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Species assemblages of leptocephali in the Subtropical Convergence Zone of the Sargasso Sea

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ABSTRACT

Species assemblages of leptocephali are described in relation to density in the Subtropical Convergence Zone (STCZ) of the Sargasso Sea. Seven transects across fronts were made during four cruises in the late winter or early spring of 1983, 1985 and 1989. About 50 species from 13 families of eels were collected at 66 stations, but fewer than 10 species were abundant in all transects. Four oceanic species, two *Anguilla* species and *Conger oceanicus* appeared to be spawning in the STCZ. Leptocephali of most species whose adults inhabit the continental shelf were consistently large in size and were more abundant at or south of fronts and in the western transects. Leptocephali of the two most common oceanic species, *Nemichthys scolopaceus* and *Serrivomer beanii*, and the most common shelf species, *Ariosoma balearicum*, were also more abundant in the western transects, but were abundant at some stations on both sides of fronts. Discontinuities in the assemblages of *Anguilla* and most shelf species occurred at the location of fronts that formed at the northernmost extent of southern Sargasso Sea surface water (defined as $\sigma_t < 25.6 \text{ kg m}^{-3}$). These species were rare or absent in mixed convergence zone water (defined as $\sigma_t 25.2\text{--}25.6$) north of the fronts. Cluster analysis and ordination of assemblages at 31 night stations reflected the greater species richness and abundance in the west and in the southern water mass. Patterns of assemblage structure within and among transects suggest that convergence of surface water toward fronts in the STCZ may concentrate leptocephali close to fronts and that frontal jets may transport leptocephali eastward.

1. Introduction

The Sargasso Sea is well known as the spawning area of the catadromous eels of the genus *Anguilla* from North America and Europe. Although lesser known, more than 100 species of marine eels live in the Sargasso Sea and in the waters of adjacent coastal and island habitats. These marine eels can be categorized into three general groups based on their adult habitats (Castle, 1984). The adults of “oceanic” eel species live and spawn in the open ocean and have completely pelagic life histories. The adults of “shelf” and “slope” eel species live in benthic habitats of the continental shelf and slope or around islands, but these species also have leptocephali that are pelagic.

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Leptocephali of the oceanic species of the Cyematidae, Eurypharyngidae, Nemichthyidae and Serrivomeridae are found in the offshore waters of the Sargasso Sea (Böhlke, 1989). Also found in these offshore waters are the leptocephali of the Chlopsidae, Congridae, Moringuidae, Muraenidae and Ophichthidae (Smith, 1969; Keller, 1976; Castle, 1979; Böhlke, 1989; Leiby, 1989), whose adults live predominantly in shelf habitats, and those of the Derichthyidae, Nettastomatidae and Synaphobranchidae (Castle, 1970; Smith, 1974; Smith and Castle, 1982; Castonguay and McCleave, 1987a; Böhlke, 1989), whose adults inhabit primarily outer continental shelf, slope and deep benthic habitats. Although there is some information about the distributions and diets of adult eels in the Atlantic Ocean (Böhlke and Chaplin, 1968; Whitehead *et al.*, 1986; Levy *et al.*, 1988; Böhlke, 1989), little is known about the reproductive ecology of most species of marine eels (Fishelson, 1992).

In contrast, the location and approximate timing of spawning of the two species of *Anguilla* in the Sargasso Sea are well documented (Schmidt, 1922; Schoth and Tesch, 1982; Kleckner *et al.*, 1983; Boëtius and Harding, 1985; Kleckner and McCleave, 1985, 1988; Tesch and Wegner, 1990). Adult *Anguilla* migrate from the coasts of North America and Europe, then spawn from about February to April in the southern part of the Sargasso Sea. Recent studies suggest that most of the spawning takes place within or south of fronts in the North Atlantic Subtropical Convergence Zone (Schoth and Tesch, 1982; Kleckner and McCleave, 1988; Tesch and Wegner, 1990).

The subtropical convergence zone (STCZ) is the region of the western Atlantic between latitudes 20N and 30N where the colder water of the northern Sargasso Sea meets the warmer water of the southern Sargasso. During winter and spring, this region has a complex and highly variable pattern of fronts (Voorhis and Hersey, 1964; Katz, 1969; Voorhis, 1969) and eddies (Voorhis *et al.*, 1976; Voorhis and Bruce, 1982). Recent studies of the fronts during the Frontal Air-Sea Interaction Experiment (Weller, 1991) used satellite imagery of sea surface temperatures and hydrographic measurements to characterize the structure and variability of frontal features in the STCZ (Halliwell and Cornillon, 1989; Eriksen *et al.*, 1991; Halliwell *et al.*, 1991; Weller *et al.*, 1991; Pollard and Regier, 1992). There appear to be two latitudinal bands of fronts that form during the winter and spring in the STCZ, the intensity and location of which vary widely within and between years (Böhm, 1988; Weller, 1991; Halliwell *et al.*, 1991). These fronts are restricted predominantly to the upper 200 m and separate colder water on the northern side from a warmer mixed layer in the upper 100 m on the southern side of frontal features (Wegner, 1982; Kleckner and McCleave, 1988; Halliwell and Cornillon, 1989; Eriksen *et al.*, 1991; Pollard and Regier, 1992). Strong frontal jets occur in association with the surface expression of well developed fronts, and convergence of surface water toward the jets appears to occur on both the warm and cold sides of fronts (Mied *et al.*, 1986; Eriksen *et al.*, 1991).

It has been hypothesized that migrating *Anguilla* adults use frontal zones in the STCZ as a cue that indicates when they have reached the general area of spawning (McCleave and Kleckner, 1985). This hypothesis has been supported by observations that *Anguilla* leptocephali are much more abundant on the south side of fronts that separate the two general water masses in the STCZ (Kleckner and McCleave, 1988; Tesch and Wegner, 1990).

Despite considerable information about *Anguilla* leptocephali, the species assemblages and distributional ecology of the leptocephali of the various eel families have not been studied in the STCZ. Adults of a wide range of shelf species of eels live on the Bahama Banks and around the islands of the Greater and Lesser Antilles at the southern edge of the Sargasso Sea (Böhlke and Chaplin, 1968). When and where these species spawn and the drift patterns of their leptocephali are not known, other than general indications that *Conger oceanicus* (Schmidt, 1931) and *Moringua edwardsi* (Castle, 1979) spawn in the vicinity of the West Indies. Leptocephali of many shelf and oceanic species have been reported from the STCZ (Böhlke, 1989), but their relative abundances in relation to hydrographic features have not been sampled systematically.

The three objectives of this study were to determine: (1) the taxonomic composition, relative abundance and length-class structure of the leptocephali in the STCZ during February, March and April; (2) the extent to which the distributions of leptocephali along individual transects indicate the presence of faunal discontinuities across fronts; and (3) the relationships among the species assemblages of leptocephali at individual stations, sampled at different times and locations, relative to fronts and density in the STCZ. To address these objectives, we analyzed the hydrography and the catches of leptocephali from four cruises in the Sargasso Sea between February and April, which were designed to study the spawning location of *Anguilla* in relation to fronts in the STCZ. In addition to characterizing the species assemblage of leptocephali of all 13 families of eels found in the region, we used catch rates of the most abundant species or groups to describe discontinuities in assemblages across frontal features. The distributions of catch rates along each transect, and the relationships of catch rates at individual stations indicated by cluster analysis and ordination were used to describe the assemblages in relation to density structure in the STCZ.

2. Data and methods

Leptocephali and hydrographic data were collected along seven predominantly north-south transects of various lengths made during four cruises in the STCZ between February and April of 1983, 1985 and 1989 (Fig. 1). Two transects across fronts were made during each of two cruises of the ORV *Cape Florida* in February (cruise CF8303) and April (CF8305) 1983 and are termed 831N, 831S, 832W and 832E. These transects had nine stations and were from 155–220 km long. Two

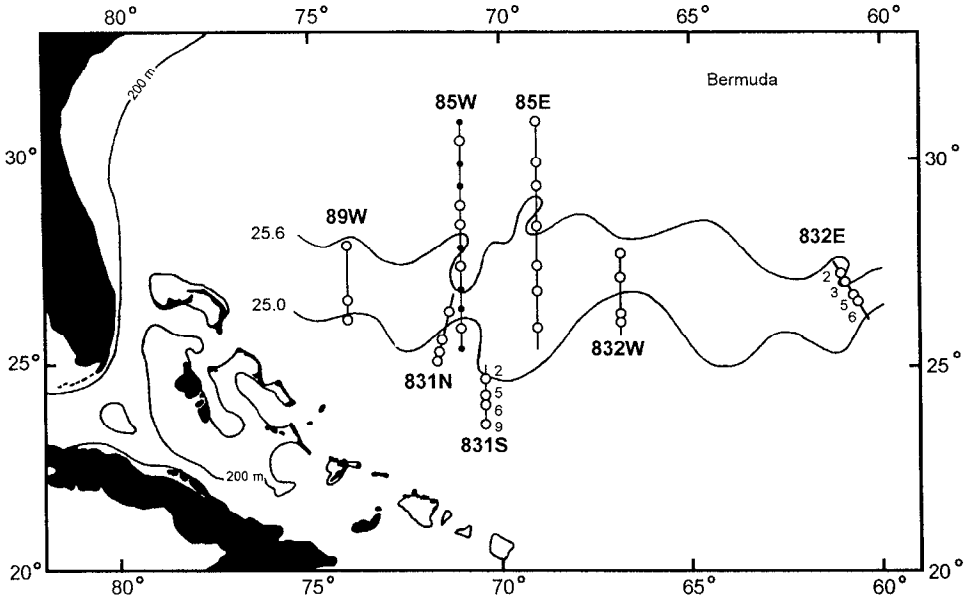


Figure 1. Locations of the 831N (12–15 February 1983), 831S (16–19 February 1983), 832W (3–5 April 1983), 832E (11–14 April 1983), 85W (25–29 March 1985), 85E (15–21 March 1985) and 89W (14–21 February 1989) transects in the Sargasso Sea. Night stations along each transect that were used in the analyses of catch rates are indicated with open circles and the day stations of 85W shown in Figure 5 are indicated with black dots. The stations of each transect were numbered sequentially, with station 1 always at the northern end. Station numbers of 831S and 832E night stations are shown because they are not represented in catch rate figures. Hypothetical locations of the two fronts (associated with the $\sigma\text{-}t$ 25.0 and 25.6 isopycnals) are drawn to be consistent with their surface expressions along the seven transects.

