Spring 2002 Ichthyoplankton Recruitment to the Delta Nursery Areas of Nueces Bay, Texas

Publication CBBEP – 40
Project Number – 0203
August 2003

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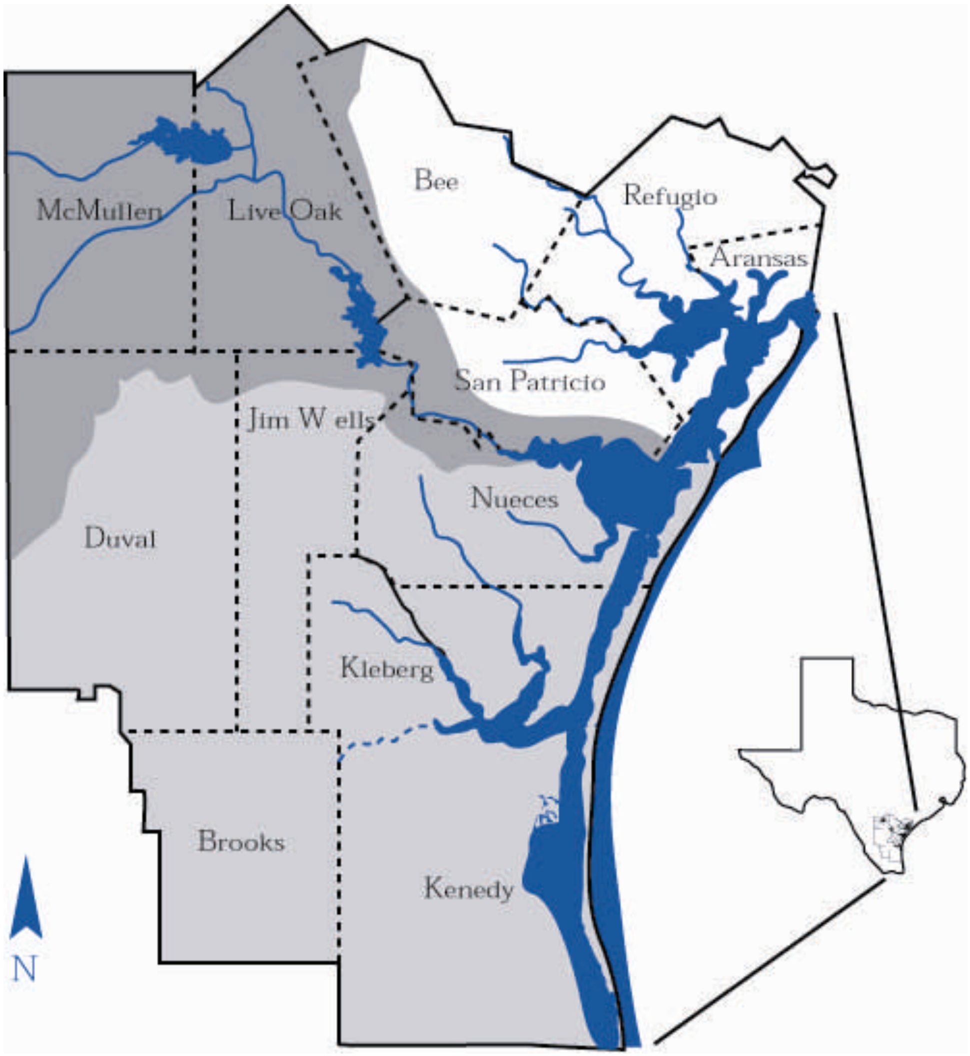

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This project has been funded in part by the United States Environmental Protection Agency (EPA) under assistance agreement #CE-9963-01-2 to the Texas Commission of Environmental Quality (TCEQ). The contents of this document do not necessarily represent the views of the EPA or TCEQ, nor do the contents of this document necessarily constitute the views or policy of the Coastal Bend Bays and Estuaries Program Management Conference or its members. The information presented is intended to provide background information, including the professional opinion of the authors, for the Management Conference deliberations while drafting official policy in the Comprehensive Conservation and Management Plan (CCMP). The mention of trade names or commercial products does not in any way constitute an endorsement or recommendation for use.

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This project was performed with funding from the Coastal Bend Bays & Estuaries Program under contract No. 0203. The Texas Parks and Wildlife Department Coastal Studies Program, Resource Protection Division provided additional interagency cooperation in the form of equipment and field logistical support. This report is a portion of the original work presented by D. Newstead, as part of a Masters Thesis to Texas A&M University-Corpus Christi.

The authors would like to thank the following individuals from the Center for Coastal Studies at Texas A&M University-Corpus Christi. Mr. Brien A. Nicolau-Co-Project Manager, for writing the Quality Assurance Project Plan, overall contract administration, report review and editing; Ms. Erin M. Albert who served as Data Manager; and Mr. Adam Cochran and Mr. Jeffery Landgraf for their laboratory assistance in processing ichthyoplankton samples. We also recognize Mr. Tom Wagner, Texas Parks and Wildlife Department Coastal Fisheries Division, for sharing his knowledge of the Nueces Estuary system.

SPRING 2002 ICHTHYOPLANKTON RECRUITMENT TO THE DELTA NURSERY AREAS OF NUECES BAY, TEXAS

By James M. Tolan, Ph.D. and David J. Newstead

EXECUTIVE SUMMARY

The objective of this study is to quantify the spring season recruitment of larval fishes to the nursery areas of Nueces Bay, Texas, and compare the distribution of fish larvae within the bay in relation to the discharge location of the major riverine input, the Nueces River. Currently, the river discharges into the bay at a location away from the Nueces Delta region - the marsh habitat complex that provides an important nursery area function for many finfish and shellfish species.

Numerous commercially and recreationally important finfish species are considered estuarine-dependent in their early-life-history stages, and as such, they must find suitable estuarine nursery habitats. For species that spawn in areas distant from these nursery areas, planktonic larvae face a wide variety of biotic and abiotic factors that can greatly influence their dispersal into estuaries. These factors can greatly influence larval survival and recruitment, and successful recruitment events can ultimately affect adult populations.

One additional water circulation vector potentially affecting the distribution of larval fish in Nueces Bay was the AEP-Central Power and Light Nueces Bay Power Plant. This structure draws water from the Corpus Christi Ship Channel inner harbor to cool the generators and discharges it into the upper portions of the bay at a rate of about 500 cubic feet per second.

Larval fish sampling was conducted biweekly during spring 2002 (7 Feb to 3 Jun) at four fixed locations along a transect from the bay mouth, through the river discharge zone and up to the front of the delta edge. Two stations were located in the eastern portions of the bay - one at the connection with Corpus Christi Bay and another near the outfall of the AEP-CP&L facility. The two other stations were located in the western half of the bay (i.e., the back bay) - one across from the river discharge location across from White's Point, and the other at the face of the delta. At each Station, triplicate ichthyoplankton collections were taken during daylight hours, and collections were standardized to reflect larval fish densities (numbers per 100 m^3 water filtered). Environmental water quality parameters (temperature, salinity, dissolved oxygen, pH, and turbidity) were recorded prior to ichthyoplankton sampling.

Fish larvae were sorted and identified to the lowest possible taxon, enumerated, and measured to the nearest 0.1 mm. Community structure of the ichthyoplankton among the Stations was determined by ordination techniques, including hierarchical agglomerative cluster analysis and non-metric multidimensional scaling. For each technique, the Bray-Curtis coefficient was employed as the similarity measure for analysis. Length frequencies of the most abundant ichthyoplankton were tested for differences among Stations with the Pearson's Chi-square test statistic. Environmental abiotic data was tested for differences among Stations with a one-way analysis of variance.

Consistent patterns for each environmental variable were seen within Nueces Bay during the spring of 2002. Temperature, salinity, and dissolved oxygen were higher in the eastern parts of the bay (areas closest to the connection with Corpus Christi Bay), whereas lowest mean values were found in the western parts of the bay (back bay Stations nearest to the delta region). Only salinity departed from this pattern, with the lowest salinity values found directly across from the river discharge zone. Turbidity measurements were opposite of the other environmental parameters, with highest mean values at the river discharge zone, and lowest values in the eastern portions of the bay.

The nine sampling trips during the spring season of 2002 resulted in the collection of 54,527 larval and juvenile fishes representing 27 species from 16 families. Numerically, three families accounted for 98.9% of the total (Engraulidae 62.5%, Gobiidae 26.3%, and Clupeidae 10.1%). Overall ichthyoplankton abundance was unimodal, with the greatest proportion of individuals collected from mid-April to mid-May.

Ordination of the ichthyoplankton community resulted in five larval fish assemblages, separating groups of Stations both temporally and spatially. Group A included samples taken in the early spring in the eastern parts of the bay and consisted mainly of pipefish (*Syngnathus scovelli*) and pinfish (*Lagodon rhomboides*). Low numbers of clingfish (*Gobiesox strumosus*) and Blenniidae larvae also characterized Group A. Group B also included collections from the early spring but consisted of larger sized individuals taken from the back bay stations, including juvenile-sized menhaden (*Brevoortia patronus*) and bay anchovy (*Anchoa mitchilli*). Larval-sized individuals from Group B included pinfish, spot (*Leiostomus xanthurus*), and Atlantic croaker (*Micropogonias undulatus*).

The greatest densities and highest degree of community diversity was found in Group C, and this group included samples taken from all stations during the main recruitment period of mid-April to May. Within the Group C community cluster, spatial separation of bay habitats is suggested by the distribution of the engraulids, with highest densities of larval-sized individuals found in the eastern portions of the bay and highest densities of juvenile-sized individuals found in the western, back bay locations. Larval gobies (Gobiidae), blennies (Blenniidae), and clingfish were collected from all stations along the bay-wide transect, but highest densities of each taxa were typically found closer to the back bay stations. Two species in Group C that were found predominantly in the eastern part of the bay were both late spring/early summer spawning sciaenids (silver perch *Bairdiella chrysoura* and spotted seatrout *Cynoscion nebulosus*).

Group D consisted of end of the season samples taken from the mid to back bay locations and were comprised of low numbers of juvenile bay anchovies and pipefish. Larval gobies, anchovies, and blennies typified this end of the season collection. The Group E community was early season samples consisting of larval gobies, clingfish, and blennies collected from the mid to front bay locations.

The most abundant ichthyoplankton (Engraulidae, Gobiidae, and Clupeidae) were tested for differences in length frequencies among the stations in order to assess any partitioning of habitats by the recruiting species. Engraulids were bimodal at each station, with two main cohorts (4-8 mm and 16-22 mm) observed. The larger size class was presumed to be a fall/winter cohort and the smaller individuals were presumed to be spring spawned. Engraulids showed a partitioning of habitats, with the greatest proportion of juvenile-size class individuals being found in the back-bay stations. Larval anchovies were much more prevalent in the eastern part of the study area, closest to the connection with Corpus Christi Bay. Gobiidae larvae were unimodal (3-5 mm) and found at much higher abundance in the back bay locations. Clupeids were primarily collected as juveniles (20-24 mm) and were also found in higher abundances in the back bay locations.

Larval abundances of many of the species found during the spring 2002 study (particularly those that spawn outside the bay and in the Gulf) indicate that back bay locations near the Nueces Delta region may be preferentially sought by the early life history stages. Though a strong salinity gradient was not always present in the bay, some taxa appear to be recruiting to this highly productive area of the bay.

