our core samples, taken inside and outside the cages, and fish stomach fullness, however, indicated that food was not limiting in the experiments. Because food was not limiting, it is unlikely that differences in duration of experiments affected growth rates. If food had been limiting, growth rates should have been lower in the 1st experiment, which ran for 15 d versus the 2nd and 3rd experiments, which ran for 11 and 10 d, respectively. The opposite trend was observed, however: growth was twice as high in the 1st experiment than in subsequent runs.

We originally predicted that growth rates would be lowest in Green Hill and higher in Point Judith and Ninigret. We predicted lower growth in Green Hill because of its high housing density, high nutrient concentrations (Lee & Olsen 1985), and poor flushing rates. Calculated nitrogen loadings and corresponding dissolved inorganic nitrogen concentrations in Green Hill were almost twice as high at Ninigret and 3 times as high as Point Judith. Our analysis, however, indicated that lower growth rates were correlated with higher temperatures. Growth rates were comparable in Point Judith and Ninigret ponds. Although Point Judith has the most development in the watershed of the 3 ponds and the greatest diversity of types of human impact—from boating to industry—apparently, its larger size and greater flushing rate compensate for many of these effects. Increased nitrogen concentrations can decrease dissolved oxygen through detrital breakdown from increased plant growth. We did not see any evidence of low dissolved oxygen in our study, but cages were set in shallow, windy locations which are highly oxygenated. However, changes in sediment characteristics and food webs due to high nutrient concentrations may have been another factor affecting fish growth in Green Hill.

Mean growth rates in the cages (0.29 to 0.44 mm d⁻¹) were comparable to those in the Mystic River estuary (0.28 to 0.35 mm d⁻¹) (Pearcy 1962), but slightly higher than those derived from free-ranging fish for Point Judith (0.19 mm d⁻¹) and for Ninigret (0.21 mm d⁻¹). Growth rates from the cages cover a smaller window of time from 4 June to 7 July 1997 versus 15 June to 31 July from 1994 to 1997 for the field data. Some of the variability is due to differences in growth rates among years, but measuring growth over a shorter period of time within years probably had an effect. In 3 caging studies (Sogard 1992, Phelan et al. 2000, this study), winter flounder grew fastest during the first experiments, suggesting that growth rates are highest early in the season. Alternatively, fish may have grown faster in the cages, where they expended less energy

avoiding predators and searching for food. Although there was no statistical difference in benthic food inside and outside the cages, food concentrations were slightly higher inside the cages (Fig. 3). This pattern could be due to fewer predators inside the cages to consume the food, or to the cages themselves providing habitat and substrate for more invertebrates.

Benthic food availability and fish stomach contents were the same at vegetated and unvegetated sites, but stomach contents differed among ponds. Fish in Ninigret ate 50 times more amphipods than those available in the cores, and a disproportionately small number of polychaetes. Most of the amphipods consumed were *Microdeutopus gryllotalpa*, and this result corroborates Worobec's (1982) report on winter flounder food habits in Ninigret pond. In Point Judith and Green Hill, *M. gryllotalpa* was not as abundant, and the amphipod component was made up of several species. Although the highest number of species was available in Ninigret and Green Hill, the lowest number of species was eaten in Ninigret, reflecting strong selection for *M. gryllotalpa*. Previous studies have found winter flounder to be opportunistic generalists, feeding on a variety of amphipods, polychaetes and crustaceans in proportion to those available in disturbed and undisturbed habitats (Carlson et al. 1997). Apparently *M. gryllotalpa* is a preferred food, but winter flounder were able to feed well and fill their stomachs on a variety of other prey.

We hypothesized that fish grown in ponds with greater nitrogen loadings and development would have higher $\delta^{15}\text{N}$ ratios. Although dissolved inorganic nitrogen concentrations (mostly from household sewage) were 2 to 3 times higher in Green Hill than in the other ponds, we did not see a corresponding shift in $\delta^{15}\text{N}$ ratios. McClelland et al. (1997) found a 2 to 4% increase in $\delta^{15}\text{N}$ of producers and consumers taken from an estuary with 61% wastewater compared to one with 16% in Cape Cod, Massachusetts. Similarly, Yelenik et al. (1996) found a linear increase in $\delta^{15}\text{N}$ in particulate organic matter and ribbed mussels *Geukensia demissa* across 3 estuaries receiving low, medium and high nitrogen loads. In our study, fish from Green Hill had intermediate $\delta^{15}\text{N}$ values and the $\delta^{15}\text{N}$ of Green Hill sediment was the lowest of the 3 ponds. The lower than expected $\delta^{15}\text{N}$ in Green Hill fish and sediment may have been due to greater bioturbation by benthic organisms such as burrowing sea cucumbers, which process sediment and may lower nitrogen concentrations. The highest $\delta^{15}\text{N}$ values were found in fish and sediment from Point Judith, the pond with the greatest amount of human development.