611-km-long transects, each with 12 stations, were made across fronts during March 1985 (CF8503) and are designated 85E and 85W. Specific details of the 1983 and 1985 transects were described by Kleckner and McCleave (1988). Six stations were made along a 200-km transect (called 89W) during a cruise of the *RV Columbus Iselin* in February 1989 (CI8901). There was a gap of two days between the first three and the last three stations. Four tows were north of the front and three were in or to the south of it, with the two southernmost tows at the same station.

In 1983 and 1985, attempts were made to center the transects across frontal features, and there were approximately even distributions of tows across most of the fronts. The general locations of fronts in all years were initially determined using infrared imagery from satellites. More precise locations of the fronts were determined using continuous records of sea surface temperature and casts of expendable bathythermographs (XBTs) made immediately before each transect. Conductivity-temperature-depth (CTD) profiles were made at 63 of the 66 stations of the

transects. In 1985 and 1989, additional temperature profiles were obtained between stations using XBTs.

At each station, usually one (1983 and 1989) or two (1985) tows of a 3-m Isaacs Kidd Midwater Trawl were used to collect leptocephali. Single oblique tows were made during the 831 and 85 transects, and double oblique tows were made during the 832 and 89W transects. In single oblique tows, the net was deployed to its maximum depth then retrieved gradually. During double oblique tows, the net was retrieved gradually to a depth of 10 m and then was redeployed in the same way. The maximum depth of the tows ranged from 250–400 m in the 1983 and 1985 transects (Kleckner and McCleave, 1988) and from about 300–311 m in 1989. The trawl had a mouth area of 8.68 m², a filtering area of 68.9 m² and was fully lined with 0.505 mm NITEX netting. The water filtered by each tow was estimated using a flow meter suspended in the center of the trawl mouth.

Plankton samples were fixed in 7.5% seawater-formalin before the leptocephali were sorted under a dissecting microscope. Specimens were identified following Smith (1969; 1974; 1979) and Böhlke (1989) and measured to the nearest millimeter total length. Leptocephali of some congeneric species could not be distinguished consistently without risk of misidentification as a result of overlapping myomere ranges or damage to some specimens. Only the generic identifications of these species were used in the analysis with the understanding that more than one species may have been represented by those genera. Throughout the subsequent analysis, the minimum number of species in a particular station or group of stations will be termed species richness, or number of taxa, even though some taxa may represent more than one species.

Because fishing effort differed among individual stations, catch data were standardized by converting them to catch rates. The numbers of individuals of each taxon at a station were converted to catch rates of the number of leptocephali per 10⁵ m³ of water filtered by the net, using the revolutions of the flow meter, a calibration factor (m rev⁻¹) and the trawl mouth area (m²). The mean tow volumes per station ranged from 0.53–0.65 × 10⁵ m³ in the 1983 transects to 1.0–1.1 × 10⁵ m³ in 1985 and 1989. Therefore, in the latter two cruises, the number of specimens collected at a station approximated the catch rate in numbers of specimens per 10⁵ m³.

Time constraints on all four cruises resulted in tows being made during both day and night. Because the original objective of these cruises was to catch recently spawned *Anguilla* leptocephali, which do not appear to migrate vertically (Castonguay and McCleave, 1987b), fishing during the day was believed to have little or no effect on the catch rate of small *Anguilla*. However, catch rates of the larger leptocephali of most species were usually lower in day tows than in night tows. Tows that began after sunset and ended before sunrise were considered night tows, and all others were designated as day tows. Stations 6–12 at or south of the front in 85E were used to compare statistically catch rates of various taxa between night and day tows.

Because catch rates of most species were usually lower in day tows, only night tows were used in the cluster analysis and ordination of assemblages at each station and for analysis of catch rates along transects.

The distributions of catch rates of certain taxa along transects were tested for uniformity using either non-standard chi-square goodness of fit tests or log-likelihood ratio G-tests (Sokal and Rohlf, 1981), which use expected frequencies based on the amount of water filtered at each station (McCleave *et al.*, 1987). The G-test is more conservative and was used in all cases except when zero values were present. In cases where expected values for a particular species were lower than five, no tests were performed. The along-transect distributions of individual species or groups of species were compared to each other with the same tests. In some cases, two oceanic species whose distributions in a transect were not significantly different were pooled to reduce the number of comparisons for that transect.

The relationships among species assemblages were examined using agglomerative, hierarchical cluster analysis and non-metric multidimensional scaling (ordination) according to general methods described by Field *et al.* (1982). Prior to analysis, the catch rates were transformed using a 'root-root' transformation (Field *et al.*, 1982) so the abundant taxa would not dominate the analysis. The catch rates at stations that had two night tows were averaged, and the data from 40 night tows at 31 stations were used in the cluster analysis and ordination. The Manhattan metric was chosen as the best similarity coefficient for the final analysis of this data set because a variety of species was absent from a large percentage of the tows. The Manhattan metric appears to function better with an impoverished fauna than does the Bray-Curtis measure (Field *et al.*, 1982). Complete linkage was used in the cluster analyses because the assemblages were generally similar in their compositions of the common species in most areas. The unweighted pair-group method produced similar results, but showed a greater amount of chaining within some clusters. The ordination of station assemblages with non-metric multidimensional scaling (Kruskal, 1964) used the same dissimilarity matrix generated for the cluster analysis. This type of ordination finds the best overall fit of the points (station assemblages) in two- or three-dimensional space, based on the dissimilarity values for all points. The distances in the plot have a monotonic relationship to the original distances, so similar points should be shown as close together and dissimilar ones far apart. The plots produced by this provide a way to visualize the dissimilarity relationships among assemblages at the various stations and to evaluate the results of cluster analysis, which tends to emphasize discontinuities by dividing stations into discrete clusters.

Leptocephali of a variety of eels with ecologically different life histories were collected, so cluster analysis and ordination was performed on three different complements of species or taxa from the same 31 stations. The broadest analysis used 40 taxa of all 13 eel families with the relatively rare specimens of the Cyematidae and Nettastomatidae pooled by family, the Ilyophinae and Synphobranchinae pooled by

subfamily, and the congrid genera *Gnathophis*, *Rechias* and *Xenomystax* pooled by genus. Another analysis used 29 taxa of the Chlopsidae, Congridae, Moringuidae, Muraenidae and Ophichthidae, whose adults inhabit the continental shelf, with pooling limited to the same three congrid genera.

The third analysis used 18 taxa of 10 families and was designed to examine the fundamental relationships among assemblages of the most abundant species or families by reducing the potential bias of random co-occurrences of extremely rare taxa in two or more widely separated stations. Because most of the shelf species were rare, were predominantly caught in southern waters and probably originated outside of the STCZ, the ecological significance of these species in this analysis was that they were of a specific shelf family rather than of a particular species. Pooling of the rarest shelf species and elimination of rare families minimized the possibility of random co-occurrences contributing ecologically meaningless information to the dissimilarity matrices. All but the three most abundant congrid taxa, the two most abundant chlopsids and the most abundant muraenid were pooled by family into three taxa. The ophichthids were all pooled into one taxon. The nettastomatids, cyematids, ilyphines and *Derichthys* were considered too rare and were not used in this analysis.

3. The species assemblage in the STCZ

About 50 species of leptocephali from 13 eel families were captured in the seven transects (Table 1). Three species comprised 67% of the 7,331 leptocephali captured. Leptocephali of the oceanic species *Nemichthys scolopaceus* were the most abundant ($N = 2,574$), with the shelf congrid *Ariosoma balearicum* ($N = 1,367$) and the oceanic species *Serrivomer beanii* ($N = 960$) second and third most abundant. The two species of *Anguilla* were the two next most abundant species and together comprised 16% of the total number of specimens. Two oceanic and five shelf species comprised 66% of the remaining specimens.

Leptocephali of at least 34 species of the five major shelf families were captured in the STCZ, but most were relatively rare (Table 1). The family Congridae had the greatest species richness, with at least one specimen of ten genera and more than 13 species. After *A. balearicum*, *Conger oceanicus* was the next most abundant congrid, largely because of high catches in two transects. Seven species of five genera of the family Chlopsidae were caught in the STCZ, but only *Chilorhinus suenisoni* and *Kaupichthys hyoprroides* were caught in substantial numbers. The only species of the four genera of the family Muraenidae that was caught consistently was *Anarchias similis* (subsequently called *Anarchias*). All of the seven species of five genera of the family Ophichthidae caught in the STCZ were rare. Only one species of Moringuidae was collected.

In contrast to most of the shelf families, the majority of the other seven families represented in the STCZ have relatively few species in general. Only one or two species of each of the oceanic families Nemichthyidae, Serrivomeridae, Eurypharyn-

Table 1. The number of leptocephali of each taxa and the total number of tows in each transect. Taxa are characterized by their adult life histories as either oceanic (OC), slope (SL), shelf (SH) or catadromous (CT).

