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Abstract—Fish species of warm-water origin appear in northeastern U.S. coastal waters in the late summer and remain until late fall when the temperate waters cool. The annual abundance and species composition of warm-water species is highly variable from year to year, and these variables may have effects on the trophic dynamics of this region. To understand this variability, records of warm-water fish occurrence were examined in two neighboring temperate areas, Narragansett Bay and Long Island Sound. The most abundant fish species were the same in both areas, and regional abundances peaked in both areas in the middle of September, four weeks after the maximum temperature in the middle of August. On average, abundance of warm-water species increased throughout the years sampled, although this increase can not be said to be exclusively related to temperature. Weekly mean temperatures between the two locations were highly correlated (r=0.99; P<0.001). The warm-water fish faunas were distinctly different in annual abundances in the two areas for each species by year (1987–2000), and these differences reflect the variability in the transport processes to temperate estuaries. The results reveal information on the abundance of warm-water fish in relation to trends toward warmer waters in these regions.

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Temperate estuaries are subject to broad temperature variations related to seasonal warming and cooling. Resident fish species are able to survive these ranges in temperature, but these variations in temperature also create the conditions for seasonal habitat for boreal and subtropical fish species. These cold and warm-water species contribute significantly to the overall species diversity of temperate estuaries worldwide (Lenanton and Potter, 1987; Hutchins, 1991) and play a significant role in the trophic interactions in the ecosystem even though they are not present year round (Able and Fahay, 1998).

Temperature and faunal variations are well documented in temperate estuaries bordering the northeastern U.S. continental shelf ecosystem (Rountree and Able, 1992; Tremain and Adams, 1995), which extends from Cape Hatteras, North Carolina, to Nova Scotia, Canada (Fig. 1). Cape Hatteras is generally the northern barrier for warm-temperate fauna, but highly mobile species are able to move northward during warm seasons (Bigelow and Schroeder, 1953; Briggs, 1974). There are many estuaries stretching from Cape Hatteras to Nova Scotia, and estuarine fish assemblages have been well described in more southern estuaries, such as Chesapeake Bay (Murdy et al., 1997), Little Egg Inlet, New Jersey (Able and Fahay, 1998), and Sandy Hook, New Jersey (Grant, 1991). However, there is little information available regarding the abundance of warm-water fishes in estuaries farther north in the estuarine waters of Narragansett Bay (Narragansett Bay and several large salt ponds along the Atlantic coast of Rhode Island are hereafter referred to simply as Narragansett Bay) and Long Island Sound.

The goal of this study was to describe the warm-water fish fauna in the areas of the northeast U.S. continental shelf ecosystem represented by Narragansett Bay and Long Island Sound. We compiled a list of the warm-water fish species found in Narragansett Bay and Long Island Sound, calculated species richness, and compared species abundances between the two estuaries. Collected data were then used to address whether there had there been an increase in the occurrence of warm-water fishes over time in response to warming of the coastal waters (Oviatt et al., 2002; Collie et al., 2008), and to determine whether similar oceanic processes are dominant in structuring the species composition in these two areas by examining the similarity in abundances of warm-water faunal assemblages.

Methods and materials

Data sources

Fish abundances were obtained from numerous long-term sampling programs in Narragansett Bay and Long Island Sound (Table 1). Concomitant environmental data were obtained when available, including surface temperature, bottom temperature, and salinity. Average water temperature (mean of surface and bottom temperature) was calculated for each week of the year.

Warm-water fishes (also called Carolinian, tropical, subtropical, transient, exotic species, in other literature) were identified by means of several regional ichthyofaunal guides (Smith, 1899; Bigelow and Schroeder, 1953). Important identifying characteristics included a significant portion of the life cycle, and usually the time and area of spawning (south of Cape Hatteras and only in late summer and fall months). It should be noted that northern puffer *(Sphoeroides maculatus)* were included because of the timing of their occurrence and their southerly distribution (Able and Fahay, 1998). In addition, the warm-water fishes that are caught in Narragansett Bay and Long Island Sound are generally found as juveniles.

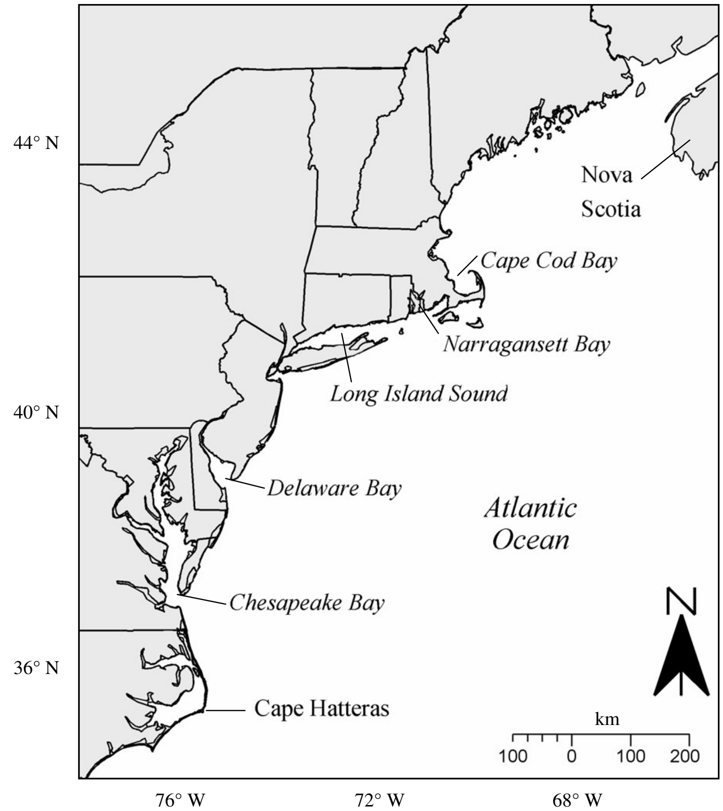

Figure 1

Map of Northwest Atlantic region between Cape Hatteras and Nova Scotia. Note the location of Narragansett Bay and Long Island Sound, which represent the sample sites for this study.

Data analysis

Timing, location, and frequency of sampling were different among the surveys considered here. Only the years in which sampling took place in all locations and during which consistent sampling methods were formed the data for the study. Sampling effort was not calculated for the different surveys but was consistent through each individual time series; therefore the accumulated data set represents internally consistent relative measures of the abundance of warm-water fishes. For area-specific analyses, data from 1987–2001 were included from surveys in Narragansett Bay, and data from 1984–2000 were included from surveys in Long Island Sound. For comparison between estuaries, only the data from overlapping years were used (1987–2000).