I. INTRODUCTION

Nearly all marine fishes are obligately dispersed in the plankton during early life history stages (egg, pre- and post-flexion, and pelagic juvenile). Many estuarine-dependent fishes spawn offshore and the planktonic stages face the challenge of locating and settling into suitable estuarine nursery habitat. The success of these early stages can subsequently affect the community structure of adult populations, many of which are recreationally and/or commercially important. The Nueces River, the major riverine input into Nueces Bay, Texas, currently discharges in a location isolated from the historical river delta. Freshwater inflow into the estuary is limited by the operation of a double-reservoir system on the Nueces, Frio, and Atascosa Rivers. These departures from the traditional estuary structure may be affecting the habitat value of the bay as a nursery for larval fishes. The purpose of this study is to quantify larval fish recruitment into Nueces Bay along a transect from the mouth of the bay, through the river discharge zone, and up to the edge of the estuarine nursery area of the Nueces Delta.

Estuaries of the Gulf of Mexico are typically shallow, turbid, and well mixed with circulation predominantly wind-driven and characterized by mixed tides and small tidal amplitude (Lyczkowski-Shultz et al. 1990; Raynie and Shaw 1994). Direct coupling (rivers feeding into marshes, encompassing secondary bays, and connected by primary bays to the ocean) is frequently broken. The Nueces-Corpus Christi Bay system on the lower Texas coast is an example of an estuarine nursery area separated from the major riverine input, the Nueces River. The river discharge point is isolated from the emergent marsh, submerged aquatic vegetation and intertidal flats that provide the nursery habitat. Processes other than salinity-driven, vertically stratified current flow control the physical transport of eggs and larvae into the estuaries of Nueces Bay. Despite this "disconnection," the Nueces Delta is considered an important nursery area for many commercially important finfish and shellfish (Henley and Rauschuber 1981).

The importance of estuaries as nursery grounds for a variety of marine organisms has been well documented (McHugh 1976; Blaber and Blaber 1980; Boesch and Turner 1984; Knox 1986; Livingston 1997). This habitat provides protection from larger piscivores for the early life history stages of fishes and other marine organisms (Valesini et al. 1997). The high primary productivity of estuaries is generally associated with nutrient loading from freshwater inputs (Armstrong 1981). Productivity is maintained by a complex of emergent vegetation, benthic algae and phytoplankton which efficiently utilizes nutrients within the estuary (Schelske and Odum 1961).

Purpose and Scope

The importance of freshwater inflows to maintenance of estuarine function has been demonstrated by numerous studies (see Grange et al. 2000 for partial review). Though interannual variability in flows and extended periods of floods or drought are natural features of estuaries, the addition of an anthropogenic trajectory to these other sources (in the form of freshwater diversion, reservoir operations, etc.) forces systems into artificial cycles, and consistent reduced inflow conditions can lead to degradation and loss of important nursery habitat (Powell and Matsumoto 1994). In accordance with Texas Water Code 11.1491, Texas Parks and Wildlife Department and the Texas Water Development Board have developed a set of freshwater inflow recommendations to sustain the unique biological ecosystems characteristic of an "ecologically sound and healthy" Nueces Estuary. These recommendations consist of monthly freshwater inflow target amounts determined by computer optimization and hydrodynamic modeling (Pulich et al. 2002). The report concludes that the required inflow amounts would be most beneficially delivered in proximity to the delta in one or two pulsed events in the spring (time of historical maximum flows), or, secondarily (in the case of persistent low flows in spring and summer), in the fall, as opposed to averaging flows through the season because the estuarine biota appear to respond most to more naturalized hydrologic events in this estuary.

The objective of this study is to determine the extent of larval fish recruitment to the Nueces Delta, and compare the distribution of fish larvae within Nueces Bay as related to discharge from the Nueces River. Specific objectives of the study are to (1) document the distribution of ichthyoplankton along a transect from the mouth of the bay through the river discharge zone and into the estuarine nursery area of the delta region, and (2) to determine if the discharge of the Nueces River away from the delta region acts as a "recruitment barrier" for transport and recruitment of fishes into the Nueces Delta.

Description of the Study Area

The Nueces River watershed encompasses > 4.3 million ha within the Edwards Plateau and Gulf Coast Section of the Coastal Plains Province (HDR Engineering, Inc. 1991, see Fig. 1). The Frio River flows into the Choke Canyon Reservoir above the Nueces River, and downstream, the Atascosa River joins the Nueces River, which is impounded by the Lake Corpus Christi Reservoir. Beyond this reservoir, the river empties into Nueces Bay.

The Nueces River currently flows along the southern edge of the Nueces Delta and empties directly into Nueces Bay (Fig. 2). The Nueces Delta is an expansive area of marsh that is bypassed by the main river flow except during flood flows. Rincon Bayou, the historical river channel, conveys floodwaters from the river immediately south of Interstate Highway 37 (IH 37) into the delta during these events. The combined reservoir operations have resulted in a 54.9% decrease in mean annual river flow into the Nueces Estuary, and a 99.6% decrease of flow into the Nueces Delta (Bureau of Reclamation 2000). The decreased flows, coupled with high evaporation rates in the shallow delta area, resulted in the formation of a negative estuary with salinity increasing upstream (into the delta) instead of downstream (Palmer et al. 2002).

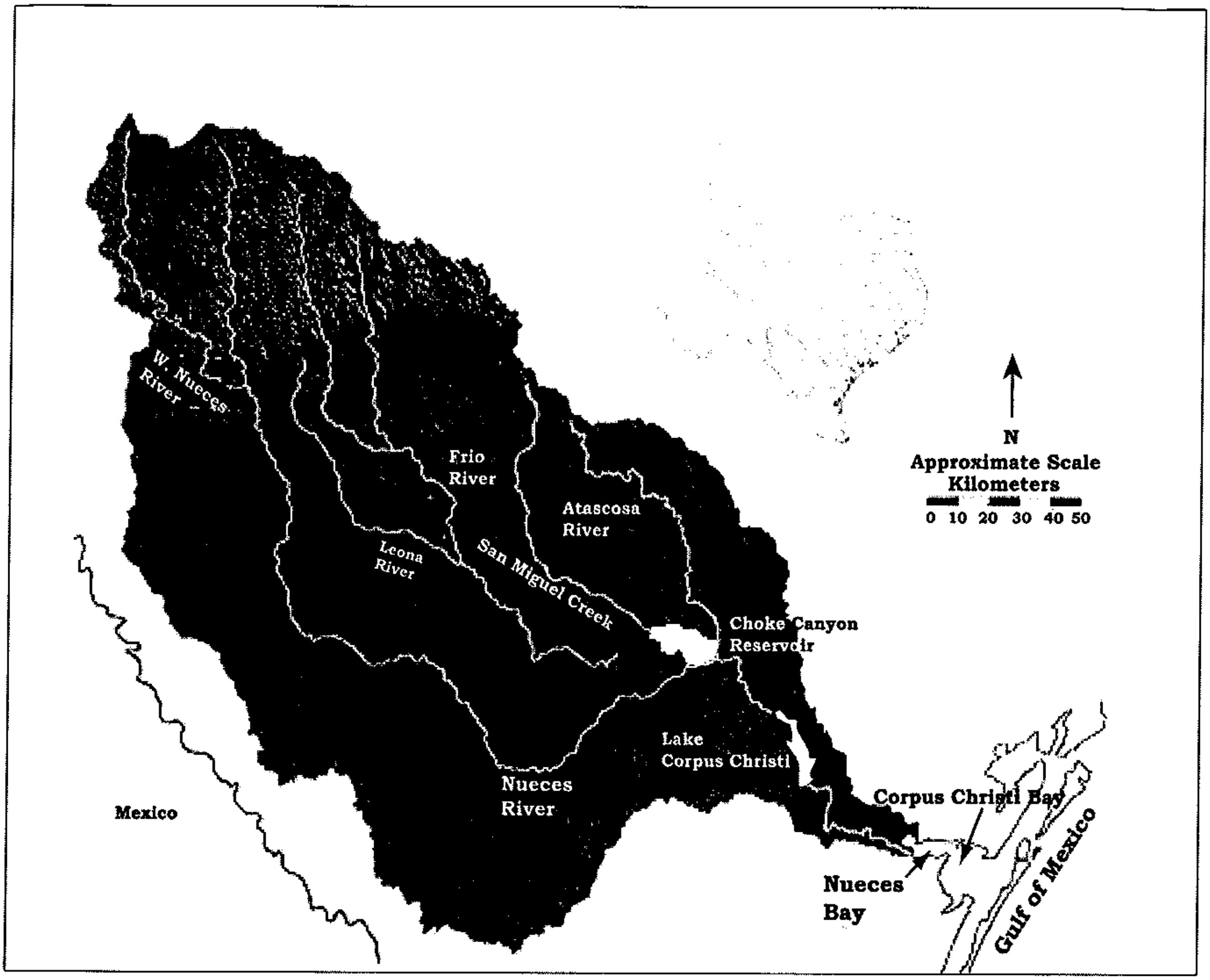

Figure 1. The Nueces River Drainage, including the two reservoirs (Modified from Bureau of Reclamation 2000).

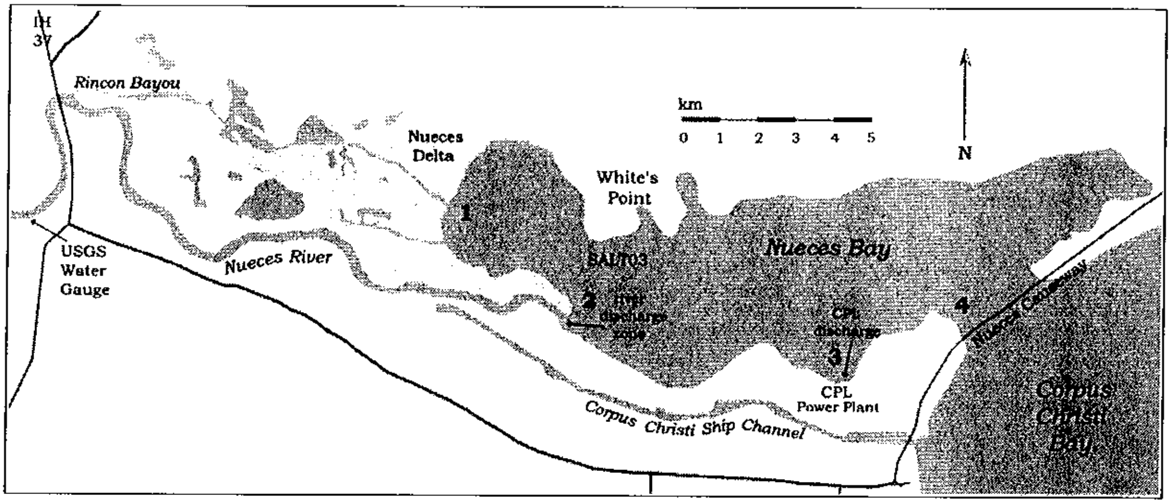

Figure 2. Study area with relevant surrounding features and sampling Stations for this study (Modified from United States Geological Survey 1984).