Family/species	Life history	831N	831S	832W	832E	85E	85W	89W
Anguillidae								
<i>Anguilla anguilla</i>	CT			132	183	96	3	2
<i>Anguilla rostrata</i>	CT	6	27	104	4	71	101	1
Chlopsidae								
<i>Catesbya pseudomuraena</i>	SH	2	1			1	1	1
<i>Chilorhinus suensoni</i>	SH	25	16	11	3	18	22	59
<i>Chlopsis bicolor</i>	SH	4	2	1	1	6	2	1
<i>Chlopsis dentatus</i>	SH	2	2	1		1	1	2
<i>Kaupichthys hyoprорoides</i>	SH	19	15	8	5	18	21	39
<i>Kaupichthys nuchalis</i>	SH	1				1	2	1
<i>Robinsia catherina</i>	SH	1	2	2			2	2
Congridae								
<i>Ariosoma balearicum</i>	SH	102	99	58	25	294	201	587
<i>Conger oceanicus</i>	SH	7	23	5		2	3	32
<i>Conger triporiceps</i>	SH	6	2	2		3		4
<i>Gnathophis</i> spp.	SH	5	3	2	1	14	8	13
<i>Rhechias</i> spp.	SH		2	1			3	3
<i>Uroconger syringinus</i>	SH	1					2	1
<i>Xenomystax</i> spp.	SH	1		1		2	1	6
Cyematidae								
Cyematidae spp.	OC	4	2	2	1	3		9
Derichthyidae								
<i>Derichthys serpentinus</i>	SL	1	2		5			
Eurypharyngidae								
<i>Eurypharynx pelecانoides</i>	OC	27	15	5	1	57	34	26
Moringuidae								
<i>Moringua edwardsi</i>	SH	20	2	12		9	13	42
Muraenidae								
<i>Anarchias similis</i>	SH	21	6	15	18	33	56	19
<i>Gymnothorax miliaris</i>	SH			1		2	3	3
<i>Gymnothorax moringa</i>	SH	5				1	2	2
<i>Gymnothorax vicinus</i>	SH		3	1				2
<i>Monopenchelys acuta</i>	SH	2	3		1	3	5	4
Nemichthyidae								
<i>Nemichthys scolopaceus</i>	OC	736	139	110	141	743	386	319
Nettastomatidae								
Nettastomatidae spp.	SL		2			4	4	3
Ophichthidae								
<i>Ahlia egmontis</i>	SH		2				5	13
<i>Myrophis platyrhynchus</i>	SH	1						3
<i>Myrophis punctatus</i>	SH	3					3	13
Serrivomeridae								
<i>Serrivomer beanii</i>	OC	347	102	43	30	204	29	205
<i>Serrivomer lanceolatoides</i>	OC	14	14	9	39	62	4	8
Synaphobranchidae								
Ilyophinae	SL	2	2			1	2	8
Synaphobranchinae	SL		5			14	43	93
Total number of tows		11	10	9	9	23	24	7

gidae and Cyematidae were collected during this study, and except for the latter, were all relatively abundant (Table 1). The 14 specimens of the family Nettastomatidae were of four genera, and the 15 specimens of the subfamily Ilyophinae (Synphobranchidae) were of five species. There were two species of *Synphobranchus* (Synphobranchidae) based on myomere counts of some specimens, but not all specimens were identified to species.

a. Species richness among transects. The numbers of species caught in the seven transects generally decreased from west to east. At least 40 species were captured in the westernmost transect (89W), and 31 were caught in both 831N and 85W. Both 831S and 85E were east of these transects and had 26 and 27 species. The two transects of 832 were east of the others, with 832E being much farther east than 832W (Fig. 1). There were 20 species caught in 832W and only 13 in 832E. No leptocephali of the Ophichthidae, Nettastomatidae and Synphobranchidae were captured during 832, and there were nine shelf species caught in 832W that were absent in 832E. The only species that was most abundant in 832E and rare or absent in the western transects was *A. anguilla* (Table 1).

b. Size ranges of leptocephali. There was evidence of recent spawning in the STCZ for both species of *Anguilla* and all four families of oceanic eels. The 6–10 and 11–15 mm length classes of *N. scolopaceus* (subsequently called *Nemichthys*) were the most abundant, and this species showed an exponential decline in abundance with length in all of the transects (Fig. 2A). The leptocephali of *Serrivomer lanceolatooides* and *Eurypharynx pelecanooides* (subsequently called *Eurypharynx*) also showed a general decrease in abundance with length, but *S. beanii* was most abundant in the middle length classes (Fig. 3A, B, D). The most abundant shelf species, *A. balearicum* (subsequently called *Ariosoma*) had a peak in abundance at about 80–90 mm in all transects, with no specimens less than 50 mm in length (Fig. 2B). Both species of *Anguilla* were spawning in the STCZ as the catches in all the transects except in 1989 were dominated by small, recently spawned leptocephali (Kleckner and McCleave, 1988).

In contrast, few small leptocephali of any shelf or slope species other than *C. oceanicus* were caught in the STCZ. Several recently spawned leptocephali of *C. oceanicus* (4 specimens 7–11 mm) were caught during 831, but only larger specimens (34–75 mm) were caught in the other cruises (Fig. 3C). There was no indication that any of the other shelf or slope species were spawning in the STCZ from February through April, because no recently spawned leptocephali were caught in any of the transects. There were a few small specimens of *Moringua edwardsi* (14 and 18 mm), *Myrophis punctatus* (17 and 20 mm) and *Gnathophis* (18 mm) collected in 831N and three specimens of *Ahlia egmontis* (16 and 19 mm) collected at station 12 of 85W. Leptocephali of this size are probably at least several weeks old and may have been transported into the region sampled by these western transects from areas closer to

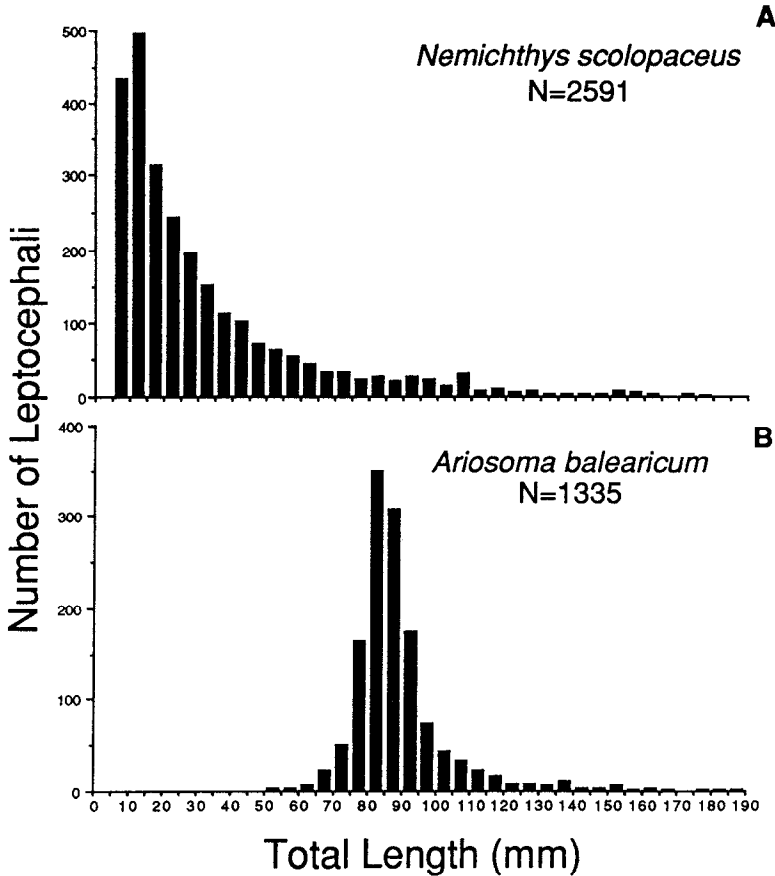


Figure 2. Length frequency distributions for (A) *Nemichthys scolopaceus* and (B) *Ariosoma balearicum* leptocephali collected in the seven transects.

the Bahama Banks. The chlopsids, muraenids and *M. edwardsi* all have about the same maximum length for their leptocephali, and the lengths of most specimens caught in the STCZ were of a relatively narrow range close to their maximum lengths (Fig. 3E).

c. Reduction of catches during daylight. Leptocephali of most taxa were generally less abundant in tows made during daylight. Stations 6–12 at or south of the front in 85E were used to compare catch rates of various taxa between night and day tows. This series of stations consisted of an approximate alternation of five night and seven day tows in the southern half of the transect and offered the least biased opportunity to compare catch rates between night and day. Catch rates in the night tows were significantly higher (one-tailed *t*-test, $p < 0.05$) for *Ariosoma*, *Nemichthys* and *S. beanii* but were not for *S. lanceolatus* or *Eurypharynx*. Catch rates of all the shelf