Describing and comparing warm-water fish fauna

Lists of warm-water species were generated for each area by using the sum of the species abundances during the different surveys. A rank correlation was calculated between total abundance of warm-water fish and year to evaluate whether species have increased in abundance through time. Correlations were then calculated between annual fish abundances in Narragansett Bay and Long Island Sound for all years, excluding 1994, during which extremely large catches of Atlantic moonfish (*Selene setapinnis*) were found in Narragansett Bay (59% of total Atlantic moonfish catch, 80% of 1994 catch, 29% of overall Narragansett Bay fish catch). Correlations were also calculated for the five most abundant individual species (representing 85% of the total catch): Atlantic moonfish, northern puffer, crevalle jack (*Caranx hippos*), planehead filefish (*Stephanolepis hispidus*), and bigeye (*Priacanthus arenatus*).

The observed species richness (S), or the number of different species present, was derived for both locations. Next, a jackknife estimation of species richness was conducted for both the Narragansett Bay and Long Island Sound data sets to estimate the number of species that were present but not sampled, following the method described by Krebs (1999). This estimation was made because, although the list of warm-water species was based on a large number of trawls and seine hauls, there are numerous species of warm-water fishes that have been observed by SCUBA divers and aquarists

Table 1

Description of data used from Narragansett Bay and Long Island Sound for this study, including the location of sampling site (RI=Rhode Island data from Narragansett Bay and the surrounding salt ponds, LIS=Long Island Sound), number of stations sampled, years when sampling occurred, sampling frequency, gear type used for sampling, and the source for the data.

Site	Number of stations sampled	Years	Sampling frequency	Gear type	Source
RI	2	1959 to present	Year round weekly	Trawl 10.4-m headrope 5.1 cm codend (*sic*) 30 min at 2 knots	University of Rhode Island Graduate School of Oceanography
	37	1987 to present	Year round monthly	Trawl 12.2-m headrope 0.95 cm codend (*sic*) 20 min at 2.5 knots	Rhode Island Department of Environmental Management
	5	1987 to present	April–November monthly	Seine 61-m net 6.4-mm mesh	
LIS	Random (about 80)	1984 to present	Fall	Trawl 9.1-m headrope 5.1 cm codend (*sic*) 30 min at 3.5 knots	Connecticut Department of Environmental Protection
	7	1984 to present	September	Seine 7.6-m net 6.4-mm mesh	
	6	1976 to present	Bi-weekly	Trawl 9.1 m headrope 6.4 mm codend liner (*sic*) 20 mins at 1.2–1.4 knots	Milford Laboratories
	5	1969 to present	May-November	Seine 9.14 m net 6.4-mm mesh	

that are not present in the databases represented in this study. In the jackknife estimation, the number of species present (S_i) was calculated with each of the years (i) removed in turn. The jackknife estimate was calculated by averaging together pseudovalues (Y_i), which represent the likely number of species for each year, by using the equation

$$Y_i = nS - (n-1)S_i,$$

where n = the number of years.

The jackknife mean and variance were calculated from the resulting pseudovalues (Y_i). The jackknife estimate was determined to obtain more likely values of species richness for each area. These estimates were compared between estuaries with a two-sample t-test (Johnson and Bhattacharyya, 2001) to determine if there was a significant difference in species richness. In addition, species accumulation curves were calculated for both populations and graphed together to assess whether the curves were similar for the two estuaries for the years 1987–2000.

A multidimensional scaling (MDS) analysis was conducted in the statistical analysis program PRIMER (PRIMER-E Ltd., Ivy Bridge, U.K.) to determine whether species composition of the annual abundances differed between Narragansett Bay and Long Island Sound. A Bray-Curtis measure of similarity was used for developing the similarity matrix (Krebs, 1999). Data were standardized, and a fourth root transformation was applied to the data to give less weight to abundant species. An MDS plot was computed for all of the years by species abundances in each location. A similarity percentage (SIMPER) analysis (in PRIMER) was then conducted to determine which of the species were driving the similarity and dissimilarity between the areas.

Timing of occurrence of warm-water fishes

Five aspects of the timing of the warm-water fauna were examined. First, the relationship between temperatures in the two estuaries was examined. Correlations were calculated between weekly mean temperatures in Narragansett Bay and Long Island Sound. Correlations were also calculated between the means of summer temperatures (June, July, and August combined) and semi-annual temperatures (May, June, July, August, September, and October combined) because the warmest months are when these fishes are found.

Second, the relationship between the annual abundance of warm water fishes and water temperature was examined in both estuaries. Correlations were calculated between the mean annual, mean semi-annual, and mean summer temperatures and fish abundances by estuary.

Third, the weekly occurrence of the warm-water fishes was compared between estuaries. Catch abundances and means were derived for each week. Next, for each year, first appearance (at least 5% of the peak abundance), peak appearance, and last appearance were identified and a mean and standard deviation were calculated for each estuary. Correlations then were calculated for these measures of timing between estuaries. The weeks of first, peak, and last appearance were compared between estuaries by using a two-sample t-test and assuming equal variances (Johnson and Bhattacharyya, 2001).

Fourth, the weeks of first appearance, peak appearance, and last appearance were compared with estuarine temperatures. For each estuary, mean temperatures were derived at certain times of year. The weeks of first appearance were regressed upon temperatures for June 1 of each year, peak appearance weeks were regressed upon peak annual temperatures, and last appearance were regressed upon October 1 temperatures. June 1[s]and October 1 were used because these are the dates between which the waters of Narragansett Bay and Long Island Sound are typically warm enough to sustain warm-water fishes.

Finally, the timing of northern puffer occurrence was examined in detail. This species was chosen for this analysis because of its abundance in both areas and because data were consistent enough to determine the peak week at which the species was captured. A correlation was calculated between weeks of peak appearance of the northern puffer in the two locations. In addition, correlations were calculated between the peak week of fish occurrence and temperature, as well as between the peak week of fish occurrence and the peak week for the 50% cumulative temperature for each year (calculated as the median temperature for the cumulative daily temperature degrees, termed “degree days”).

Results

Comparison of warm-water fish fauna

The total number of warm-water fish sampled in Narragansett Bay (1987–2001) was 4683, and the total warm-water fish sampled in Long Island Sound (1984–2000) was 7075, for a total of 11,758 individuals. The most frequently occurring species was Atlantic moonfish (66.3%), followed by crevalle jack (9.6%), and northern puffer (8.1%) (Table 2).

The number of warm-water fishes has increased in more recent years of the survey. Most warm-water fish were caught in 1994, 2000, and 1998, whereas the fewest warm-water fish were caught in 1987, 1991, 1992, 1993, and 1995 (Fig. 2). A rank correlation between catch abundance and year indicated that the abundance of warm-water fish has increased (r=0.73; P=0.003).