Nueces Bay is a secondary bay of the Corpus Christi Bay system, with a combined surface area of 518 km^2. It is a shallow, well-mixed, wind-driven bay located in a semi-arid zone. Mean precipitation of 71.9 cm yr^{-1} is exceeded by mean evaporation of 100 cm yr^{-1}. Precipitation is bimodally distributed with peaks in the spring and fall. Mean summer and winter air temperatures are 33.3 and 8.3°C, respectively. Mean annual water temperature is 23°C (Ruth 1990). Prevailing winds are southeasterly to south-southeasterly throughout most of the year, with strong northerly frontal systems occurring intermittently throughout the winter (Texas Department of Water Resources 1982). Salinity may vary from near fresh (<2‰) during heavy flood events ("freshets") to hypersaline (>45‰) during prolonged dry periods. Mean annual salinity is reported as 25‰ (HDR Engineering, Inc. 1991). Tides are primarily diurnal with an average amplitude of ~10 cm, with seasonal water levels creating a range of ~0.1 m. Tidal range is controlled primarily by the wind (Ruth 1990).

The Nueces Delta consists of approximately 5,850 ha of middle and high marsh, with 35 ha of smooth cordgrass (*Spartina alterniflora*) distributed along the fringes of tidal channels (Espey, Huston & Associates 1981). Drift algae (*Gracilaria* sp.) is the dominant submerged aquatic vegetation in the bay (Tom Wagner personal communication). Seagrasses (*Halodule beaudettii* and *Ruppia maritima*) are concentrated in small patches along the northern edge of the study area. Relict (and some extant) oyster reefs (*Crassostrea virginica*) are scattered in the western and northern portions of the bay, with a concentrated area of reefs located near White's Point, directly across from the river discharge.

An additional non-freshwater inflow to Nueces Bay was from the AEP-Central Power and Light (CPL) power plant located between the Corpus Christi Ship Channel and Nueces Bay. Water drawn from near the bottom of the Corpus Christi Ship Channel is pumped through the power plant to cool the generators and then discharged into the southeastern portion of the bay. This input may serve as an additional recruitment vector for planktonic eggs and larvae drawn into the Inner Harbor and Ship Channel, and could also affect recruitment by altering circulation patterns in the bay (Powell et al. 1997). The cooling water discharge constitutes between 14-19% of the total water input into the bay (Whitledge 1993). The plant ceased operations in 2003.

II. LITERATURE AND HISTORICAL DATA REVIEW

Physical transport mechanisms responsible for circulation are important in the dispersal of larvae. Major influences on circulation in estuaries include tide, river flow, wind, nontidal forcing from the coastal ocean, and topographically induced circulation (Norcross and Shaw 1984). The presence of two-layered, vertically stratified current flow has been proposed as a recruitment mechanism linking offshore spawning grounds with estuarine nursery areas in some Atlantic coastal systems (Weinstein et al. 1980; Hettler et al. 1997). Upstream transport of larvae may play an important role as a mechanism linking offshore spawning grounds with estuarine nursery areas (Shaw et al. 1988). Distribution and population structure of fishes are indirectly related to the estuarine environment through food web dynamics that are ultimately defined by changes in river flow (Livingston 1997).

Fish that utilize estuaries as nursery areas employ a range of life history strategies in order to settle into favorable habitat. A major problem encountered by these fishes is the net seaward flow of estuarine waters combined with tidal flux, which may affect transport into, or away from, estuaries (Boehlert and Mundy 1988). For those species residing in estuaries through their entire life cycle (estuarine residents), the problem of export of early life history stages is sometimes counteracted by production of large, demersal eggs and short early life history stages (Hildebrand and Schroeder 1928; Kneib 1997). Some species brood their young within a pouch (Syngnathidae) or mouth (Ariidae) (Dando 1984), or seek more protected habitats near the margins of estuaries. Estuarine-dependent species require estuarine habitat only during a particular life history stage. Many of these fishes are spawned offshore or near passes and face the problem of locating and entering estuarine areas in spite of the net seaward movement of water (Valesini et al. 1997). These fishes [including several that are commercially and recreationally important such as black drum (*Pogonias cromis*), Atlantic croaker (*Micropogonias undulates*), spot (*Leiostomus xanthurus*), spotted seatrout (*Cynoscion nebulosus*), flounder (*Paralichthys* spp.), and others] generally have an extended larval phase and experience a wide range of physical processes before potentially being delivered to an estuarine area.

Recruitment can be defined as the addition of a new cohort of young individuals to a population (Sale 1990). The process of settlement or transfer of individuals from planktonic to demersal populations is a major event in the recruitment process (Sale 1990). Various biotic and abiotic factors interacting during these early life history stages can affect the dispersal and settlement of a particular cohort. Numbers of larvae surviving to dispersal and settling out of the planktonic phase may be one of the ultimate determinants in adult population sizes (Richards and Lindeman 1987). Variability in the planktonic dispersal processes has a great influence on larval supply, which may result in considerable seasonal variation in community structure (Underwood and Fairweather 1989; Roberts 1991).

The spawning of many temperate fish species is in phase with the onset of seasonal production cycles. Spring and fall phytoplankton blooms are often closely followed by increases in zooplankton abundance (Riley 1967). The "match-mismatch" hypothesis suggests that the strength of the spatial and temporal correlation between the production of zooplankton (food source) and the production of fish eggs can have significant effects on larval survival and subsequent recruitment, and thus serve as a significant source of interannual variability (Cushing 1975).

III. METHODS OF ANALYSIS

Sample Collection

Sampling was conducted approximately biweekly during the spring recruitment period in 2002. Biweekly sampling began in February and extended until early June. Hettler et al. (1997) demonstrated that estuarine-dependent fish recruitment in Beaufort Inlet, North Carolina showed an increased range of abundance estimates with increasing sampling intervals (2d, 4d, 7d, 14d, 30d between samples); however, the differences between 7d and 14d intervals were small for most target species.

Four fixed stations were sampled along a transect from the bay mouth through the river discharge zone and to the delta edge. Station 1 was at the westernmost margin of the bay, outside of Rincon Bayou; Station 2 was located at the river discharge zone across from White's Point; Station 3 was located near the outflow of the CPL power plant; and Station 4 was located at the Nueces Causeway (Fig. 2). Triplicate ichthyoplankton samples were collected at each station during daylight hours using a 60 cm diameter pull-net with 500 µm mesh. The net was pulled in an arc in order to minimize the influence of motor wash from the boat. A General Oceanics Flowmeter was attached to the net allowing calculation of the volume of water filtered, and collections were standardized to reflect fish density (fish 100 m^{-3}). Collections were initially preserved in 10% seawater formalin. After 48 h, all collections were transferred to 95% ethanol for final storage and preservation.

In the laboratory, all fish larvae were sorted by species from whole collections, enumerated and measured to the nearest 0.1 mm with an ocular micrometer. Lengths recorded are notochord length for pre-flexion larvae, and standard length (SL) for flexion and post-flexion larvae and juveniles. For samples containing a large number of individuals of a particular species, a Folsom Plankton Splitter was used to divide the whole sample in half, and this process was repeated until a reasonable number of individuals was present in the subsample. A whole count was then extrapolated from the fraction for that species, and the entire sample was searched for all other species. Up to twenty individuals of each species were measured for each replicate sample. If more than twenty individuals were present, a random subsample of 20 individuals from each species was measured. Ichthyoplankton identification was facilitated by reference to published descriptions (Hoese and Moore 1977; Fritzsche 1978; Hardy, Jr. 1978; Johnson 1978; Jones et al. 1978; Martin and Drewery 1978; Ditty and Shaw 1994; Farooqi et al. 1995). A description and relative quantification of the remaining zooplankton was also noted during processing of samples.

At each station prior to ichthyoplankton collections, water quality parameters [temperature (°C), salinity (PSU), dissolved oxygen (D.O. mg l^{-1}, and % saturation,), pH (SU), and turbidity (Nephelometric Turbidity Units (NTU)] were measured with a YSI 6650 sonde. Continuous water temperature and salinity data were also collected near Station 2 by a salinity monitoring station (SALT03; see Fig. 2) operated by the Conrad Blucher Institute for Surveying and Science, and those data are incorporated into the analysis.

Data on freshwater discharge volume was obtained from a USGS water level monitoring station at Calallen (USGS 08211500) and was used as an approximation of inflow to the bay (see Fig. 2).

Statistical Tests

Ordination

The PRIMER v5.0 (Plymouth Routines in Multivariate Ecological Research) software program was used for analysis of the ichthyoplankton community. Community structure was analyzed using a hierarchical agglomerative cluster analysis based on the Bray-Curtis similarity measure. The Bray-Curtis coefficient is calculated by the formula:

$$S_{jk}(i) = 100 \left\{ 1 - \frac{S_{i=1}^{p} |y_{ij} - y_{ik}|}{S_{i=1}^{p} (y_{ij} + y_{ik})} \right\} \qquad \text{Eq. 1}$$

where y_{ij} is density of the i^{th} species in the j^{th} sample, and y_{ik} is the density of the i^{th} species in the k^{th} sample. In the Bray-Curtis measure, $S = 0$ if the two stations have no species in common, and $S = 1$ if the community composition is identical, because $| y_{ij} - y_{ik} | = 0$ for all i. For the cluster analysis, the group-average linkage algorithm was chosen in order to emphasize the community structure of the samples, in addition to the abundances of each taxa. For each species, the mean density among the replicate samples was fourth-root transformed prior to analysis. A dendrogram was created based on the coefficients of similarity between all samples. Analysis of the dendrogram revealed that a level of 35% similarity was appropriate to distinguish sample clusters.

The Bray-Curtis similarity matrix was also used as input for a non-metric multidimensional scaling (MDS) analysis of the sample events. MDS seeks to compute coordinates for a set of points in a unit-less space such that the distances between the pairs of points fit as closely as possible to the measured similarity between a corresponding set of objects (SYSTAT 1992).

The SIMPER (SIMilarity PERcentages – PRIMER v5.0) routine was used to examine the contribution of individual species (i) to the structure of each community cluster. Values of $S_{jk}(i)$ are averaged over all pairs of samples (j,k) between fish assemblages to give the average contribution , $Savg_{(i)}$, of the i^{th} species to the total within-group similarity. The ratio of $Savg_{(i)}$ to its standard deviation, $Savg_{(i)}/SD(Si)$, indicates how consistently a species discriminates among the assemblages. If a species is found at consistent levels (i.e., densities) throughout an assemblage, then the standard deviation of its contribution is low, and the ratio is high (Clarke and Warwick 1994). Such a species will contribute more to the intra-group similarity, and can be thought of as typifying that group.

Length-frequencies of abundant ichthyoplankton

Length-frequencies of Engraulidae, Gobiidae, and Clupeidae were tested for differences among Stations using Pearson's Chi-square test statistic. Successive sampling events on which abundances of these families generally exceeded 100 individuals per station were selected for the analysis. Because no more than 20 individuals of a particular taxon were measured in each replicate, these lengths were "bootstrapped" to the total number of individuals present in the replicate, and lengths from all replicates from each station were used for the Chi-square test. Bin sizes for engraulids were in 2 mm increments from 2 to >38 mm, 1 mm increments from 1 to >8 mm for gobiids, and 1 mm increments from <19 to 42 mm for clupeids. In all cases, the null hypothesis was homogeneity of length-frequency among stations (H_o: Station 1 = Station 2 = Station 3 = Station 4). All pairwise comparisons of Chi-square length frequencies were tested with Bonferroni-adjusted *p* values.