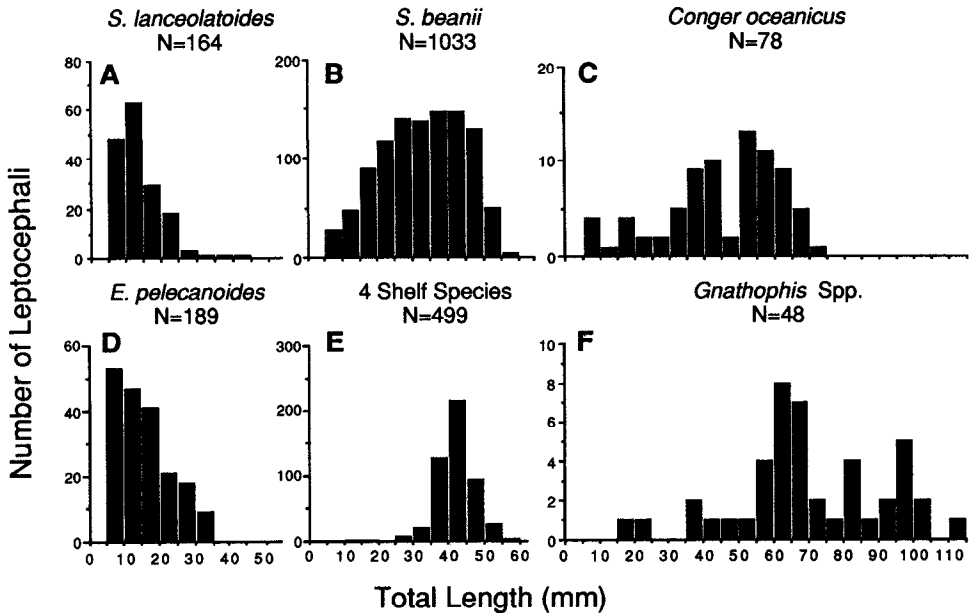


Figure 3. Length frequency distributions for (A) *Serrivomer lanceolatus*, (B) *Serrivomer beanii*, (C) *Conger oceanicus*, (D) *Eurypharynx pelecyanoides*, (E) *Anarchias similis*, *Chilorhinus suensoni*, *Kaupichthys hyoprroides* and *Moringua edwardsi* and (F) *Gnathophis* spp. collected in the seven transects.

species other than *Ariosoma* were pooled and were significantly different between night and day tows ($p = 0.01$, Mann-Whitney test).

4. Hydrography and water mass characteristics

The seven transects were relatively similar in temperature and salinity characteristics below 200 m but were more variable in the upper 200 m where frontal features were most distinct (Kleckner and McCleave, 1988). The temperature structure at the southern ends of the 1985 transects was relatively similar to that of the shorter, nearby 1989 and 1983 transects. A mixed layer of 24°C water in the upper 100 m was encountered in the southern ends of transects 89W, 831S and 832W. The warmest sea surface temperatures (SST) in the other transects were 24°C in 85W, 22°C in 85E and 23°C in 831N and 832E. The coldest SST in the northern ends of the 1985 transects was 19°C and in the northern ends of the shorter transects was 21–23°C.

The majority of the surface water in 1985 had a salinity of 36.6 psu, and this isohaline generally rose from a maximum depth of 240 m in the southern end of both transects to the surface between stations 1 and 2 in the northern ends. The salinity structure in the 1983 transects differed in that these transects had a variable subsurface layer of subtropical underwater (Worthington, 1976; Gunn and Watts,

1982; Olson *et al.*, 1984), with salinities ≥ 36.8 psu. A thin layer of this water extended from the south between depths of about 100 and 175 m, with lower salinity water above and below this layer (Kleckner and McCleave, 1988).

Wegner (1982) used density to differentiate the adjacent water masses that are found in the STCZ. The northern Sargasso Sea surface water and 18°C water (Worthington, 1959) were characterized as having densities greater than σ_t 26.2, which correlates to an approximate temperature of 18.2°C and a salinity of 36.6 psu. The southern Sargasso Sea surface water (SSSW) was characterized as having densities less than σ_t 25.6 and an approximate temperature-salinity correlation of 21.5°C and 36.6 psu. The water between these two water masses was termed mixed convergence zone water (MCZW) and had densities between σ_t 25.6 and 26.2. In the present study, the MCZW formed a layer approximately 100 m thick that remained between 100–200 m in 831, shoaled to about 50 m in 89W and 832W, shoaled to the surface in a small segment of 832E and generally formed a surface layer in the northern half of both 1985 transects. In contrast to the 1985 transects in which only half of the stations sampled SSSW, all of the 89W and 1983 stations, except 832E station 3, sampled SSSW.

Each transect crossed frontal features, but the density structure of these fronts was variable among the transects. The most distinct density front in 85E occurred just south of station 6, and this location corresponded to the southernmost point where MCZW was found at the surface (Fig. 4D). The density structure along 85W differed considerably from that of 85E. The minimum density in 85W was σ_t 25.0 in the southern end (25.3 in 85E) and the 25.6 isopycnal rose abruptly to the surface just south of station 9 defining a pool of SSSW about 170 m deep (Fig. 5). Another small pool of this water was present between stations 6 and 8. This pattern of two relatively deep pools of SSSW south of station 6 was in contrast to the shallower lens of this water that extended between station 6 and 12 in 85E (Fig. 4D). In 85W, the most distinct density front reached the surface just south of station 9 and separated MCZW from the southern pool of SSSW. Other density fronts reached the surface just south of stations 5 and 10 in 85W (Fig. 5). The six stations of the westernmost transect 89W were distributed from a front at the southern end of the transect to where the MCZW shoaled to a depth of 40 m in the north (surface temperature range of 21–24°C). A density front reached the surface just south of station 5 in 831N, and there was a diffuse front in the northern third of 831S (Fig. 1). In the 832 transects in the east, the layer of MCZW was closer to the surface in the northern ends than in 831. In the northern half of 832E, the MCZW reached the surface for a distance of about 12 km. SSSW was present on both sides of this thin ridge of MCZW, and a distinct front was present on the southern edge of the ridge. The MCZW did not reach the surface in 832W and only reached a minimum depth of 50 m in the north. An indistinct front reached the surface between stations 4 and 5 in

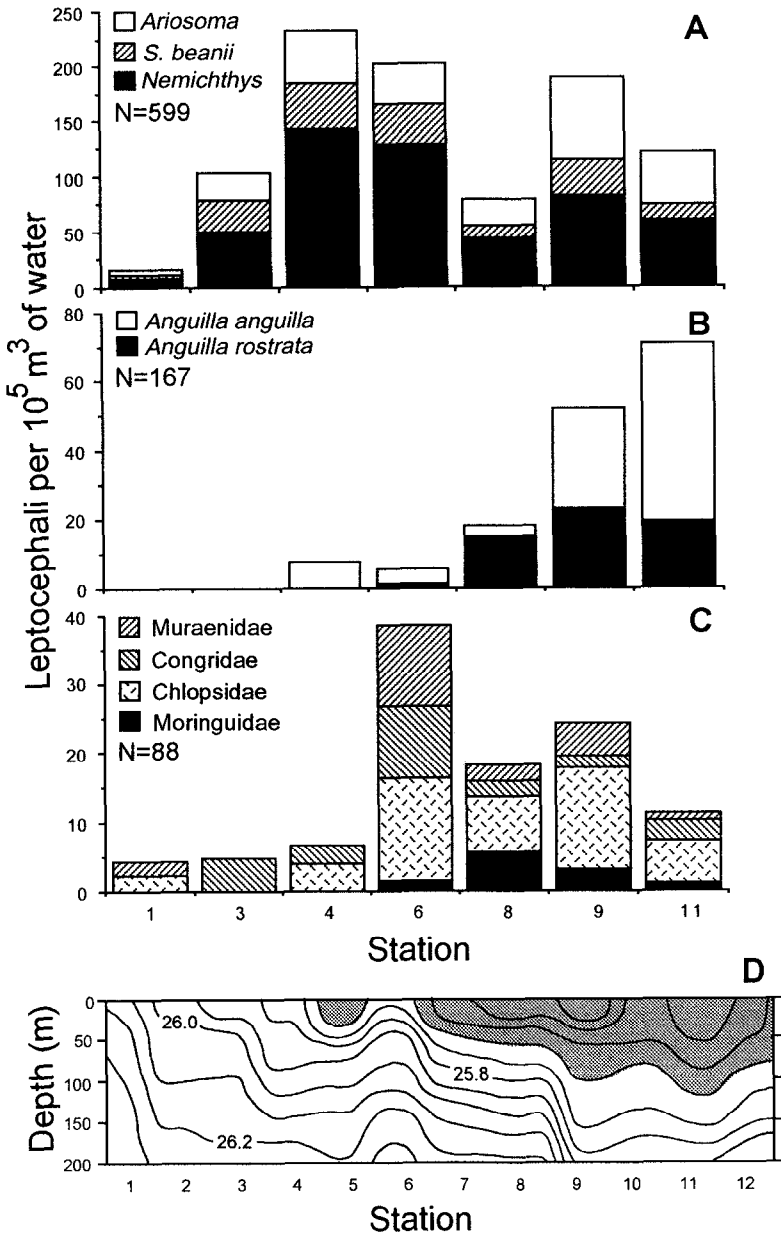


Figure 4. Catch rates of (A) *Ariosoma balearicum*, *Serrivomer beanii* and *Nemichthys scolopaceus*, (B) the two species of *Anguilla* and (C) all shelf species other than *A. balearicum* pooled by family at each night station along 85E. The total number of leptocephali from these stations is shown for each panel. (D) Density section of 85E showing the station locations along the transect. The presence of SSSW ($\sigma-t < 25.6$) is indicated with shading. The north end of the transect is to the left and the south to the right.