The abundance of warm-water fish was correlated between Narragansett Bay and Long Island Sound. A correlation in abundance between areas that included data from all years was not significant (r=0.17, P=0.56), but when 1994 was excluded, a significant correlation was found (r=0.83, P=0.001). The annual abundances of the dominant species were also correlated between Narragansett Bay and Long Island Sound: Atlantic moonfish (omitting 1994) (r= 0.81, P=0.001), northern puffer (r=0.63, P=0.02), and planehead filefish (r=0.56, P=0.04). There was no significant correlation between the number of bigeye or crevalle jack caught in Narragansett Bay and Long Island Sound.

The observed species richness of warm-water fishes in Narragansett Bay and Long Island Sound were 26 and 28 species, and the resulting jackknife estimates of species richness were 33.9 and 39.2 species. Species richness did not differ significantly between estuaries (t=2.5, df=31, P>0.05). The species accumulation curves are similar in slope, although the curve for Long Island Sound is steeper and species

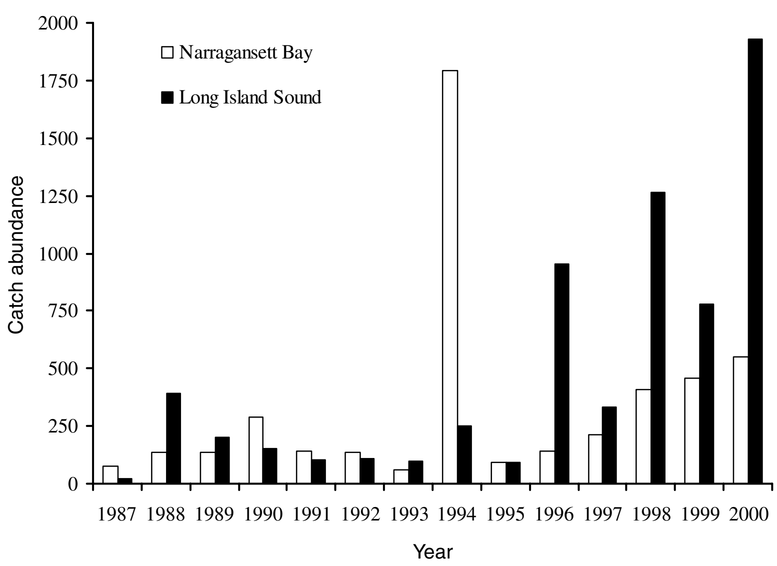

Figure 2

Sum of warm-water fish caught in trawl and seine surveys in Narragansett Bay and in Long Island Sound for the years 1987–2000.

Table 2

Warm-water fish species caught in regular monitoring surveys in Narragansett Bay and Long Island Sound waters (1987–2000). The number of each species caught in Narragansett Bay (NB) and Long Island Sound (LIS), total number caught, and percent of overall catch represented by each species are presented.

	Common name	Scientific name	Number caught in NB	Number caught in LIS	Total number caught	% of overall catch
1	Northern puffer	*Sphoeroides maculatus*	537	417	954	8.11
2	Crevalle jack	*Caranx hippos*	1059	64	1123	9.55
3	Atlantic moonfish	*Selene setapinnis*	2155	5639	7794	66.29
4	Planehead filefish	*Stephanolepis hispidus*	28	169	197	1.68
5	Bigeye	*Priacanthus arenatus*	71	55	126	1.07
6	Northern sennet	*Sphyraena borealis*	16	21	37	0.31
7	Flying gurnard	*Dactylopterus volitans*	9	38	47	0.40
8	Blue runner	*Caranx crysos*	109	2	111	0.94
9	Lookdown	*Selene vomer*	27	27	54	0.46
10	Bigeye scad	*Selar crumenophthalmus*	4	110	114	0.97
11	Bluespotted cornetfish	*Fistularia tabacaria*	15	92	107	0.91
12	Striped mullet	*Mugil cephalus*	8	133	141	1.20
13	Orange filefish	*Aluterus schoepfi*	2	30	32	0.27
14	Short bigeye	*Pristigenys alta*	2	21	23	0.20
15	Spot	*Leiostomus xanthurus*	29	0	29	0.25
16	Glasseye snapper	*Heteropriacanthus cruentatus*	2	19	21	0.18
17	Inshore lizardfish	*Synodus foetens*	0	19	19	0.16
18	White mullet	*Mugil curema*	0	112	112	0.95
19	Rough scad	*Trachurus lathami*	261	0	261	2.22
20	Gray triggerfish	*Balistes capriscus*	5	4	9	0.08
21	Sheepshead	*Archosargus probatocephalus*	332	0	332	2.82
22	Permit	*Trachinotus falcatus*	0	33	33	0.28
23	Red goatfish	*Mullus auratus*	0	17	17	0.14
24	Trunkfish spp.	*Lactophrys* spp.	0	12	12	0.10
25	Spotfin butterflyfish	*Chaetodon ocellatus*	0	8	8	0.07
26	Schoolmaster	*Lutjanus apodus*	0	7	7	0.06
27	Rough scad	*Trachurus lathami*	0	5	5	0.04
28	Sargassum fish	*Histrio histrio*	2	0	2	0.02
29	Spotted goatfish	*Pseudupeneus maculatus*	2	0	2	0.02
30	Cero	*Scomberomorus regalis*	2	0	2	0.02
31	Mahogany snapper	*Lutjanus mahogoni*	3	0	3	0.03
32	Atlantic needlefish	*Strongylura marina*	0	4	4	0.03
33	Pinfish	*Lagodon rhomboides*	0	4	4	0.03
34	Round scad	*Decapterus punctatus*	0	3	3	0.03
35	Mackerel scad	*Decapterus macarellus*	0	2	2	0.02
36	Filefish spp.		0	2	2	0.02
37	Striped burrfish	*Chilomycterus schoepfii*	0	2	2	0.02
38	French grunt	*Haemulon flavolineatum*	1	0	1	0.01
39	Guaguanche	*Sphyraena guachancho*	1	0	1	0.01
40	King mackerel	*Scomberomorus cavalla*	1	0	1	0.01
41	Snakefish	*Trachinocephalus myops*	0	1	1	0.01
42	Mullet spp.		0	1	1	0.01
43	Gag	*Mycteroperca microlepis*	0	1	1	0.01
44	Dwarf goatfish	*Upeneus parvus*	0	1	1	0.01

accumulate at a slightly faster rate than in Narragansett Bay (Fig. 3). The curve for Long Island Sound is slightly more asymptotic. Both curves for Narragansett Bay and Long Island Sound begin to plateau in 1994, which means it took seven years for the majority of the species to be sampled.