Abiotic data

An analysis of covariance (ANCOVA) was used to detect differences in abiotic data among the stations. Sampling date (julian day) was used as the covariate in order to adjust each station dependent variable mean for the temporal nature of sampling over the spring season. In each test, the assumption of homogeneity of the slopes of the regression lines was accepted. Homogeneous subsets were delineated using Tukey's honestly significant difference (HSD) multiple comparison method, which tests for differences among all pairwise comparisons of means while controlling the maximum experimentwise error rate (a = 0.05).

IV. RESULTS

Abiotic Data

Hydrological parameters were measured at each site during each sampling event with few exceptions (related to equipment malfunction). Descriptive values for abiotic variables [temperature (°C); salinity (PSU); pH (SU); D.O. (mg l^{-1} and % saturation); turbidity (NTU)] are reported by station in Table 1. Differences in abiotic variables between stations were tested with one-way ANOVA and results are presented in Table 2.

Temperature showed a typical seasonal increase throughout the study period each year. Water temperature was not stable above 20°C at all stations until mid-April. Temperature was not significantly different between Stations 3 and 1 (high and low range based on Tukey's HSD), although the western-most stations (Stations 1 and 2, henceforth referred to as "back bay") were cooler overall than the other two stations. The influence of the warm CPL discharge on surface water temperatures could be seen throughout the study period.

Salinity also increased throughout the study period each year. The lowest recorded salinity, and the greatest range (9.1 PSU) of salinities occurred at Station 1, with the lowest mean salinity occurring at Station 2 (26.3 PSU), directly across from the river discharge location. Salinity increases through each study period were most notable in the back bay stations, where the ranges of salinity values at Stations 1 and 2 were nearly double those of Stations 3 and 4.

In general, pH measurements were well within normal ranges for estuarine waters, with values relatively higher throughout the bay from February through March. These values were coincident with elevated D.O. values associated with the lower temperatures found in the early spring of 2002.

Dissolved oxygen levels showed a peak in March, and declined slightly towards the end of the spring recruitment period. At each Station, mean D.O. saturation levels were all above 100%, indicating no potential recruitment problems associated with depressed D.O. levels during the spring period. While not significant based on the ANOVA, D.O. levels followed the same general pattern seen in temperature, salinity, and pH, with higher values recorded in the eastern portions of the bay relative to the back bay stations.

Turbidity was highest in the back bay locations, with the highest turbidity recorded at Station 2 across from the river discharge location. The high degree of variability associated with the turbidity measurements, whether caused by wind events or inflow

Table 1. Hydrological parameters of study stations in Nueces Bay, Texas during 2002 sampling events.

	Station	N	Mean	Std. Dev.	Min.	Max.
Temperature (°C)	Station 1	9	20.4	5.8	11.0	27.3
	Station 2	9	20.6	6.0	11.6	27.8
	Station 3	9	22.5	5.8	12.9	30.0
	Station 4	9	21.6	5.9	12.9	28.4
Salinity (PSU)	Station 1	9	27.3	3.6	22.5	31.6
	Station 2	9	26.3	3.0	22.6	30.6
	Station 3	9	28.5	1.5	26.2	31.0
	Station 4	9	28.7	1.6	26.7	31.3
pH (SU)	Station 1	9	8.0	0.1	7.8	8.1
	Station 2	9	8.0	0.1	7.9	8.2
	Station 3	9	8.1	0.1	7.9	8.2
	Station 4	9	8.0	0.1	7.8	8.2
D.O. (mg l^{-1})	Station 1	9	8.2	1.9	5.7	10.5
	Station 2	9	8.3	2.0	5.8	10.9
	Station 3	9	8.6	2.3	5.8	11.9
	Station 4	9	8.4	2.1	6.0	12.0
D.O. (% saturation)	Station 1	9	104.0	15.9	80.9	135.1
	Station 2	9	105.8	15.7	83.4	137.4
	Station 3	9	115.2	24.3	84.5	158.1
	Station 4	9	110.7	21.2	87.4	158.2
Turbidity (NTU)	Station 1	8	100.0	64.1	12.2	189.0
	Station 2	8	123.4	144.8	11.8	428.9
	Station 3	8	32.8	38.1	2.1	118.0
	Station 4	8	42.0	50.5	2.6	133.6

Table 2. Results of ANCOVA on abiotic variables among stations in Nueces Bay, Texas, spring 2002. Station means are arranged from high to low values. Means joined by a line indicate a non-significant difference (Tukey's HSD test, *P* < 0.05).

Dependent Variable	df	F-Ratio	*P* > F	Homogeneous subset
Temperature	3,28	0.89	0.459	3 4 2 1
Salinity	3,28	4.05	0.017	4 3 1 2
pH	3,28	1.57	0.219	3 4 2 1
D.O. mg l^{-1}	3,28	0.12	0.949	3 4 2 1
D.O. % sat.	3,28	0.64	0.596	3 4 2 1
Turbidity	3,24	2.03	0.137	2 1 4 3

events into the back bay locations, precluded detection of any significant differences seen with the Tukey's HSD procedure.

The red tide-causing organism, *Karenia brevis*, began appearing in area bays in December 2001 and spread westward into Nueces Bay by early February 2002. At times, high cell counts of the organism were detected in association with some fish kills in Nueces Bay (Texas Department of Health 2002). On 21 February, numerous dead adult striped mullet (*Mugil cephalus*) were observed floating on the surface between Stations 3 and 4, and on 18 April, thousands of juvenile Gulf menhaden (*Brevoortia patronus*) were observed swimming in distress in the same general location. A water sample taken in the area was confirmed by the Texas Department of Health to contain *K. brevis*, but cell concentrations were not quantified.

Ichthyoplankton Community

Nine sampling trips were conducted over the spring 2002 recruitment period, resulting in 108 total samples. A total of 54,527 larval and juvenile fish representing at least 27 species from 16 families were collected during the study. Three families accounted for 98.9% of the total number of individuals (Engraulidae 62.5%, Gobiidae 26.3%, and Clupeidae 10.1%). A complete taxonomic list with mean Station densities is given in Appendix 1. Graphical representations of larval densities among stations over time are given for all fish (Fig. 3), Clupeidae (Fig. 4), Engraulidae (Fig. 5) and Gobiidae (Fig. 6). Clupeids, mostly *Brevoortia patronus*, were found primarily at Station 1. Larval (preflexion, flexion and postflexion) anchovies (*Anchoa* sp.) were found in high densities at Stations 3 and 4, while juvenile and larger anchovies (*A. mitchilli* and *A. hepsetus*) occurred mostly at Stations 1 and 2. Gobies comprised a considerable proportion of the total ichthyoplankton at Stations 1, 2 and 3. Overall spring ichthyoplankton abundance was unimodal in 2002, with the majority of recruitment taking place from mid-April until mid-May (Fig. 3).

Ordination

An agglomerative hierarchical clustering procedure was conducted on taxa at the family level (with the exception of Engraulidae) for each station. Engraulids were further divided based on whether or not they were identifiable to the species level. Many of the anchovies, particularly at the back bay stations, were fairly large (>20 mm) and distinctly different morphologically from the early larval stages (to ~15 mm) which could not be resolved to the species level. These were grouped as Large anchovies [principally *Anchoa mitchilli* (Bay anchovy) but including some *A. hepsetus* (Striped anchovy)] and *Anchoa* sp., which probably represent distinct fall and spring-spawned cohorts based on reported spawning periods (Pattillo et al. 1997). This helped resolve some of the (apparent) similarity between stations where none would be expected.

A dendrogram, based on the Bray-Curtis Similarity measurement (group-average linkage algorithm), was created with 4^{th}-root transformed densities (Fig. 7). At a

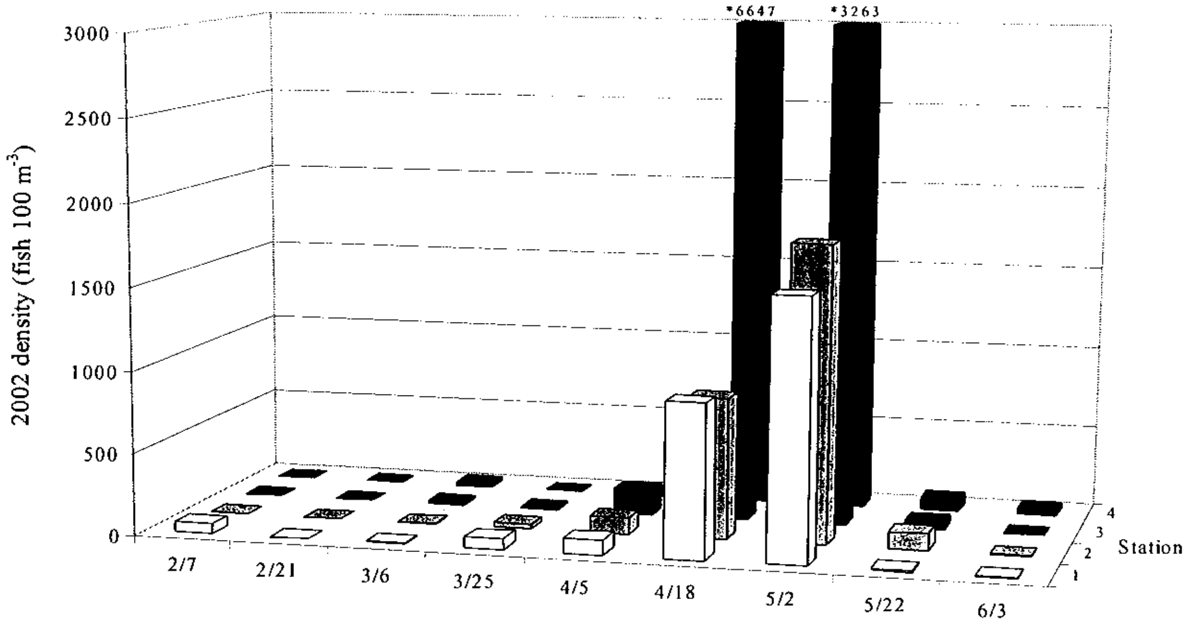

Figure 3. Total fish densities (fish 100 m^{-3}) by station for all sampling events in Nueces Bay during 2002.