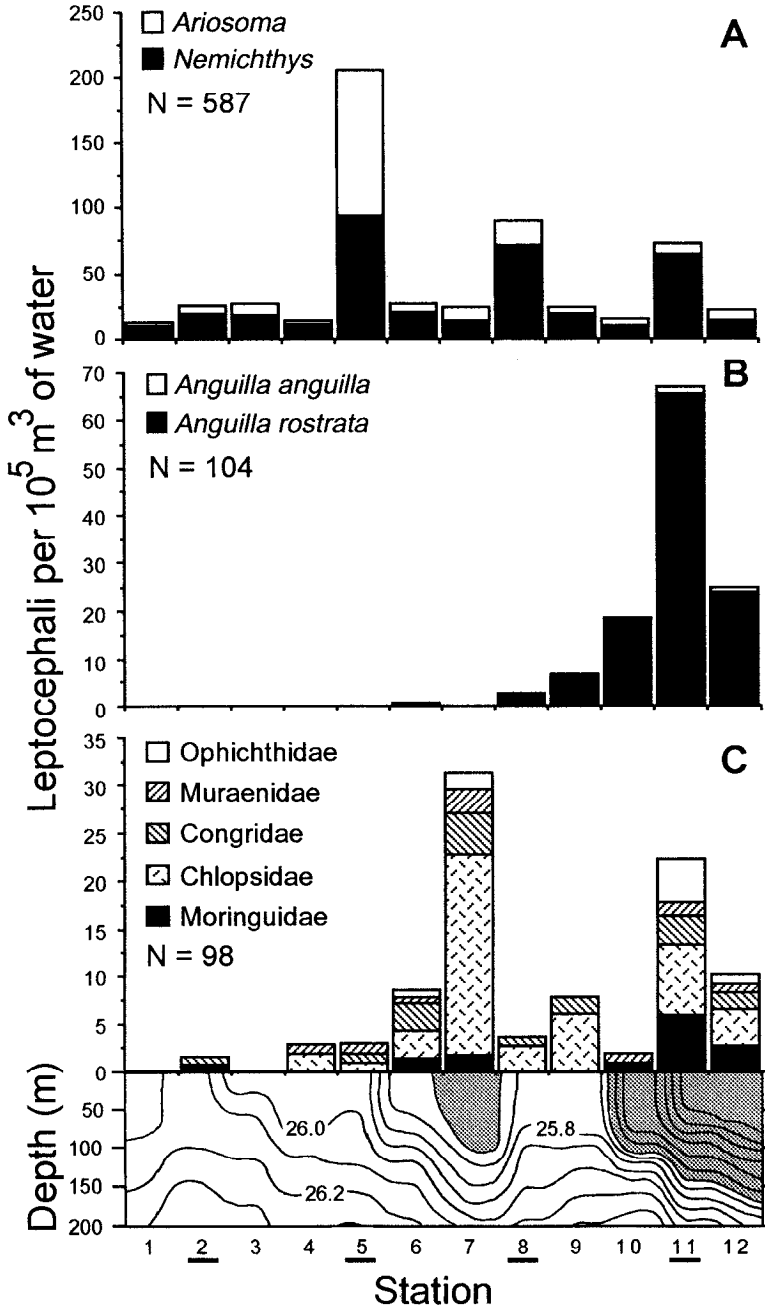


Figure 5. Catch of (A) *Ariosoma balearicum* and *Nemichthys scolopaceus*, (B) the two species of *Anguilla* and (C) all shelf species other than *A. balearicum* and *Anarchias similis* pooled by family at each station along 85W, superimposed on a density section of 85W, with shading indicating SSSW ($\sigma-t < 25.6$). The total number of leptocephali from these stations is shown for each panel. Stations with two night tows are underlined. The north end of the transect is to the left and the south to the right.

the central part of 832W. Kleckner and McCleave (1988) included temperature, salinity and density sections of all the 1983 and 1985 transects.

5. Distribution of leptocephali in relation to water density

Several trends were present in the distributions and catch rates of leptocephali in the transects. One consistent trend in all the transects was that most of the major taxonomic groups showed contrasting along-transect distributions of catch rates. The distribution of rare shelf species (all shelf species except *Ariosoma* and *Anarchias*) was different from the distributions of *Ariosoma*, *Anguilla*, *Nemichthys* and *S. beanii* within all of the transects analyzed ($p < 0.01$ for *S. beanii* in two 1983 transects; $p < 0.001$ for other comparisons). The distributions of *Ariosoma*, *Anguilla*, and the two most abundant oceanic species in each transect were usually different from one another ($p < 0.001-0.05$), with a few exceptions noted below in the descriptions of individual taxa. In addition, each of these five major species or groups of species was not uniformly distributed along each transect ($p < 0.001-0.05$) except for the rare shelf species in 831S.

a. Rare shelf species. In the two long 1985 transects, the rare shelf species were generally more abundant at or south of frontal features in stations that sampled SSSW. Catch rates of rare shelf species in 85E were greatest at station 6 near the front, decreased in stations to the south and were low in all the stations to the north (Fig. 4C, D). Fourteen rare shelf species of 12 genera were caught in the five night tows from station 6 southward, but only five species of four genera were caught in the five night tows of the northern stations. This discontinuity between the assemblages of rare shelf species corresponded approximately to the northern limit of SSSW (Fig. 4D). Although the most diverse assemblage was at station 6, which was in the southern edge of the MCZW, profiles of velocity across fronts in this region (Eriksen *et al.*, 1991; Weller *et al.*, 1991; Pollard and Regier, 1992) indicate that station 6 was close to the likely location of a frontal jet associated with the surface expression of the density front. Just to the west in 85W, the hydrographic structure was more variable, and this variability was reflected by the distributions of rare shelf species along this transect. The highest catch rates of rare shelf species occurred at or south of station 7, in the two pools of SSSW (Fig. 5C). The highest catch rates of chlopsids, congrid, and muraenids were at station 7 despite the fact that both tows at this station were day tows. Twelve rare shelf species were collected in stations 11 and 12, and 13 rare shelf species were caught south of the northernmost front in stations 6 and 7, which included only one night tow. Two night tows at station 8, in MCZW between the two pools of SSSW, collected only two rare shelf species. Catch rates for most shelf species were also low north of the fronts in stations 1-5, which included four night and six day tows, all in MCZW. Only six rare shelf species were caught in these ten tows. These low catches in MCZW stations, and the location of the stations with greater abundances and numbers of rare shelf species within the two pools of

SSSW in 85W, are congruent with the association of the diverse assemblage of shelf species with the distribution of SSSW observed in 85E.

Although the shorter transects did not cross the transition between SSSW and MCZW, rare shelf species appeared to be most abundant at or just south of frontal features. In 89W, there was a marked difference between the high catch rates at station 6, at the southern edge of the front, and lower catch rates north of the front. The catch rates of rare shelf species at station 6 were higher than at any other station of this study (Fig. 6A). The leptocephali of *C. oceanicus* ($n = 28$), *M. edwardsi* ($n = 30$), the two common chlopsids ($n = 53$) and ophichthids of three species ($n = 22$) were unusually abundant in the two tows at station 6. At least 22 shelf species were collected at station 6, but only 13 shelf species were collected in the two night stations north of the front, with Ophichthidae the only shelf family not represented there. There was also a discontinuity in the distributions of rare shelf species across a front to the southeast in 831N. Catch rates of rare shelf species in both night (Fig. 6B) and day stations north of the front in 831N were lower than in all the stations south of the front. At least 12 rare shelf species collected south of the front were absent in northern stations, but this may have been biased by fewer night tows in the north. Farther southeast in 831S, there was a diffuse frontal feature at the northern end of the transect, but the distribution of catch rates of the rare shelf species were not significantly different from uniform in this transect. Nighttime catch rates of rare shelf species ranged from 17 to 39 leptocephali per 10^5 m^3 , which was comparable to those of stations 6–9 in 831N. The most unusual aspect of this transect was that *C. oceanicus* was the most abundant rare shelf species (Table 1), and a wide range of sizes (7–70 mm) was collected throughout the transect, including the smallest leptocephali of this study. To the northeast in 832W, rare shelf species appeared to be more abundant south of the front, and their catch rate was greatest at station 8 (Fig. 6C). The night tow at this station collected as many leptocephali of these species as all other tows in this transect combined, with a catch rate comparable to most SSSW stations to the west. The 832E transect was much farther east than the others and abundances of shelf species there were low in comparison (Table 1).

b. Ariosoma and Anarchias. The leptocephali of *Ariosoma* and *Anarchias* were distributed throughout the transects, but their catch rates were variable and did not show consistent patterns relative to density structure within each transect. In contrast to the rare shelf species, *Ariosoma* and *Anarchias* were collected in substantial numbers in several of the MCZW stations of both 1985 transects but were generally less abundant in the northern stations. In 85E, *Ariosoma* had substantial catch rates at and on both sides of the front (Fig. 4A, D). *Ariosoma* were caught in small numbers throughout 85W (Fig. 5A), but 56% of the 85W specimens were from station 5, just north of the northernmost front. *Anarchias* was collected at almost

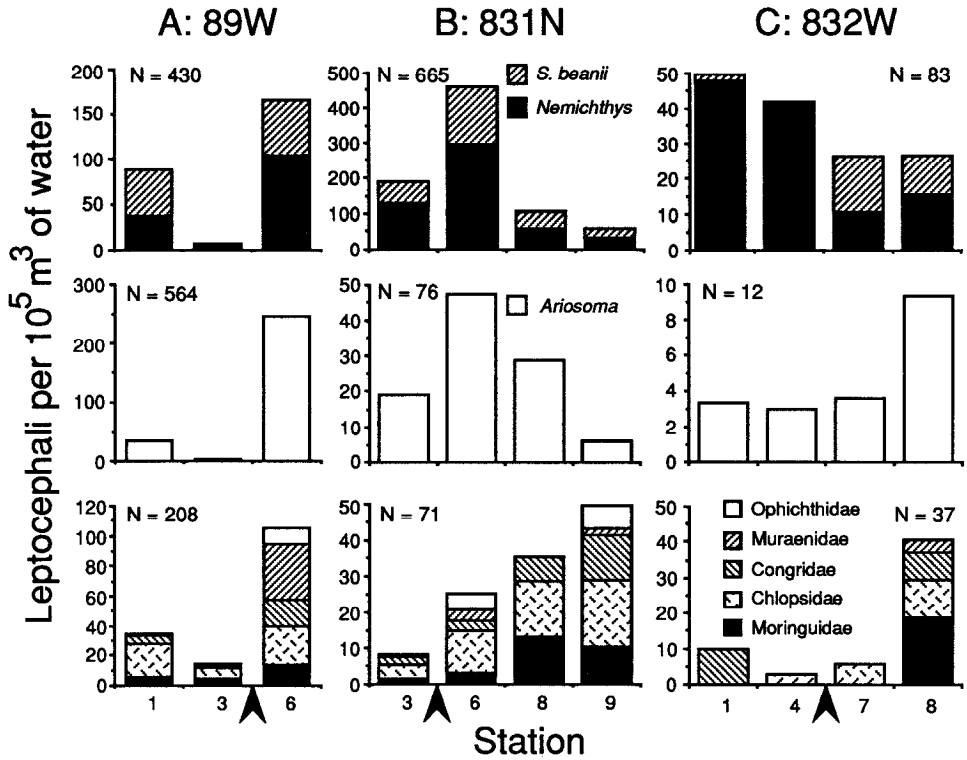


Figure 6. Catch rates of *Serrivomer beanii*, *Nemichthys scolopaceus*, *Ariosoma balearicum* and all shelf species other than *A. balearicum* and *Anarchias similis* pooled by family at each night station of (A) 89W, (B) 831N and (C) 832W. The general location of the front in each transect is indicated by an arrowhead.

every 1985 station and had comparable catch rates at some stations in both water masses.