Multivariate species analyses indicated that the warm-water fish faunas were different between Narra-

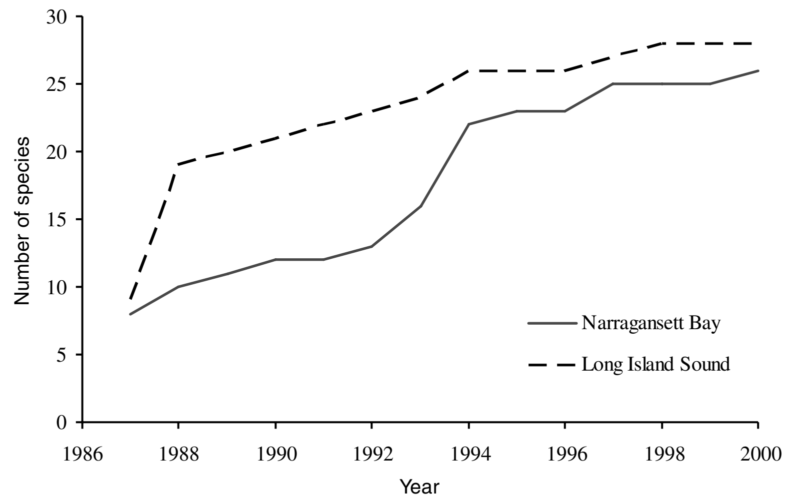

Figure 3

Species accumulation curves for Narragansett Bay and Long Island Sound warm-water fish species caught by trawl and seine surveys (1987–2000).

gansett Bay and Long Island Sound. Two groups were identified in the analysis, predominantly segregating on the basis of area (Fig. 4). Narragansett Bay data from 1993 was an outlier in the multivariate analysis (Fig. 4); the lowest abundance of warm-water fish in Narragansett Bay was present in this year.

The SIMPER analysis indicated that the species contributing most to the dissimilarity between Narragansett Bay and Long Island Sound were rough scad (*Trachurus lathami*), crevalle jack, blue runner (*Caranx chrysos*), flying gurnard (*Dactylopterus volitans*), bluespotted coronetfish (*Fistularia tabacaria*), and the orange filefish (*Aluterus schoepfi*). With the exception of crevalle jack, the species contributing to dissimilarity were found in moderate numbers and were present in greater abundance in one of the locations or during different years. The species that were most similar among locations were the most abundant, namely Atlantic moonfish, northern puffer, planehead filefish, and bigeye (Table 2).

Timing of occurrence of warm-water fishes

It was expected that because of the close spatial proximity of the sampling areas, that temperatures in Narragansett Bay and Long Island Sound would be similar. Temperatures were significantly correlated between the two estuaries. Of the several different correlations calculated, weekly mean temperatures in Narragansett Bay and Long Island Sound were significantly correlated (r=0.99; P<0.001), as were annual mean surface temperatures (r=0.83, P<0.001).

The relationship between annual fish catch and mean temperatures was equivocal. Annual abundance in Narragansett Bay was significantly correlated with mean summer temperatures and annual abundance on Long Island Sound was significantly correlated with semi-annual temperature (Table 3). However, annual abundance in Narragansett Bay was not correlated with semi-annual temperature and annual abundance in Long Island Sound was not correlated with summer temperature.

The general pattern of timing of fish occurrence was similar between estuaries. Fish were first caught in abundance (>5% of peak) in mid-July (week 30) in both Narragansett Bay and Long Island Sound at mean temperatures of 18°C in both areas (Fig. 5). Peak abundance occurred in mid-September in both estuaries. Last occurrence occurred in November in Narragansett Bay, and last occurrence, about 3 weeks later in Long Island Sound. Because of their nature, the species analyzed prefer warm conditions, and as expected, over 80% of the warm-water fishes were caught at temperatures between 17 and 21°C and the cumulative temperature reached 100% at 23°C (Fig. 6).

There were mixed results in the examination of the patterns of timing of fish appearance and disappearance. The time of first, peak, and last occurrence were not significantly different between Narragansett Bay and Long Island Sound (first: t=0.69, df=26; peak: t=1.3, df=26; last: t=2.8, df=26) (Fig. 7). However, there were no significant correlations between the interannual patterns in timing of first, peak, or last appearance among years in the two locations.

The peak week of occurrence of northern puffer was weakly correlated between the two areas during 1987–2000, but the annual means were very similar between estuaries, with a mean percent difference of only 0.32%. The final correlations of timing of occurrence were con-