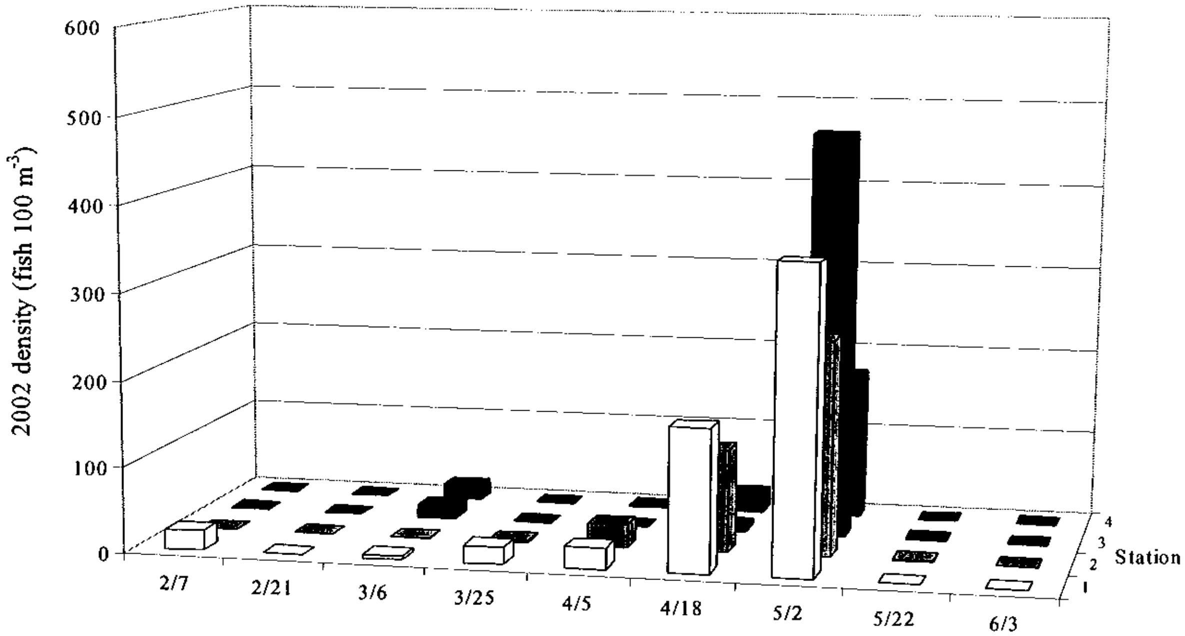

Figure 4. Total densities (fish 100 m^{-3}) of Clupeidae by station for all sampling events in Nueces Bay during 2002.

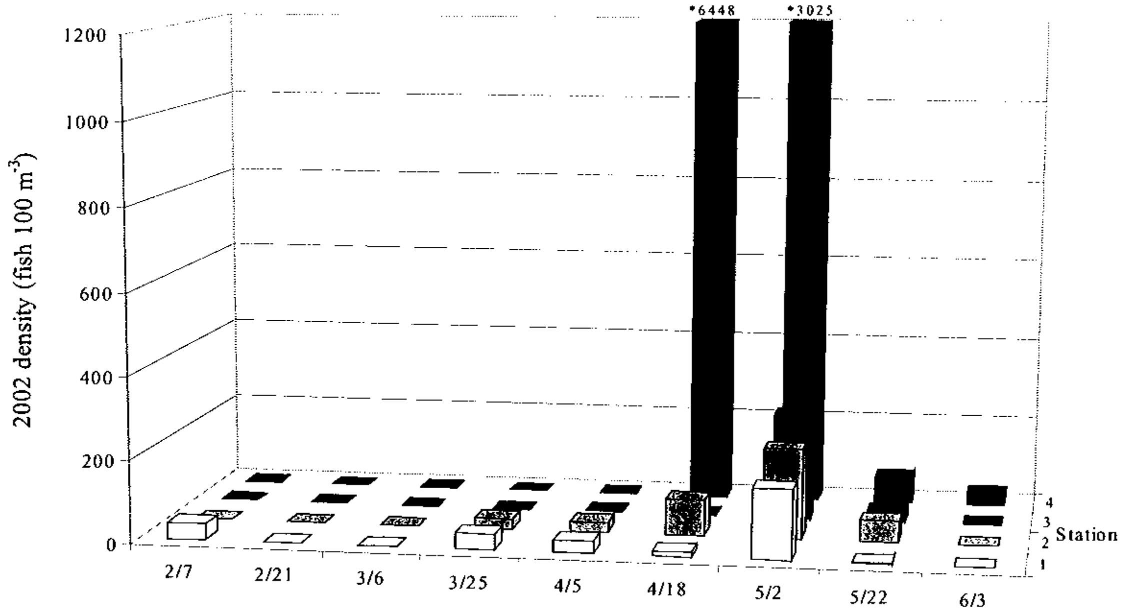

Figure 5. Total densities (fish 100 m^{-3}) of Engraulidae by station for all sampling events in Nueces Bay during 2002.

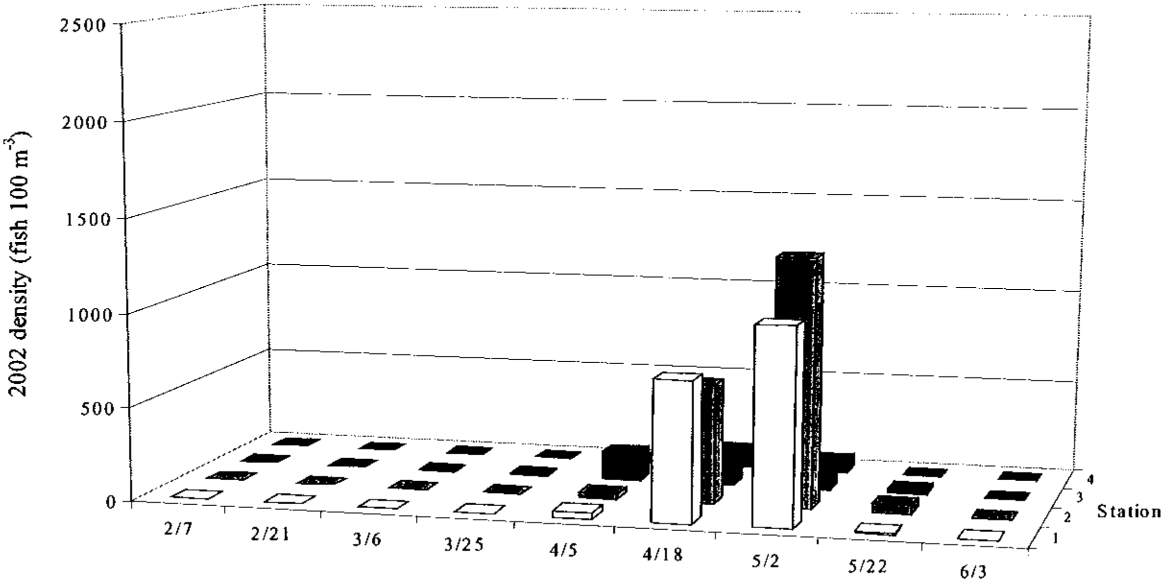

Figure 6. Total densities (fish 100 m^{-3}) of Gobiidae by station for all sampling events in Nueces Bay during 2002.

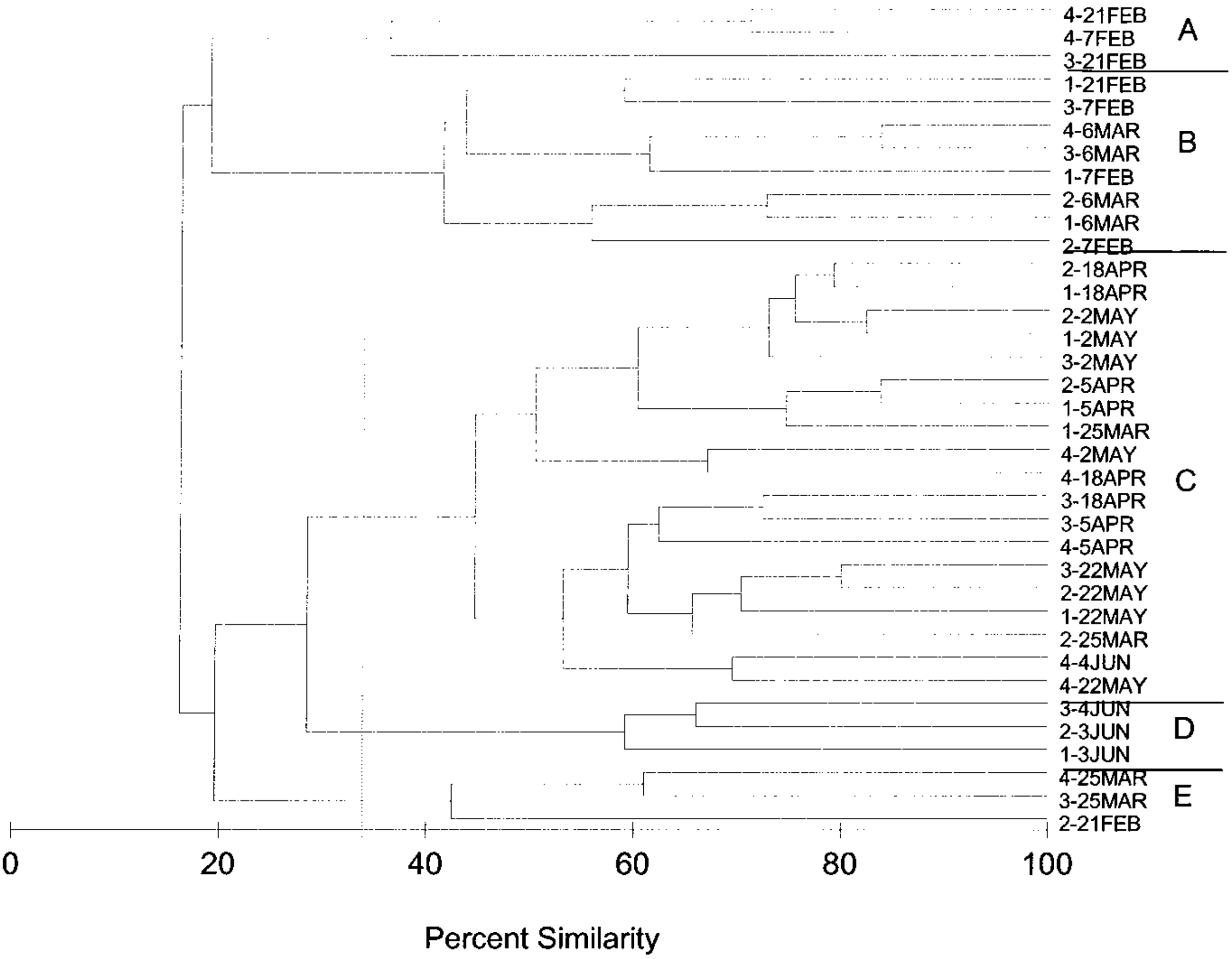

Figure 7. Group-averaged cluster dendrogram, based on Bray-Curtis similarity, showing the percent similarity of the spring ichthyoplankton communities at the four stations in Nueces Bay during spring 2002. Sample events are arranged in station-date format (e.g., 4-21FEB, Station 4 - 21 Feb 2002). Five main station groups (A-E) are distinguished by the dotted line at an arbitrary similarity level of 35% (X-axis).

similarity level of 35%, five distinct larval fish assemblages, or Groups of stations could be defined. These five Groups, presented in their optimal two-dimensional MDS configuration, are shown in Figure 8. Group A was composed of early season samples from Stations 3 and 4, and consisted primarily of low numbers of *Syngnathus scovelli* and *Lagodon rhomboides* (SIMPER Analysis; see Table 3). Low numbers of Blenniidae and *Gobiesox strumosos* larvae also characterized Group A. Group B also consisted of early season samples (7 Feb to 6 Mar), but were primarily samples taken from the back bay Stations (1 and 2). The best within-group discriminating species in Group B included juvenile-sized *Brevoortia patronus* and increased numbers of *L. rhomboides*, but also included many *A. mitchilli*, the larger of the anchovies that were identifiable to the species level. Early season Sciaenidae juveniles collected in low abundances within Group B included *Leiostomus xanthurus* and *Micropogonias undulatus*, both of which are identified as fall to early spring recruiting species which spawn in the nearshore to mid-shelf water in the Gulf of Mexico (Patillo et al., 1997).