In the SSSW sampled by the shorter transects, *Anarchias* and *Ariosoma* were most abundant at stations within or south of the frontal features. In the westernmost transect 89W, the catch rate of *Ariosoma* at station 6 ($n = 525$) at the southern edge of the front was higher than at any other station of this study (Fig. 6A). The leptocephali of *Ariosoma* and *Anarchias* were generally caught in at least small numbers throughout 831N, but *Ariosoma* was most abundant at station 6, just south of the front (Fig. 6B). In 831S, *Ariosoma* had variable catches at and south of the diffuse front in the north, but *Anarchias* was only caught in the northern half of the transect. To the northeast, the catch rates of *Ariosoma* (Fig. 6C) and *Anarchias* in night tows of 832W were greatest at station 8 south of the front. The greatest catch rate of *Ariosoma* in 832E was in the day tow of station 4 at the surface expression of the density front, which formed along the interface between the SSSW and the ridge of MCZW. *Anarchias* was more abundant relative to other shelf species in this

easternmost transect than in others, and was most abundant at and to the north of the ridge of MCZW.

c. Oceanic species. There were relatively high catch rates of oceanic species at stations in both SSSW and MCZW and these species were usually found throughout the transects. The less abundant oceanic species, *Eurypharynx*, *S. lanceolatus* and Cyematidae spp. showed no consistent patterns of distribution relative to density structure. *Nemichthys* and *S. beanii* were less abundant in the northernmost 1985 stations and in the southernmost 1983 stations, but had relatively high catch rates at some stations located on both sides of fronts. In 85E, *Nemichthys* and *S. beanii* were not distributed differently along the transect ($p > 0.1$) and their catches were variable in both the SSSW and MCZW stations with station 1 in the north having a conspicuously lower rate for both species (Fig. 4A, D). The distributions of oceanic species in 85W (Fig. 5A) were generally similar to those in 85E, but their abundances were much lower (Table 1). Because 85W had one fewer night tow in general and two fewer night tows in SSSW than 85E, the lower abundances of *Serrivomer* and *Nemichthys* in 85W may have been related to the amount and location of night sampling relative to the hydrographic structure of each transect.

Oceanic species also had variable catch rates on both sides of fronts in the shorter transects. These species had relatively high catch rates at some of the 89W stations in the west. The catch rates of *Nemichthys* and *S. beanii* were greatest at station 6 at the front and lowest at station 3 near the northern edge of the front (Fig. 6A). However, the catches of *Eurypharynx* ($n = 12$) and Cyematidae spp. ($n = 6$) at station 3 were the largest of any tow of this study. To the southeast in 831N, station 6 was the closest night tow to the surface expression of the front and had the highest catch rates of *Nemichthys* and *S. beanii* (Fig. 6B) of this study. The distributions of *Nemichthys* and *S. beanii* in this transect were not different ($p > 0.1$), and their pooled distributions were not different than that of *Ariosoma* ($p > 0.05$). There were generally fewer leptocephali of oceanic species collected in 831S than in 831N (Table 1), and most species were more abundant to the north in the diffuse frontal feature. The catch rates of *Nemichthys* in 832W were greatest at stations 1 and 5, and the catch rate of *S. beanii* was greatest at station 7 (Fig. 6C). The greatest catches of *S. lanceolatus* were in the night tows at stations 5 and 6 of 832E just south of the front and in the day tow at station 1 north of the ridge of MCZW. The catch rates of *S. beanii* were greatest at stations 7, 8, 9 (all day tows) and 2, but were low compared with most of the other transects. The catch rate of *Nemichthys* at station 3 (68 leptocephali per 10^5 m^3) in the narrow band of MCZW (Fig. 1), was higher than at any station of 831S or 832W, but this species was rare south of the front.

d. Anguilla. The two species of *Anguilla* showed east-west variations in relative abundance within and among cruises and transects (Table 1, Fig. 4B, 5B) and were

clearly more abundant south of the fronts and in the more southerly SSSW stations of 85E and 85W, than north of the fronts in MCZW. Their distributions were shifted more to the south than those of the rare shelf species and were not collected in the small pool of SSSW at station 7 of 85W (Fig. 4B, 5B). *Anguilla anguilla* were rare in 85W, and no leptocephali of either species were captured north of station 6 in 85W or north of station 4 of 85E. *Anguilla* leptocephali were also rare to the west in 89W and 831N (Table 1), but at least one species was collected throughout 831S, 832W and 832E (Kleckner and McCleave, 1988). The highest catch rates of *A. anguilla* of this study were in the easternmost transect 832E.

6. Cluster analysis and ordination of station assemblages

The dendrograms produced by the cluster analysis showed patterns that appeared to be related to the greater abundances and number of species in the western transects and the impoverished assemblages of shelf species at MCZW stations away from fronts and in the easternmost transect (832E). The major clustering patterns generated by both the 40 taxa analysis (13 families of shelf, oceanic, slope and *Anguilla* species) and the 29 taxa analysis (five shelf families from the first analysis) were similar in structure and general composition of stations. These two dendrograms had two large clusters and one small cluster that were labeled I, II and III, respectively (Fig. 7). The composition of stations in clusters I and II was almost identical between the two dendrograms, suggesting that because the shelf taxa were in both analyses, the compositions of shelf taxa were largely responsible for the formation of the three major clusters in the 40 taxa dendrogram. To test statistically the differences between the three major clusters in each analysis, a Monte Carlo test (Roff and Bentzen, 1989; McElroy *et al.*, 1992) was used to compare the overall distributions of the catch rates of all the taxa in clusters I, II and III within both the 29 and 40 taxa dendrograms. The distributions of catch rates in all three clusters were significantly different from each of the other two clusters within both dendrograms ($p < 0.001$).

Cluster I of both dendrograms included most of the 1985 MCZW stations, all or most of the 832 stations, 85E station 11, and the same three 831 stations that were either north of the front or farthest from it in the south (Fig. 7). The two 832 stations that collected the most shelf species were the only stations that changed major cluster location between the two, by grouping with cluster II in the 29 taxa dendrogram but not in the 40 taxa dendrogram. Cluster I had a lower overall catch rate than clusters II and III for 24 of the 40 taxa. The catch rates of rare shelf species were especially low in cluster I compared to clusters II and III (Table 2). *Anguilla anguilla* was the only common species that had the highest catch rate in cluster I, and this was due to the high catch rates of this species at the 832W and 832E stations that had low catch rates of shelf species.