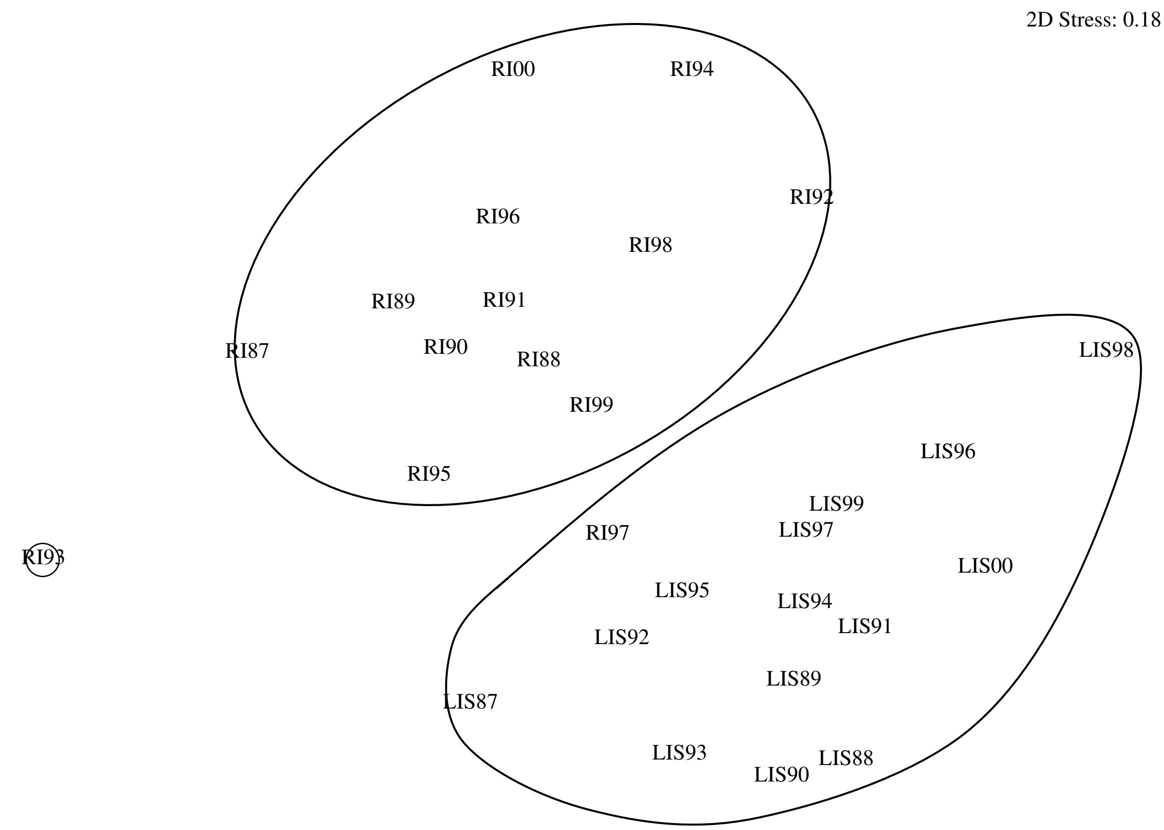

Figure 4

Multidimensional scaling plot of standardized, fourth-root transformed, fish abundance data by year (1987–2000) and location based on Bray-Curtis similarity. The two main groupings indicate that fish abundances in Narragansett Bay (RI) and Long Island Sound (LIS) were not similar to each other annually. The line contours describe 45% similarity from the clustering algorithm. Note that the year 1993 appears to be an outlier, lacking similarity to the Narragansett Bay or Long Island Sound populations. In addition, RI 97 seems equally similar to both the RI and the LIS groupings.

ducted for the weeks of peak fish occurrence and the temperature of that week, as well as the week of 50% minimum and maximum temperature as determined by cumulative degree days and both were significant (r=0.67; P=0.01 and r=0.67; P=0.01, respectively).

Discussion

Despite their brief seasonal appearance, warm-water fish species are an important part of the overall faunal assemblage in temperate estuaries worldwide. These summer visitors contribute significantly to the overall species diversity of temperate estuaries (Wallace et al., 1984; Francis et al., 1999), increasing both food sources and overall productivity (Chapin et al., 2000; Cardinale et al., 2002). The majority of the warm-water species found in this study have been recorded in the study areas only as juveniles; however, it is an open question whether this will always be the case. Many warm-water species are highly adaptable, and may eventually be able to over-winter in temperate estuaries, becoming part of the resident species assemblage. An influx of these new residents could affect the ecosystem structure and function in these estuaries.

The diversity and abundance of Narragansett Bay and Long Island Sound warm-water fish are increasing, apparently because of warming coastal waters. The species assemblages of both areas are similar. However, differences in both species presence and overall species abundance exist between the two data sets. For example, large schools of Atlantic moonfish were caught in a Narragansett Bay trawl survey in 1994, leading to a huge increase of overall catch abundance for that year. Schooling fishes, such as the Atlantic moonfish, caught during our study may influence the interpretation of the survey data. Another difference in species presence was indicated by the presence of a species in only one of the two areas surveyed uring the years of this study (1987–2000). Species such as the inshore lizard-

Table 3

Correlations (r) and probability values (P) between annual fish catch in Narragansett Bay and Long Island Sound and mean summer temperatures (June, July, August) and mean half-year temperatures (May, June, July, August, September, October) for each location (1987–2000). Catch columns are the total numbers of warm-water fishes caught in each location per year through both seining and trawl sampling.

	Narragansett Bay			Long Island Sound		
		Temperature °C			Temperature °C	
Year	Catch	Summer	Semi-annual	Catch	Summer	Semi-annual
1987	75	18.77	16.83	21	23.80	15.20
1988	138	19.16	16.59	392	20.57	17.80
1989	138	19.76	17.32	200	24.74	18.09
1990	289	19.25	17.34	150	21.33	17.50
1991	144	20.16	18.38	105	21.51	16.77
1992	137	18.69	16.98	109	22.87	15.74
1993	58	19.38	17.53	97	21.17	17.62
1994	1794	20.20	17.33	253	21.99	18.23
1995	91	20.09	19.16	94	20.37	14.82
1996	143	18.80	17.05	952	18.73	19.91
1997	213	18.51	16.75	335	17.94	19.51
1998	411	18.43	17.29	1267	22.93	19.83
1999	457	19.73	17.77	780	20.98	19.13
2000	550	18.99	16.83	1927	20.58	20.05
r		0.346	0.071		0.230	0.746
P		0.048	0.105		0.767	0.004

fish (*Synodus foetens*), spotfin butterflyfish (*Chaetodon ocellatus*), and striped burrfish (*Chilomycterus schoepfii*) were all recorded only in Long Island Sound during the years studied but are known to occur in Narragansett Bay as well. Spotfin butterflyfish have often been seen in Narragansett Bay (Meng and Powell, 1999), and catch records for inshore lizardfish were extremely high during the summer and fall of 2006. The data presented in this study may therefore represent only a snapshot of the areas that were sampled and may not completely represent the ecosystems being studied. Because of data limitations due to difficult sampling areas and a lack of frequency of sampling, it was important to look at overall estimates of species diversity, not just the actual numbers of species that were caught. The calculated species richness indicates that the number of warm-water species in the two locations is the same. Although the actual numbers of species found in each area are not equal (26 in Narragansett Bay vs. 28 in Long Island Sound), many additional species have been found by local aquarists and scuba divers in both areas that do not appear in the data sets. Examples of these include fishes seen mostly in rocky or vegetated habitats where sampling is difficult, such as foureye butterflyfish (*Chaetodon capistratus*) (Allen, 1985) and doctorfish (*Acanthurus chirurgus*) (Allen, 1985).

The annual abundance of warm-water species recorded in Narragansett Bay was similar to the abundances in Long Island Sound among the years used in this study (1987–2000). Annual abundance is correlated between locations for all warm-water fishes (omitting 1994 as an outlier), and for three of the five most abundant species. Despite these correlations, the multivariate analyses provided evidence of distinct species compositions in each location and indicated that the interannual variability in timing of occurrence is not correlated between areas. Based on the MDS analysis Atlantic moonfish, planehead filefish, and northern puffer contributed to the similarity in species composition and abundance between locations in the multivariate analyses. In contrast, the moderately and least abundant species, as well as the species that occurred in only one of the sampling areas, contributed to the differences in warm-water fishes present between locations. The recorded absence of species that were knowingly present in the estuaries, such as doctorfish and foureye butterflyfish, likely led to the resulting differences in the MDS plots between estuaries.