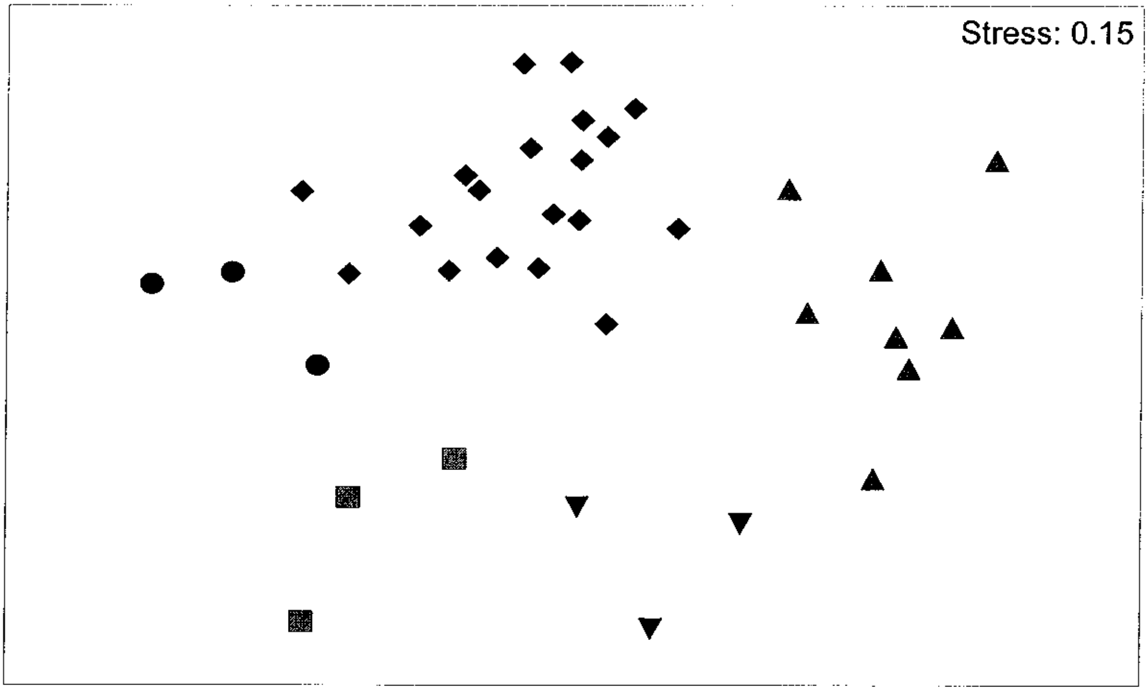

Figure 8. Multidimensional scaling plot (2-D configuration) depicting the five groups delineated by group-average cluster analysis of the spring ichthyoplankton community in Nueces Bay during 2002 (? Group A, ? Group B, ?Group C, ? Group D, ¦ Group E).

Table 3. SIMPER analysis mean densities (fish 100 m^{-3}, above), ratio value (Savg$_{(i)}$/SD (S$_i$) below in parentheses, and average similarity (Si, within-group) of the spring 2002 ichthyoplankton community clusters defined by group-average cluster analysis. Ratio values in bold represent the best within-group discriminating taxa.

	Assemblage				
Taxa	Group A	Group B	Group C	Group D	Group E
Clupeidae					
Brevoortia patronus	0.00	7.99	89.86	0.00	0.00
	---	**(0.73)**	**(0.50)**	---	---
Engraulidae					
Anchoa sp.	0.00	0.00	539.14	0.60	0.00
	---	---	**(0.42)**	**(6.59)**	---
Anchoa hepsetus	0.00	0.00	2.10	0.00	0.00
	---	---	(0.11)	---	---
Anchoa mitchilli	0.00	5.68	33.11	0.07	0.00
	---	(0.19)	(0.33)	---	---
Gobiesocidae					
Gobiesox strumosus	0.08	0.00	0.59	0.00	0.27
	---	---	(0.30)	---	**(1.47)**
Atherinidae					
Menidia sp.	0.08	0.00	0.29	0.00	0.00
	---	---	(0.24)	---	---
Syngnathidae					
Syngnathus scovelli	0.87	0.06	1.50	0.07	0.00
	(1.61)	---	(0.32)	---	---
Sparidae					
Lagodon rhomboides	0.32	0.92	0.91	0.00	0.09
	(0.58)	**(0.65)**	(0.26)	---	---
Sciaenidae					
Bairdiella chrysoura	0.00	0.00	3.36	0.00	0.00
	---	---	(0.08)	---	---
Cynoscion nebulosus	0.00	0.00	0.45	0.00	0.00
	---	---	(0.08)	---	---
Leiostomus xanthurus	0.00	0.30	0.03	0.00	0.00
	---	(0.32)	(0.08)	---	---
Micropogonias undulatus	0.00	0.06	0.10	0.00	0.00
	---	(0.19)	(0.11)	---	
Gobiidae	0.00	0.00	225.85	0.07	1.94
	---	---	**(0.64)**	---	**(0.58)**
Gobionellus boleosoma	0.00	0.00	0.24	0.00	0.00
	---	---	(0.11)	---	---
Microgobius sp.	0.00	0.00	1.90	0.00	0.00
	---	---	(0.11)	---	---
Blenniidae	0.08	0.00	1.27	1.14	0.18
	---	---	(0.37)	**(3.34)**	---
Average Similarity (S$_i$)	38.81	19.49	19.08	35.40	21.31

From the MDS configuration, it is clear that the early spring samples identified in Group E (late February to late March) are more similar in their community composition to Group A, and this is due to the increasing abundance of *Gobiesox strumosus* and Blenniidae larvae (Table 3). Group E also showed consistent abundances of Gobiidae larvae (second highest within-group discriminating taxa), and these samples signaled the beginnings of the reproductive period for the gobiids. Group D consisted of late season samples from Station 1, 2, and 3, but were primarily populated by low numbers of juvenile anchovies (*A. mitchilli*), pipefish (*S. scovelli*), and end of the season larval-stage gobies (Gobiidae). Within-group discriminating taxa identified in Group D included relatively high numbers of Blennidae larvae, as well as low numbers of larval anchovies (*Anchoa* sp., see Table 3).

The highest abundances and greatest degree of overall diversity of the ichthyoplankton community was identified in Group C, which spanned the spring season from the end of March to a single sample from Station 4 in the beginning of June. This reinforces the unimodal nature of the spring recruitment seen in Figure 3. Within-group discriminating taxa identified in Group C included high numbers of juvenile stage *B. patronus* found at Stations 1 and 2, and very high densities of larval gobies collected from all Stations, but with the highest densities found at Stations 1, 2, and 3. Consistent levels of the highest densities, those of larval anchovies typically encountered at Stations 3 and 4 during the mid to late spring (See Fig. 5), were identified as one of the discriminating taxa characteristic of Group C. The highest consistent densities of other taxa were also identified within this Group, including juvenile-sized anchovies (*A. mitchilli*, 33.11 fish 100 m^{-3}) from Station 1 and 2, larval *Bairdiella chrysoura* (3.36 fish 100 m^{-3}) found predominantly at Station 4, and *Syngnathus scovelli* found at Stations 1, 2, and 3. Highest densities of *Gobiesox strumosus* (0.6 fish 100 m^{-3}) were also identified in Group C, although this species was encountered throughout the spring recruitment season and across all stations. Similarly, Blenniidae larvae (1.27 fish 100 m^{-3}) were found at all stations along the study transect in the Nueces Bay estuary system.

Length-Frequency Distributions

The most abundant ichthyoplankton (Engraulidae, Gobiidae, and Clupeidae numerically representing 98.9% of the total) were tested for differences in length-frequencies among stations. In this study, engraulids were generally discernible to species level by the time they reached approximately 15-18 mm SL, and gobiids (at least to the generic level) at approximately 8 mm SL. Nearly all clupeids were represented by a single species (*Brevoortia patronus*). Total numbers and median bin size for each family by Station are presented in Table 4. The overall median size for engraulids was 4-6 mm, although this was due to the very large number of larval anchovy at Station 4 (Fig. 9). At each Station, multiple cohorts of engraulids were encountered, with greater proportions of the larger, juvenile-sized individuals (>22 mm SL) encountered at the face of the Delta (Station 1). Across the bay transect, consistent groups of 4-8 mm and 16-20 mm larvae were collected. Based on the Chi-square test, each Station was found to have significantly different length-frequencies of engraulid larvae (Table 5).

Table 4. Total numbers and median length-class by Station for length-frequencies of the most abundant families collected in Nueces Bay, Texas.

	Engraulidae		Gobiidae		Clupeidae	
	Median (mm)	*N*	Median (mm)	*N*	Median (mm)	*N*
Station 1	20-22	1,013	4	5,915	21	1,836
Station 2	8-10	1,283	4	5,370	22	1,211
Station 3	8-10	563	3	1,133	21	1,122
Station 4	6-8	33,189	4	613	21	557

Table 5. Results of Pearson's Chi-square tests to detect length-frequency differences among Stations for the most abundant families collected in Nueces Bay, Texas. Significant differences among Stations (based on Bonferroni-adjusted *p* values) are identified in bold.

	Engraulidae				Gobiidae				Clupeidae			
	Station				Station				Station			
	1	2	3	4	1	2	3	4	1	2	3	4
Station 1	.				.				.			
Station 2	**0.001**	.			0.076	.			**0.001**	.		
Station 3	**0.001**	**0.001**	.		**0.001**	**0.001**	.		0.228	**0.001**	.	
Station 4	**0.001**	**0.001**	**0.003**	.	**0.003**	0.016	**0.001**	.	**0.001**	**0.001**	**0.002**	.