Stable isotopes can also be used to estimate the number of levels in a food chain, with each $\delta^{15}\text{N}$ increment of ~3‰ representing one trophic level (e.g., Fry 1988,

Hobson & Welch 1995, Wainwright et al. 1993, Keough et al. 1996, Vander Zanden et al. 1997). In our study, fish $\delta^{15}\text{N}$ values averaged over the 3 experiments were 11.32, 10.53, and 10.86‰, or ~2 trophic levels above the sediment for Point Judith, Ninigret and Green Hill ponds, respectively. These values agree with the gut-content analysis, which indicated the fish were eating benthic organisms, mostly polychaetes, harpacticoid copepods and amphipods that feed on sediment. These values are comparable to published values for the common mummichog *Fundulus heteroclitus* and striped killifish *F. majalis* (9.2 to 10.6‰) (Currin et al. 1995), which feed at approximately the same position in the food chain (Bigelow & Schroeder 1953). Significant changes in $\delta^{15}\text{N}$ between Day 0 and experimental fish, reflecting growth and turnover of tissue, were observed only during Expt 1, apparently because only then were growth rates sufficiently high.

$\delta^{13}\text{C}$ values were typical of estuarine variation and reflected sources of organic carbon derived primarily from benthic algae (Haines & Montague 1979, Fry & Sherr 1984, Stephenson et al. 1986, Currin et al. 1995). Values of $\delta^{13}\text{C}$ in the fish (-11.23 to -13.65) agreed with values from Georges Bank fish (Wainwright et al. 1993) and common mummichog captured in Massachusetts, but were slightly more positive than $\delta^{13}\text{C}$ values of common mummichog and striped killifish collected from North Carolina and Mississippi marshes (Currin et al. 1995). The increase of $\delta^{13}\text{C}$ from the sediments ranged from 5.47 to 7.93‰ and was comparable to $\delta^{13}\text{C}$ enrichments seen in other marine food webs (Fry & Sherr 1984). However, the carbon signature of the sediments did not follow the carbon signature of the fish. Point Judith sediment had the greatest $\delta^{13}\text{C}$ value of the ponds, whereas fish from Point Judith had the lowest $\delta^{13}\text{C}$ values. This contradictory result may be explained by food habits of benthic organisms on which the fish were feeding. Fish in Point Judith ate a disproportionate number of food items with predatory or suspension-feeding habits. This could have affected the $\delta^{13}\text{C}$ value in the fish tissue, causing it to be lower than expected.

Fish caging studies can be a useful tool for assessing habitat quality, with some caveats. A 2 yr caging study in 3 Northeastern estuaries in eelgrass, macroalgae, unvegetated, and marsh creek habitats found no difference in winter flounder growth in vegetated and unvegetated habitats, but there was a difference among estuaries and an estuary-habitat interaction (Phelan et al. 2000). Phelan et al. found that growth rates varied between years and among estuaries, and stressed the importance of estuary-habitat interaction. In 1994, winter flounder grew fastest in Great Bay-Little Egg Harbor, New Jersey. In 1995, they grew fastest in the Hudson-Raritan, New Jersey system.

These results suggest that simply comparing habitat types can be valuable, but the value of a habitat may change with time and location. Many factors, such as time of spawning, settlement, and food densities, must converge to produce optimum growth rates (Rose et al. 1996). Year-to-year variations in oceanic currents and climate may change conditions of individual estuaries and may interact with habitats in an estuary and thus cause variation in growth.

Other studies have found indications that different species of fish prefer different habitats. Sogard (1992) found that winter flounder grew more quickly in unvegetated cages and tautog grew more quickly in vegetated cages. Her experimental data were corroborated by field data which found each species to be most abundant in the habitat where it grew fastest. A clear trade-off between habitat selection and foraging quality was found for naked goby, which were most abundant inside eelgrass beds where slowest growth occurred. Able et al. (1999) found that winter flounder and tautog grew more slowly in cages placed under man-made structures in the Hudson-Raritan estuary (New York City). Guindon & Miller (1995) compared growth of caged southern flounder *Paralichthys lethostigma* in marsh creek sites known to have high or low densities of that species. They found growth rates to be higher in sites where southern flounder appeared to be absent, suggesting that fish usage of a particular site may be dictated by factors other than optimizing growth rate. Because southern flounder spawn offshore, larval transport may explain part of the discrepancy. Other studies (e.g., Sogard 1992, Gotceitas et al. 1997) suggest some fishes may tradeoff optimal growth for protection from predation.

Data from fish caging studies can provide insight on habitat quality when used with some caution. Our study and others (Sogard 1992, Able et al. 1999, Phelan et al. 2000) indicate that growth rates and caging studies can be useful for comparing habitat quality of vegetated and unvegetated sites within estuaries. These studies highlight the importance of traditionally undervalued habitats such as unvegetated shallows to fish. Our study also underlined how complex it is to predict how human effects such as eutrophication will affect fish habitat. In our study, growth rates varied as expected along an anthropogenic gradient, but high temperatures were also a likely cause. Future studies comparing growth along an anthropogenic gradient should be careful to control for environmental parameters such as temperature, and use caution when interpreting results.

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