Based on the elusive nature of the juvenile warm-water fishes, the data set used for this study may have been compiled with insufficient sampling effort. For data sets with adequate effort, the species accumulation curves reach asymptotic levels quickly (Thompson et al., 2003). However, neither Narragansett Bay nor Long Island Sound data exhibited this pattern, which means that there were likely more species in the systems than there were samples to represent them. Species accumulation also occurs more quickly with increas-

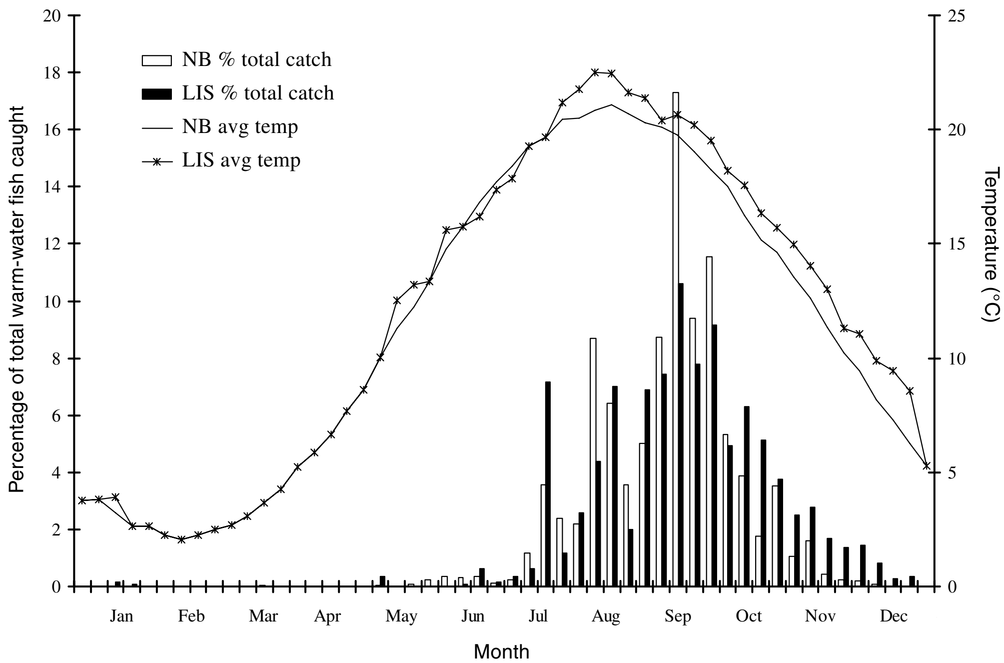

Figure 5

Weekly mean (surface and bottom) temperature data from Narragansett Bay, including all catch data from Narragansett Bay waters as well as from Rhode Island Salt Ponds, and Long Island Sound graphed with the percentage of total occurrences of warm-water fish caught in trawl and seine surveys in these two locations (1987–2000). The line graphs represent the mean annual temperatures, and the bar graphs represent the annual fish catch at each location.

ing sampling area and effort (Ugland et al., 2003). Because Long Island Sound is much larger than Narragansett Bay, there is a greater potential sampling area, which could explain the steeper increase and the more asymptotic nature of the species accumulation curve of the former area. The warm-water fish assemblages were largely similar between the two estuaries but there were spatially-specific variables that may have influenced the temporal occurrence of these species.

Timing of occurrence is an important factor in the structure of warm-water fish faunas; however, the processes that lead to the appearance of warm-water fishes in the early summer and to their disappearance in the fall are not completely understood. The mean weeks of first, last, and peak appearances are all very similar between Narragansett Bay and Long Island Sound and there is the same 4-week time lag between the week of peak temperatures (week 33) and the week of peak fish abundance (week 37)

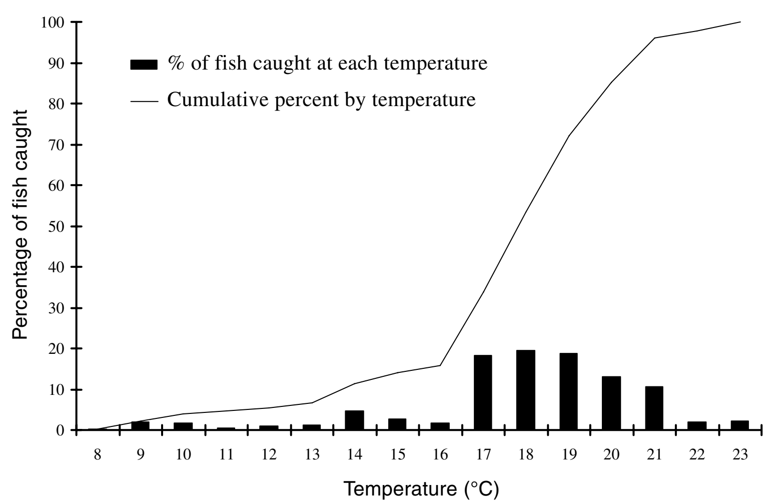

Figure 6

Percentage of warm-water fish sampled in Narragansett Bay and Long Island Sound (1987–2000) as a function of concomitant temperature data and the cumulative percentage of fish caught at each temperature. Bar graphs represent the percentage of total fish catch at each temperature, and the line represents the cumulative temperature percentage.