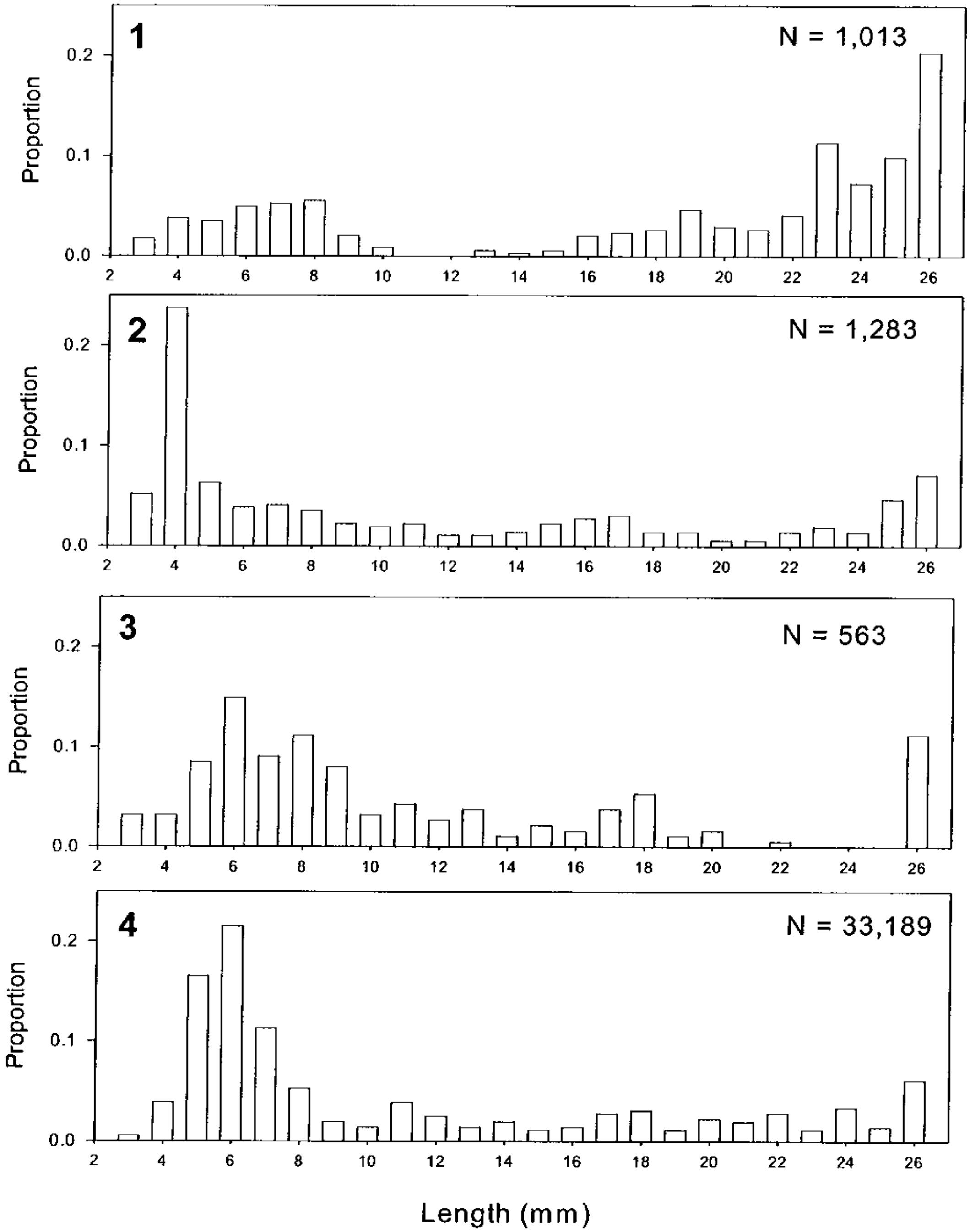

Figure 9. Length frequencies, arranged by Station, of Engraulidae larvae and juveniles collected during the spring 2002 season. All individuals >26 mm are included within the final bin.

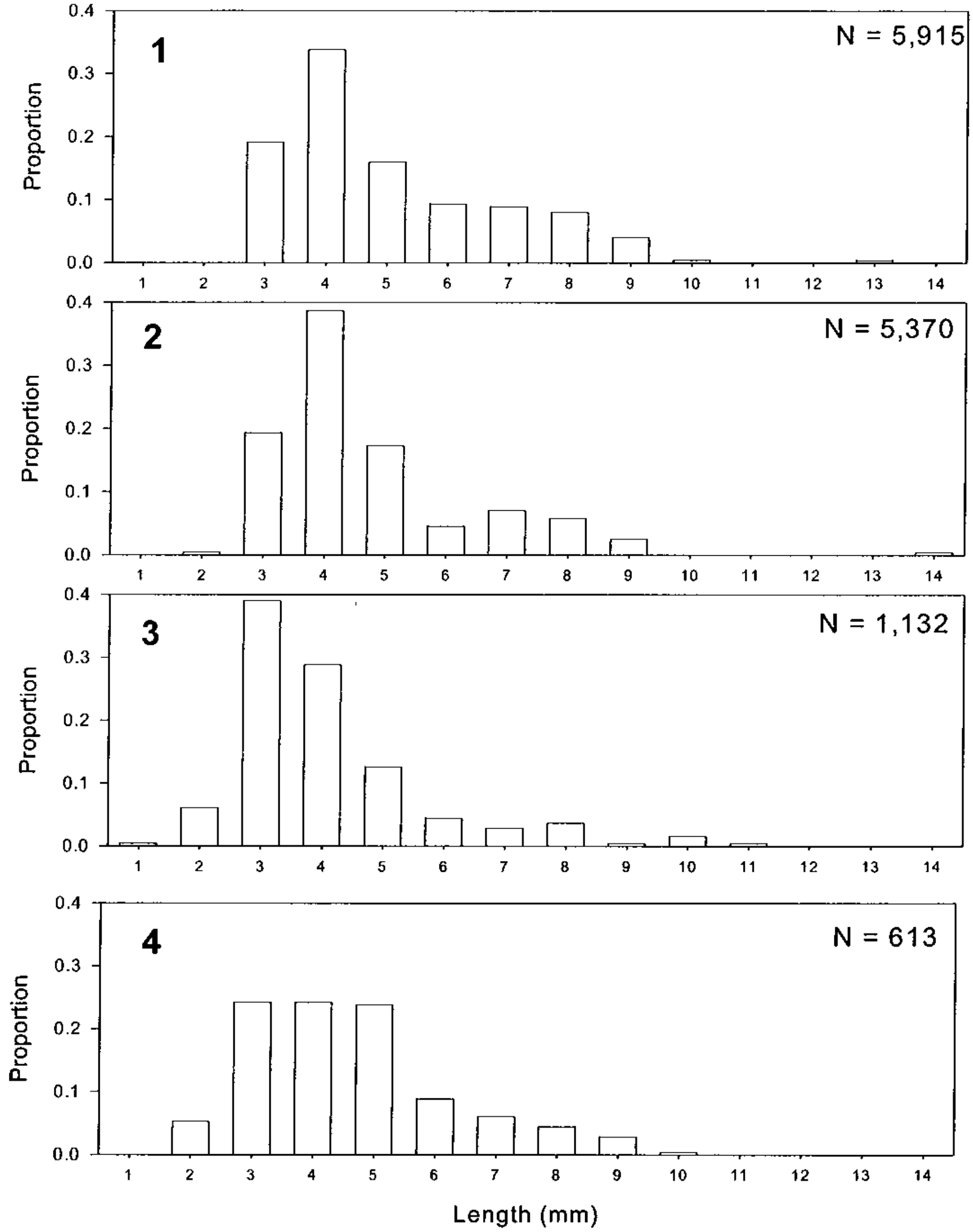

Figure 10. Length frequencies, arranged by Station, of Gobiidae larvae and juveniles collected during the spring 2002 season. All individuals >14 mm are included within the final bin.

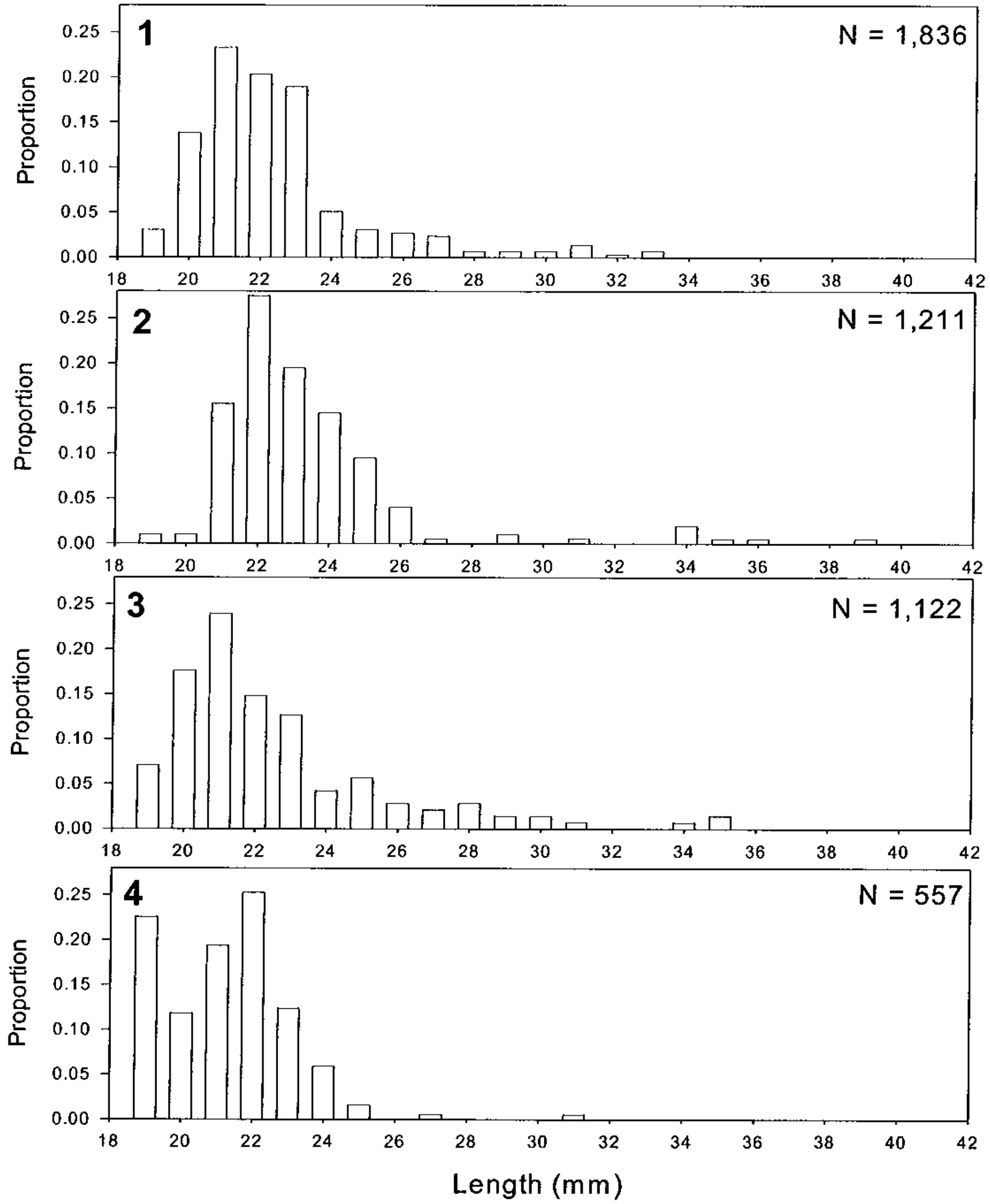

Figure 11. Length frequencies, arranged by Station, of Clupeidae larvae and juveniles collected during the spring 2002 season. All individuals <19 mm are included within the first bin.

Median size of Gobiidae larvae was 4 mm, with the greatest numbers of larvae collected in the back bay Stations (Fig. 10). Length-frequencies were unimodal at each Station, although a number of pair-wise comparisons were identified as significantly different (Table 5). Fewest gobiids were collected near the mouth of the Bay (Station 4), closest to the connection with Corpus Christi Bay.

Clupeids were collected at all Stations at a much larger size, with an overall median value of 21-22 mm SL. This family was found predominantly at Stations 1, 2, and 3, with increasing numbers encountered in the back-bay Stations (Fig. 11). The highest numbers of small individuals (<19 mm SL) were collected at Station 4, and the length-frequencies at this Station were significantly different from all other Stations (Table 5).