Cluster II in both dendrograms contained primarily 831, 1989 and 1985 stations

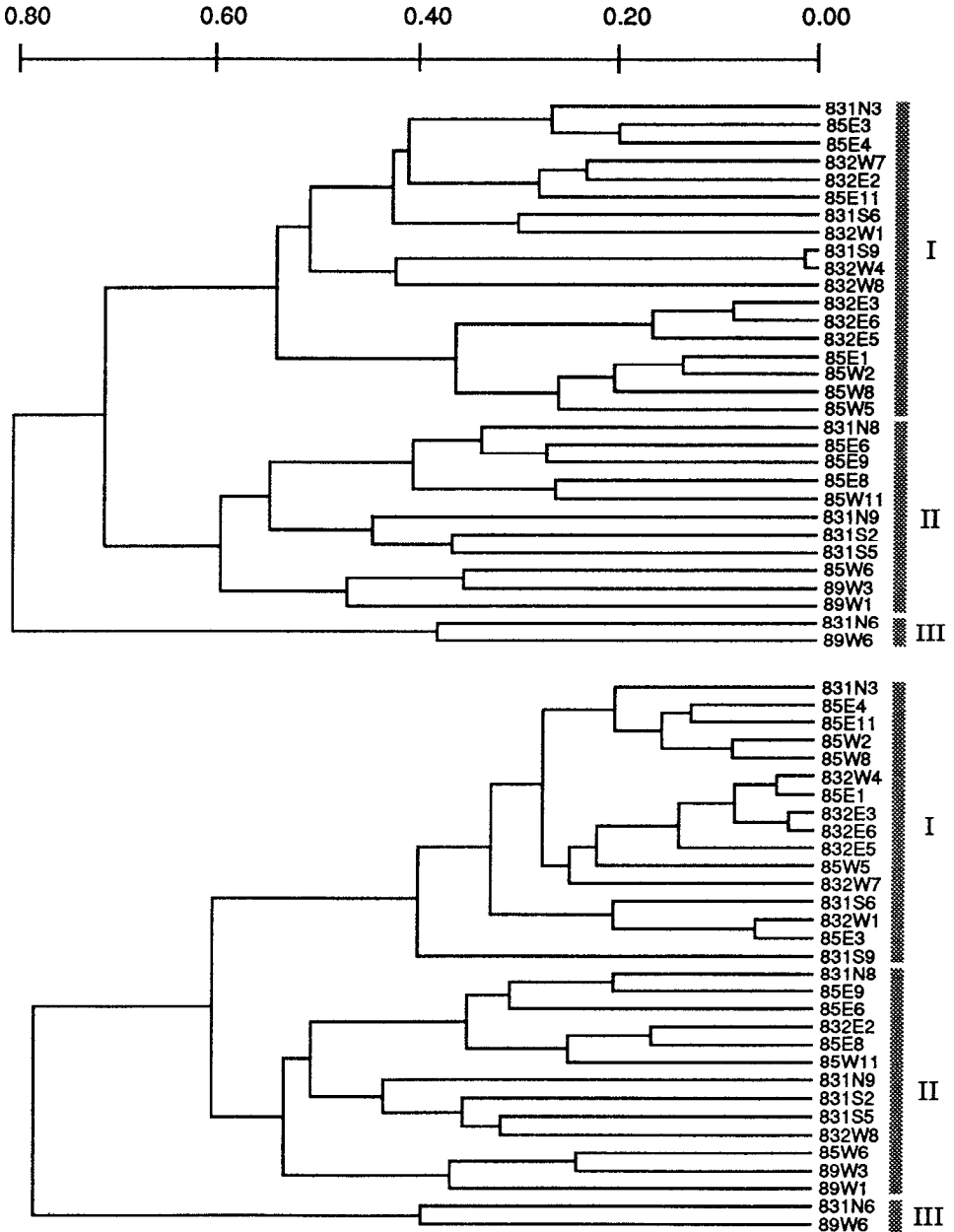


Figure 7. Dendrograms from cluster analysis using the assemblages of (A) 40 taxa of shelf, slope and oceanic species and (B) 29 taxa of shelf species, at the 31 night stations.

Table 2. The overall catch rates of various taxa (expressed as leptocephali per 10^5 m³ of water filtered) at the stations included in each of the three clusters of the 40 taxa dendrogram. Taxa are characterized by their adult life histories as either oceanic (OC), slope (SL), shelf (SH) or catadromous (CT).

Taxa of leptocephali	Life history	Cluster group		
		I	II	III
Rare shelf species (total)	SH	7.1	25.8	63.2
— <i>Conger oceanicus</i>	SH	0.7	1.6	10.2
— <i>Moringua edwardsi</i>	SH	1.1	4.6	11.2
— <i>Chilorhinus suenisoni</i>	SH	1.2	4.6	12.6
— <i>Ophichthidae</i>	SH	0	1.3	8.7
<i>Ariosoma balearicum</i>	SH	23.6	25.8	199.1
<i>Anarchias similis</i>	SH	2.3	5.3	2.1
<i>Nemichthys scolopaceus</i>	OC	54.0	52.8	149.6
<i>Serrivomer beanii</i>	OC	14.4	22.3	85.3
<i>Serrivomer lanceolatoides</i>	OC	3.5	3.2	3.8
<i>Eurypharynx pelecanoides</i>	OC	2.3	6.3	2.8
<i>Anguilla rostrata</i>	CT	5.6	11.2	0
<i>Anguilla anguilla</i>	CT	11.3	3.5	0

(Fig. 7) that sampled SSSW and, except for 89W stations 1 and 3, were at or south of fronts crossed during the transects. The overall catch rates of most taxa were higher in cluster II than in cluster I, but were generally lower than Cluster III (Table 2). Station 6 in 85E had high catch rates of most shelf and oceanic species, and station 6 in 85W had high shelf species richness (Fig. 4, 5). These were the only stations in cluster II that were located in MCZW. However, both were at or south of the northernmost front in each transect and may have been within or close to the frontal jets that are usually associated with these features.

Cluster III of both dendrograms contained the two stations that were closest to the southern side of the fronts in the two westernmost transects and had unusually high catch rates of both shelf and oceanic species (Table 2). Station 6 of 89W had the highest catch rate and species richness of shelf species of any station, and station 6 of 831N had the second greatest species richness, as well as the highest catch rates of *Nemichthys* and *S. beanii* of this study (Fig. 6).

The cluster analysis using the assemblages of 18 taxa of oceanic, *Anguilla* and shelf species (rare species pooled by family) was designed to describe the basic assemblage structure of the region by reducing the bias of random co-occurrences of rare species. This analysis resulted in a dendrogram with two major cluster groups (not shown) that were also statistically different from each other ($p < 0.001$) using the Monte Carlo test. These two clusters had the same general composition of stations as the dendrograms from the 29 and 40 taxa analyses (Fig. 7), except the two high catch rate stations of cluster III were included in cluster II, and the stations within the two major clusters tended to be grouped more by cruise. The dissimilarity matrices

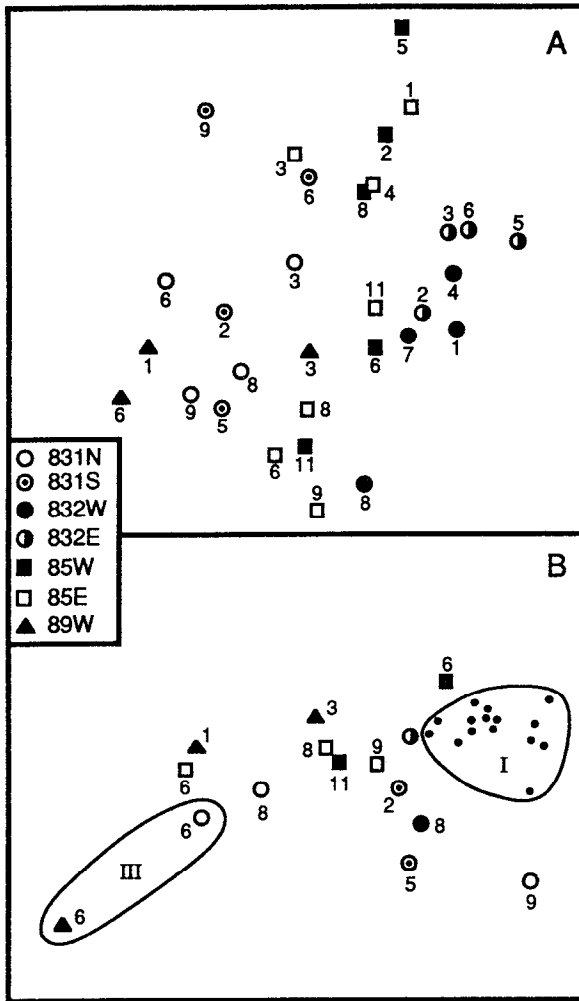


Figure 8. Multidimensional scaling of the assemblages of (A) 18 shelf, slope and oceanic taxa (stress = 0.33) and (B) 29 shelf taxa (stress = 0.20) at the 31 night stations. The transects are coded with symbols, and stations within transects are indicated with numbers. The stations in cluster I (stations not identified) and cluster III from cluster analysis (Fig. 8B) are circled in the 29 taxa panel.

generated for the three dendrograms, were used to create multidimensional scaling (MDS) plots.

The MDS plots for the three analyses were similar in their general characteristics with the distribution of points (station assemblages) showing partial geographic analogies to the actual relative locations of the transects. The two-dimensional plot of the assemblages of 18 taxa showed the most distinct distribution of stations in the analogous east-west and north-south axes (Fig. 8A). In this plot, the 831 and 1989

stations were in the left half, the 1985 stations were in the middle and all but one of the low species richness and abundance stations of 832 were in the right half of the plot. There was also some indication of clumping of most of the 1985 MCZW stations in the top half and the 1985 SSSW stations toward the bottom of the plot. The major exception to this was station 6 of both 85E and 85W, which were in MCZW close to the front, had high catches of shelf species and did not group with the other MCZW stations in the plot.

The MDS plot of the assemblages of shelf species (Fig. 8B) had some similar spatial trends to the 18 taxa plot, but the 1985 MCZW and 832 stations of cluster I were grouped closer together, and there was less spread of points between top and bottom than there was in the first plot. The two stations that formed cluster III in the shelf species dendrogram were located in the lower left of the plot. This plot supports the general trend described by the separation of stations into three major clusters, but also indicates that the assemblages of shelf species form a continuum from high diversity and abundance in the west to impoverished assemblages in the east and in MCZW. Although most similar to the 29 taxa plot, the station assemblages in the MDS plot for the 40 taxa analysis (not shown) were spread more in all three dimensions and the relationships were less informative when viewed in two dimensions.

7. Discussion

The longer 1985 transects crossed fronts located at the boundary between MCZW and SSSW and provided the clearest examples of discontinuities in assemblages of leptocephali. Differences between the assemblages of leptocephali in stations that sampled the two water masses were indicated by both the along-transect catch rates and the relationships of the 1985 stations within the dendrograms and MDS plots. The most distinct trend in catch rates was the impoverished assemblage of *Anguilla* and rare shelf species found in MCZW north of fronts (Fig. 4, 5). This trend was also expressed by the splitting of most of the 1985 stations in the dendrograms (Fig. 7) and in the MDS plots (Fig. 8), in accordance with their general locations relative to the fronts.