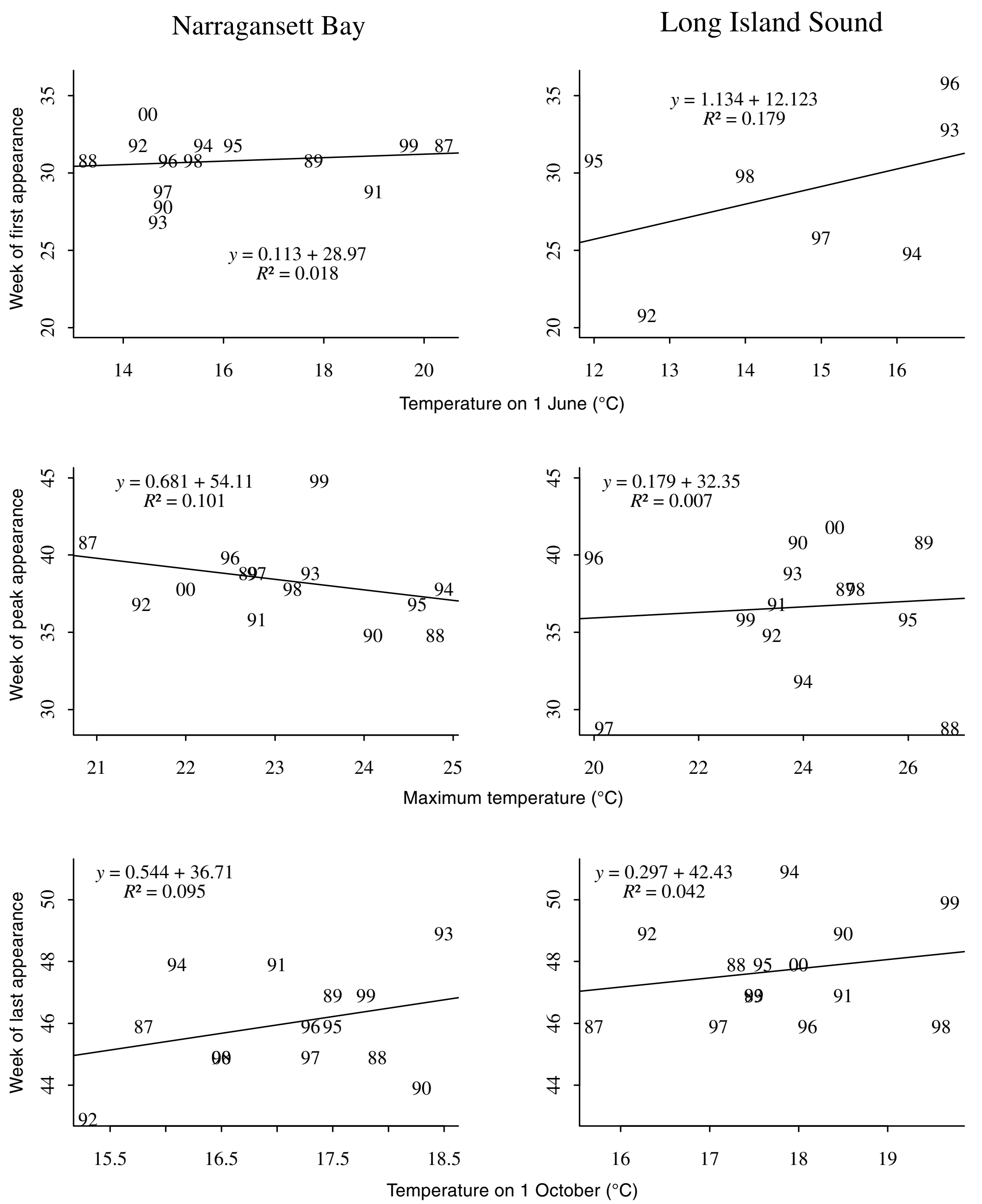

Figure 7

Correlations between temperatures and weeks of the year (1–52) of first (5% of peak), last, and peak appearance of warm-water fishes in both Narragansett Bay and Long Island Sound (1987–2000).

in both locations. In regard to their fall disappearance, warm-water fishes may experience different fates after seasonal periods in temperate estuaries. For some species, eastern Atlantic Ocean populations exist, raising the possibility that dispersal can range across the Atlantic Ocean (Markle et al., 1980), which is especially a possibility for species that are strong swimmers, such as the carangids (McBride and McKown, 2000). However, it is believed that most warm-water species do not successfully return to their place of origin, but die off as waters cool to temperatures below their physiological tolerances in the fall months. Moss (1973) conducted a series of experiments with planehead filefish and found that their lowest lethal temperature limit was 5.6°C, which is slightly less than the suggested lowest lethal temperature of about 8°C for northern puffer (Hoff and Westman, 1966), 7.4° to 9°C for crevalle jack (Hoff, 1971), and 10°C for spotfin butterflyfish (McBride and Able, 1998). The rapidly decreasing temperatures in the fall cooling cycle determine the length of time the warm-water fish are able to survive in temperate waters before colder temperatures overtake them.

Trends in water temperature indicated that seasonal warming and cooling were the same between the two locations and that the warmer years were correlated with greater abundance of warm-water fishes. This has been observed in other estuarine waters as well, where major influxes of tropical and subtropical fish in New Zealand are linked to warm summers, although there have been several warm periods not accompanied by influxes (Francis et al., 1999). The incidence of warm-water fish is generally increasing with time, indicating that this pattern of increased warm-water fish abundance is likely to continue to rise as temperate coastal waters continually warm on a global scale. However, this increase in warm-water fish abundance may not be exclusively related to temperature. The majority of warm-water fishes are caught between 17° and 21°C, and very few fish are caught at temperatures greater than 21°C. It is possible that very few fish are caught at 21°C because temperatures are rarely recorded higher than 21°C in Narragansett Bay or Long Island Sound. In addition, not all warm years on record are accompanied by heightened warm-water fish catch, and this result highlights the possibility that nontemperature-related factors are contributing to the observed temporal trend. There are likely other processes that influence the abundance of these fishes, such as shifts in the transport mechanisms responsible for supplying warm-water fishes to more northern habitats.

It is hypothesized that the major mode of northward transport for warm-water fishes is the Gulf Stream Current. Because many warm-water fishes arrive as larvae or juveniles, larval transport mechanisms are important to their arrival to summer habitats (Flierl and Wroblewski, 1985; Hare et al., 2002). Western boundary currents such as the Gulf Stream and the Kuroshio Current, and their associated warm-core rings, meanders, and streamers provide physical mechanisms responsible for the pole-ward transport of many warm-water species (Craddock et al., 1992; Watanabe and Kawaguchi, 2003). The Gulf Stream and its associated currents consist of warmer Sargasso Sea water and introduce warm-water fish species into the continental shelf and slope waters near southern New England (Markle et al., 1980; Cowen et al., 1993). Hare et al. (2002) hypothesized four phases exist for northward larval transport and these are associated with warm-core rings. They hypothesized that larval fish were 1) entrained into the Gulf Stream, 2) transported to the northeastern shelf along the edge of the Gulf Stream, 3) carried in warm-core ring streamers from the Gulf Stream and across the Slope Sea (the region between the Gulf Stream and the shelf edge of Cape Hatteras), and 4) ejected from warm-core ring streamers at the shelf edge where larval fishes enter the shelf-slope frontal zone. This mode of transport is the most likely explanation for how warm-water fishes end up in Narragansett Bay and Long Island Sound, where they are observed in their early life stages.

The observations presented here have not been previously documented and provide valuable information regarding the community structure in these locations. Besides adding to our knowledge of the occurrence of warm-water fishes in northern estuaries, the changes in faunal assemblages noted in this study will become increasingly pertinent for future studies on climate change. If waters continue to warm on a global scale, it is thought that major western boundary current systems, such as that of the Gulf Stream Current, may weaken (Frank et al., 1990) and therefore would transport fewer juvenile warm-water fishes northward to temperate areas. It is also thought that the general fish assemblages of temperate estuaries may shift from more vertebrate species (fish) to more invertebrate species (crabs) with increasing water temperatures (Collie et al., 2008). These ideas are contradictory to the thought that warming temperate waters would support more warm-water fishes in temperate areas in the future. The information presented in this study may provide insight into future changes in species composition and abundance that may occur if warming trends continue in the coastal regions of the northwest Atlantic Ocean.

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Literature cited

Able, K. W., and M. P. Fahay.
1998. The first year in the life of estuarine fishes in the Middle Atlantic Bight, 342 p. Rutgers Univ. Press, New Brunswick, NJ.

Allen, G. R.
1985. Butterfly and angelfishes of the world, vol. 2, 352 p. Aquarium Systems, Mentor, OH.

Bigelow, H. B., and W. C. Schroeder.
1953. Fishes of the Gulf of Maine. Fish. Bull., Fish. Wildl. Serv. 53: i–577.

Briggs, J. C.
1974. Marine zoogeography, 475 p. McGraw-Hill Book Co., New York, NY.

Cardinale, B. J., M. A. Palmer, and S. L. Collins.
2002. Species diversity increases ecosystem functioning through interspecific facilitation. Nature 415:426–429.

Chapin, F. S., III, E. S. Zavaleta, V. T. Eviners, R. L. Naylor, P. M. Vitousek, H. L., Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S. E. Hobbie, M. C. Mack, and S. Diaz..
2000. Consequences of changing biodiversity. Nature 405:234–242.

Collie, J. S., A. D. Wood, and H. P. Jeffries.
2008. Long-term shifts in the species composition of a coastal fish community. Can. J. Fish. Aquat. Sci. 65:1352–1365.

Cowen, R. K, J. A. Hare, and M. P. Fahay.
1993. Beyond hydrography: Can physical processes explain larval fish assemblages within the Middle Atlantic Bight? Bull. Mar. Sci. 53(2):567–587.

Craddock, J. E., R. H. Backus, and M. A. Daher.
1992. Vertical distribution and species composition of midwater fishes in warm-core Gulf Stream meander/ring 82-H. Deep-Sea Res. 39(1):S203–S218.

Flierl, G. R., and J. Wroblewski.
1985. The possible influence of warm core Gulf Stream rings upon shelf water larval fish distribution. Fish. Bull. 83:313–330.

Francis, P. F., C. J. Worthington, P. Saul, and K. D. Clements.
1999. New and rare tropical and subtropical fishes from northern New Zealand. N. Z. J. Mar. Freshw. Res. 33:571–586.

Frank, K. T., R. I. Perry, and K. F. Drinkwater.
1990. Effects of climate change on fish. Trans. Am. Fish. Soc. 119:353–354.

Grant, D.
1991. Tropical waves. Underw. Nat. 20(2):26–27.

Hare, J. A, J. H. Churchill, R. K. Cowen, T. J. Berger, P. C. Cornillon, P. Dragos, S. M. Glenn, J. J. Govoni, and T. N. Lee.
2002. Routes and rates of larval fish transport from the southeast to the northeast United States continental shelf. Limnol. Oceanogr. 47(6):1774–1789.

Hoff, J. G.
1971. Mass mortality of the crevalle jack, *Caranx hippos* (Linneaus) on the Atlantic Coast of Massachusetts. Chesapeake Sci. 12:49.

Hoff, J. G., and J. R. Westman.
1966. Temperature tolerances of three species of marine fishes. J. Mar. Sci. 24(2):131–140.

Hutchins, J. B.
1991. Dispersal of tropical fishes to temperate seas in the Southern Hemisphere. J. R. Soc. West. Aust. 74:79–84.

Johnson, R. A., and G. K. Bhattacharyya.
2001. Statistics Principles and Methods, 4th ed., 723 p. John Wiley and Sons, Inc., New York, NY.

Krebs, C. J.
1999. Ecological Methodology, 2nd ed, 620 p. Harper and Row, Publishers, Inc., New York, NY.

Lenanton, R. C. J., and I. C. Potter.
1987. Contribution of estuaries to commercial fisheries in temperate Western Australia and the concept of estuarine dependence. Estuaries 10(1):28–35.

Markle, D. F., W. B. Scott, and A. C. Kohler.
1980. New and rare records of Canadian fishes and the influence of hydrography on resident and nonresident Scotian Shelf ichthyofauna. Can. J. Fish. Aquat. Sci. 37:49–65.

McBride, S. R., and K. W. Able.
1998. Ecology and fate of butterflyfishes, *Chaetodon* sp., in the temperate, Western North Atlantic. Bull. Mar. Sci. 63(2):401–416.

McBride, S. R., and K. A. McKown.
2000. Consequences of dispersal of subtropically spawned crevalle jacks, *Caranx hippos*, to temperature estuaries. Fish. Bull. 98:528–538.

Meng, L., and J. C. Powell.
1999. Linking juvenile fish and their habitats: an example from Narragansett Bay, Rhode Island. Estuaries 22(4):905–916.

Moss, S. A.
1973. The responses of planehead filefish, *Monacanthus hispidus*, to low temperature. Chesapeake Sci. 14(4):300–303.

Murdy, E. O., R. S. Birdsong, and J. A. Musick.
1997. Fishes of the Chesapeake Bay, 324 p. Smithsonian Institution Press, Washington DC.

Oviatt, C., A. Keller, and L. Reed.
2002. Annual primary production in Narragansett Bay with no Bay-wide winter-spring phytoplankton bloom. Estuarine Coastal Shelf Sci. 54(6):1013–1026.

Rountree, R. A., and K. W. Able.
1992. Fauna of polyhaline subtidal marsh creeks in southern New Jersey: composition, abundance, and biomass. Estuaries 15(2):171–185.

Smith, H. M.
1899. Fish fauna of the Woods Hole region. Science 10(259):878–881.

Thompson, G. G., P. C. Withers, E. R. Pianka, and S. A. Thompson.
2003. Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. Austral Ecol. 28:361–383.

Tremain, D. M., and D. H. Adams.
1995. Seasonal variations in species diversity, abundance, and composition of fish communities in the Northern Indian River Lagoon, Florida. Bull. Mar. Sci. 57(1):171–192.

Ugland, K. I, J. S. Gray, and K. E. Ellingsen.
2003. The species accumulation curve and estimation of species richness. J. Anim. Ecol. 72(5):888–897.

Wallace, J. H., H. M. Kok, L. E. Beckley, B. Bennett, and S. J. M. Blaber.
1984. South African estuaries and their importance to fishes. S. Afr. J. Sci. 80(5):203–207.

Watanabe, H., and K. Kawaguchi.
2003. Decadal change in abundance of surface migratory myctophid fishes in the Kuroshio region from 1957 to 1994. Fish. Oceanogr. 12(2):100–111.