The distributions of the rare shelf species were largely responsible for these relationships in the dendrograms and MDS plots, as the catch rates of *Ariosoma*, *Anguilla* and the oceanic species were different from those of the rare shelf species relative to the locations of fronts in these transects. The same pattern of three major cluster groups seen in the 29 shelf taxa dendrogram was seen in the 40 taxa dendrogram, despite the different distributions of the oceanic and *Anguilla* species. The rare shelf species had high catch rates up to the northernmost fronts, but the catch rates of *Anguilla* were greatest farther south, away from the likely location of frontal jets (Fig. 4, 5). The oceanic species, which appeared to be spawning within the STCZ, and *Ariosoma* did not show discontinuities across fronts in the 1985 transects.

The three shorter transects that sampled both sides of a front also showed differences in catch rates among some of the ecologically different species (Fig. 6), but they did not sample the transition between the two water masses. The significance of the various patterns of catch rates in the shorter transects was difficult to assess because the distribution of night tows along each transect was inadequate for describing potential discontinuities across the fronts.

The hydrographic characteristics of the shorter transects suggested that the frontal features in these transects may have been part of the more southern of two bands of fronts that often form in the STCZ (Böhm, 1988; Halliwell *et al.*, 1991; Weller, 1991). Composite traces of SST fronts in AVHRR satellite images for February and April 1983 (Böhm, 1988), which included the area in which the 831 and 832W transects were made, indicated another band of fronts was present north of the band sampled by the transects in both months. The fronts in 1983 and 1989 were associated with the 25.0 isopycnal (Fig. 1). Further evidence of this pattern was seen in a density section along a transect at about 60W, which crossed the STCZ in 1979 (Wegner, 1982). This section showed a front at about 23N, which was also associated with the 25.0 isopycnal, and a second front at about 27N, at the boundary between the SSSW and MCZW.

If the 89W, 831 and 832W transects were south of a northern band of fronts, it is possible that another region with a relatively rich assemblage of shelf species, like those associated with the fronts in the 85 transects, was present at the northern fronts. The close proximity of the layer of MCZW to the surface in the north end of 832W and 89W suggested that another front was present just to the north of both transects. Although the shelf assemblage at the 89W northernmost station 1 had a lower catch rate and fewer shelf species than station 6 at the southern edge of the front, it was located close to station 6 in the MDS plots and had a relatively rich assemblage of shelf species in comparison to other stations in SSSW. This station may have reflected another region with greater densities of shelf species associated with the northern front. A more distinct discontinuity in shelf assemblages may have been present across the northern fronts at the boundary between the two water masses.

Faunal discontinuities across oceanic fronts have also been observed in the distributions of mesopelagic fishes. Backus *et al.* (1969) observed a discontinuity in the mesopelagic fish assemblages across the STCZ in June 1963, which corresponded to the location of a temperature front separating the warmer mixed layer from the colder stratified water of the northern Sargasso Sea. In contrast to the trends observed for leptocephali, there was a greater number of species of mesopelagic fishes north of the front. Collections of mesopelagic fishes at stations within and on both sides of a mixing zone between two water masses in the subtropical convergence zone near New Zealand also showed a discontinuity across the frontal zone (Robertson *et al.*, 1978). Similar discontinuities in mesopelagic fish assemblages across fronts

separating two water masses have been described in association with warm-core rings of the East Australian Current (Brandt, 1981) and cold-core rings of the Gulf stream (Backus and Craddock, 1982). A study of a Gulf Stream warm-core ring found that one species of mesopelagic fish, which was originally more abundant in the water surrounding the ring, appeared to be accumulating in the front at the edge of the ring as a result of convergence (Olson and Backus, 1985). The authors proposed that simple maintenance of depth by the fish would result in convergence accumulating them at the front.

Leptocephali are also capable of basic depth regulation. Some species show evidence of vertical migrations down to 250–300 m during the day, while others appear to stay within the upper 100 m (Castonguay and McCleave, 1987b; Schoth and Tesch, 1984). Leptocephali that remain in or periodically enter the upper 100 m should become concentrated at fronts by convergence. The discontinuity in the assemblages of the leptocephali of the rare shelf species between the two water masses in the STCZ, and the greater concentrations of these species within or close to some of the fronts, suggested that leptocephali may have accumulated within the fronts by convergence from the south. The tows closest to the south side of fronts in the two westernmost transects, 89W (station 6) and 831N (station 6), had the highest overall catch rates of leptocephali of all the tows in this study. Although the collection of exceptionally large numbers of *Nemichthys* and *S. beanii* in the 831N station and *Ariosoma* in the 89W station were largely responsible for the much greater catch rates, these stations also collected more species and generally had higher catch rates of most oceanic and shelf species than other stations in either water mass. The highest catch rate of rare shelf species in 1985 was at 85E station 6, the closest station to the front at the boundary between the MCZW and SSSW.

Similar transitions between these two water masses, such as occurred at the northern edge of fronts in the 1985 transects, have been documented in other density sections from this region (Wegner, 1982; Pollard and Regier, 1992). One of the major fronts studied during the Frontal Air-Sea Interaction Experiment in 1986 had the 25.6 isopycnal, which separates MCZW and SSSW, at the northern edge of the front in each of eight density sections along more than 100 km of the front (Pollard and Regier, 1992). Several of these sections showed the same pattern of eddies of SSSW north of the front that was seen in both the 1985 density sections (Fig. 4, 5). Acoustic Doppler current profiler (ADCP) data from the 1986 transects indicated that surface water was converging towards the front on both sides (Eriksen *et al.*, 1991; Pollard and Regier, 1992). The similar density structure and relationship between the two water types in the 1985 sections of this study suggested there were similar patterns of convergences and jets along the fronts crossed by the 1985 transects.

Leptocephali should be subject to the influences of the convergence of surface water toward the fronts because most species appear to occupy the upper 100 m of the ocean (Schoth and Tesch, 1984; Castonguay and McCleave, 1987b; Kajihara *et*

al., 1988; M. J. Miller unpublished data). If the leptocephali of shelf species originated outside of the frontal zones to the south or west, they may have accumulated at fronts by convergence and been transported by frontal jets from the western corner of the Sargasso Sea into the frontal zone farther offshore. ADCP sections in this region indicated that the core of these frontal jets can be at least 20 km wide and 150 m deep, with speeds as high as 50 cm s^{-1} (Mied *et al.*, 1986; Eriksen *et al.*, 1991; Pollard and Regier, 1992). An ADCP section of the 1989 transect indicated that the southernmost station 6 of this transect was within a broad band of eastward flow with speeds as high as 36 cm s^{-1} (A. Haro, unpublished data). Although these frontal jets are narrow relative to the scale of the STCZ, they may transport significant volumes of water eastward and might be an important mechanism for transporting leptocephali from regions of greater abundance around the banks of the northern Bahamas in the west to offshore areas in the STCZ. These banks comprise the largest amount of warm water shelf habitat adjacent to the Sargasso Sea, and many eel species are found there (Böhlke and Chaplin, 1968; Böhlke, 1989).

There are several possible circulation patterns that may contribute to the transport of leptocephali of shelf species from the Bahama Banks region into the frontal zone of the STCZ. Northward transport of these leptocephali from the southern Bahama Banks and the Lesser Antilles may occur as a result of Ekman surface drift caused by the prevailing westward direction of the trade winds in the southern Sargasso Sea. Transport of shelf species into the western edge of the frontal zone could result from recirculation of water from the Florida Current, which flows north along the western edge of the Bahama Banks (Leaman *et al.*, 1987), into the complex eddy region north of the banks (Amos, 1971; Ingham, 1975; Olson *et al.*, 1984). Water from the Florida Current also passes through the northwest Providence Channel (Richardson and Finlen, 1967; Leaman and Molinari, 1987). If leptocephali are transported farther east through the Providence Channel, they could entrain into an anticyclonic circulation cell that exists, at least seasonally, off the northeast corner of the northern Bahamas (Stommel *et al.*, 1978; Gunn and Watts, 1982; Fiadeiro and Veronis, 1983; Olson *et al.*, 1984; Rosenfeld *et al.*, 1989; Lee *et al.*, 1990). One hypothesis that accounts for several aspects of the distribution and abundance of shelf species in this study is that this circulation cell may transport leptocephali from regions north and east of the Bahama Banks (with a diverse assemblage of leptocephali) to areas where the leptocephali become entrained by convergence into the net eastward flow of surface water associated with the fronts. Once in the fronts, leptocephali would be transported to offshore areas of the STCZ.

This mechanism, and the greater potential influence of convergence in the west where fronts are closer to large shelf areas, may account for some of the general trends observed in this study. The apparent continuum of station assemblages in the MDS plots in analogous east-west and north-south directions, and the general

reductions in diversity and abundances of the leptocephali of shelf species to the east and north of fronts, could be created by eastward transport in, and convergence into, both bands of fronts in the STCZ. This eastward flow could also transport some species of oceanic leptocephali from the area of apparently greater concentrations in the west to more offshore areas in the STCZ. The greater abundances of *S. lanceolatooides* and *A. anguilla* in the easternmost 832E transect indicated that the low catches of other species there were not due to any bias in sampling efficiency.

The hypothesis that eastward transport of leptocephali in fronts may be an important factor influencing the assemblage structure in the STCZ is indirectly supported by the distribution of *Anguilla* leptocephali. Both species of *Anguilla* had spawned south of the northernmost fronts in the STCZ and had different patterns of along-transect distribution relative to frontal features than most of the shelf and oceanic species. The *Anguilla* leptocephali did not show evidence of spawning in MCZW, as the oceanic species did, nor did they show greater catch rates close to fronts in regions of the likely location of frontal jets, as most shelf species did. The contrasting distribution patterns shown by *Anguilla*, which spawns in the STCZ, and most of the shelf species that appear to originate from the south and west of the STCZ, support the hypothesis of eastward transport of shelf species by the fronts, because there was no indication that convergence was causing accumulation of *Anguilla* at these fronts.

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