V. DISCUSSION

Estuarine-dependent fishery species require estuaries as nursery habitats for at least one life history stage (Weinstein and Brooks 1983; Worthington et al. 1992), and many of these fishes are spawned offshore and face the problem of locating and entering estuarine nursery areas (Blaber and Blaber 1980; Valesini et al. 1997). Several environmental factors affect the distribution of these young organisms that, for the most part, rely on prevailing winds, astronomical tides, local rainfall, and circulation patterns for their transport. Some of these factors may be affected by or work synergistically with freshwater inflows to the bays and estuaries (Longley 1994). Physiological and behavioral mechanisms related to salinity and (indirectly) to freshwater inflow have been reported to affect the transport of these life stages within the bay (Darnell and McEachran 1989; Wilber and Bass 1998). Previous studies of the Guadalupe (Pulich et al. 1998) and Trinity-San Jacinto (Lee et al. 2001) estuaries have demonstrated spatial correspondence between species abundance (both juveniles and adults) and salinity gradients in the bays, where salinity was used as a proxy measure for estuary-wide freshwater inflow. In a similar analysis of the Nueces Estuary, Pulich et al. (2002) found almost a complete lack of a typical estuarine salinity gradient, with only a rudimentary salinity gradient compressed into the upper portions of the back-bay.

Salinity in Nueces Bay is highly and immediately affected by freshwater inflow. Large inflow events typically drop salinity levels to 10 PSU or less (Fig. 12). Salinity generally increases approximately 10 PSU in the month following a large inflow, and continues to increase to 25-30 PSU in the following months, assuming no additional large inflows. Freund and Dodson (1995) report that high and low salinity values in Nueces Bay tend to persist for 2-3 months. In 2002, the spring recruitment period was preceded by a large pulse inflow event in November and December prior to the study period, and the recovery period seen in Fig. 8 appears to support the assertions of Freund and Dodson (1995). In 1999 and 2000, inflow events during the spring period decreased the salinity throughout the bay, particularly in the back bay stations. These inflow events preceded a temporary decline in ichthyoplankton abundance for these years, but a second peak in recruitment was observed in the subsequent, post-inflow sampling (Newstead 2003). A significant springtime inflow event did not occur during 2002 and salinities were similar throughout the bay during recruitment. However, relative to ichthyoplankton recruitment

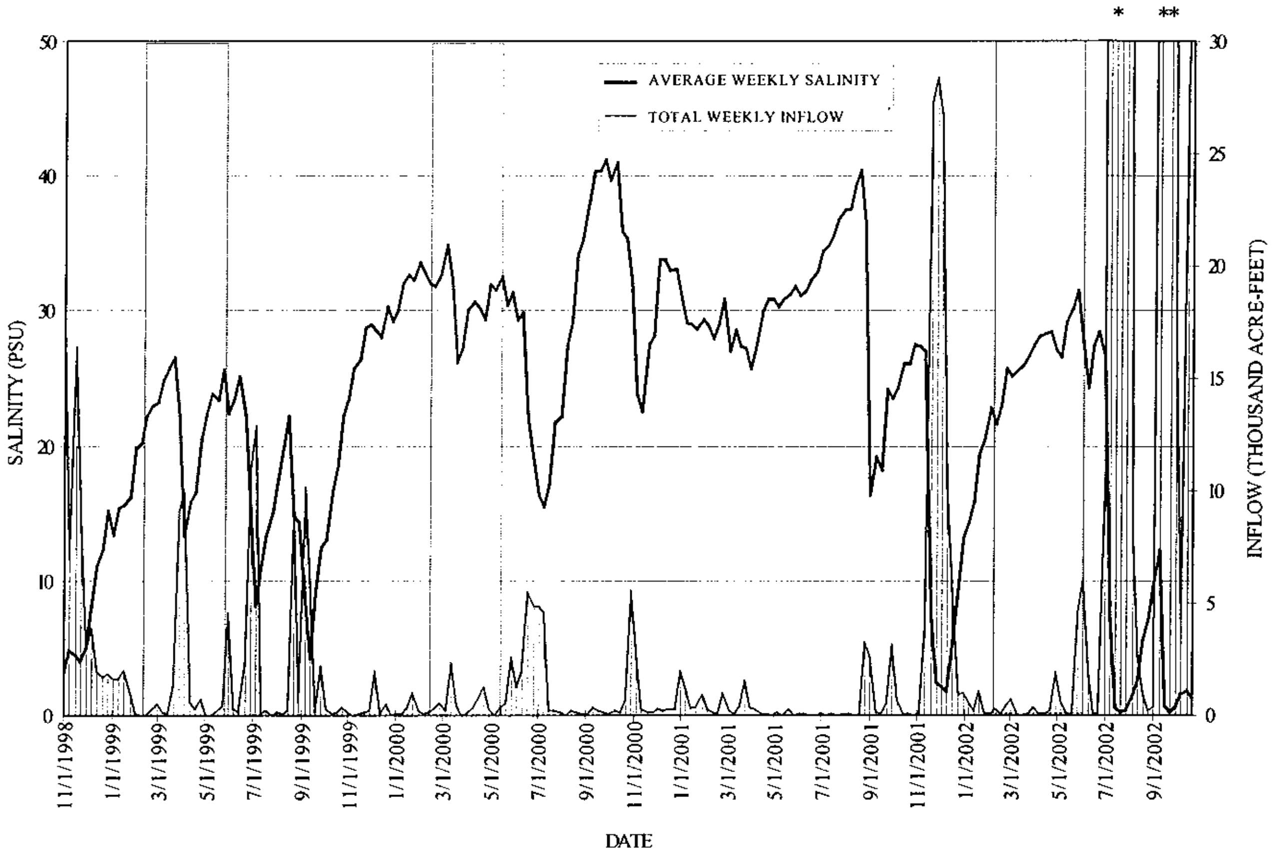

Figure 12. Salinity of Nueces Bay (weekly average at SALT03) and total weekly discharge amounts at USGS Calallen gauge (U.S. Geological Survey, unpublished data) from November 1998 through October 2002. Sampling periods are shaded. (* 14 consecutive days >30,000 acre-feet day^{-1}, totaling ~750,000 acre-feet; ** 12 consecutive days >30,000 acre-feet day^{-1}, totaling ~750,000 acre-feet). Modified from Newstead, 2003.

in 1999 and 2000 (Newstead 2003), recruitment was delayed until late spring in 2002. This could have been tied to the effects of persistent blooms of the red tide organism, *Karenia brevis*, seen at the mid- to upper-bay Stations during March and April.

Temperature differences between stations may be partly an artifact of the sampling regime. In order to avoid rough water conditions associated with increasing afternoon winds, the back of the bay [delta Station (1) and river discharge Station (2)] was usually sampled earlier in the day, though not always in the same order, and Stations 3 and 4 were then sampled afterwards. Due to the shallowness of the bay, water temperature at Stations 1 and 2 may not have had time to rebound from its diel overnight low, while the other stations may have been warmer due to their depth (greater volume per area) and the fact that they were usually sampled later in the day after solar heating could have slightly warmed the surface waters. Station 3 showed the overall highest temperatures, which may be partly attributable to the pumping of heated water discharged from the cooling towers of the power plant located adjacent to the site. In a one-year study of temperature, salinity and nutrient content of Nueces Bay, temperature in the vicinity of the power plant discharge was consistently 3-7°C above the mean for all bay stations (Whitledge 1993). D.O. values show a similar trend to that of temperature, which may also be a result of the discharge water. Primary productivity could have been enhanced by the higher dissolved inorganic nitrogen and phosphorus content of the discharge water in comparison with ambient waters of Nueces Bay (Whitledge 1993), leading to higher D.O. in the vicinity.

D.O. concentrations ranged from 8.74 – 12.02 mg l^{-1} at all Stations for the first four sampling events (7 February – 25 March). These high D.O. levels (maximum D.O. saturation values ranging from 135.1% to 158.2%) measurements may have been related to the presence of the *K. brevis* bloom, although these samples also corresponded with the coolest water temperatures of the season. In a rare North Carolina red tide occurrence, no severe impact to the larval fish community as a whole was reported, though species-specific effects were suggested with some species potentially benefiting from secondary consequences related to red tides such as decreased predator abundance and enhanced food availability (Warlen et al. 1998). The pattern seen in the North Carolina red tide outbreak was lower than normal densities during the event, followed by unusually high peaks of 1-3 wks duration for selected larvae later in the season. The researchers attributed this pattern to early season mortality due to red tide exposure followed by increased recruitment later in the season (Warlen et al. 1998). The timing of maximum occurrences of Engraulidae and Clupeidae (later in the spring as compared to 1999 and 2000, see Newstead 2003), as well as the very high densities of larval engraulids encountered at Station 4 after the red tide event (18 April through 2 May, see Fig. 5) appears to support this theory.

On the 18 April sampling event (see Fig. 4), a large aggregation of gulls was observed feeding on juvenile *Brevoortia patronus* which were gasping and whirling at the surface between Stations 3 and 4. Inspection of Figure 4 shows that during this sampling event, clupeid densities were lowest at Stations 3 and 4, despite the apparent recruitment to Stations 1 and 2. The following sampling event showed that after the red tide event, densities of *B. patronus* increased dramatically across the estuary, but especially at red tide affected Stations at the front of the bay. Though D.O. levels at Stations 3 and 4 were not below the 3 mg l^{-1} minimum suggested as a threshold for this species (Christmas et al. 1982), the observed dying menhaden may have been associated with a localized area of low dissolved oxygen, possibly attributable to decaying fish associated with fish kills reported prior to this date. On this sampling date, all Stations exhibited their seasonal minima of D.O. and % saturation. In the Galveston Bay system of the upper Texas coast, 17 of 28 fish kills occurring between 1980-1989 were caused by low D.O. Five of these were attributed to discharge of cooling water from power plants (Lowe et al. 1991).

An increase in zooplankton abundance (in this study, only the qualitative fraction of the total zooplankton community that was retained by the 500 ?m mesh net) is generally noted immediately prior to the onset of the main recruitment period (Cushing 1975). Increased zooplankton abundance was not noted until late March in 2002, which coincided with the main recruitment period seen in late March and April. Taggart and Leggett (1987) reported that microzooplankton density was coherent with temperature (with a lag of ~3-6 d) in a northwest Atlantic bay, and that density of fish larvae was in phase with microzooplankton density. Temperature was suspected to be the primary factor controlling the spatio-temporal occurrence of fish eggs and larvae in this same bay (Laprise and Pepin 1995).

Gelatinous plankton was routinely encountered in collections throughout the spring sampling period. In some cases, sample durations had to be lowered because the densities of gelatinous plankton clogged the net to the point of lowering net filtering efficiency. The ctenophore *Beröe ovata* was frequently collected early in the sampling period (end of February to April), while cnidarians such as *Stomolophus meleagris* and *Aurelia aurita* were more common towards the end of the spring period. Jellyfish can be potentially significant predators on larval fish when they co-occur at high densities (Gamble and Hay 1989). Though predation on larval fish was not observed by this study, there exists the possibility that recruitment may have been affected either directly or indirectly through alterations in food web dynamics. In a study of zooplankton in the Nueces Estuary, Buskey (1993) reported that the abundance of mesozooplankton was usually lower at stations where ctenophores were abundant.

Size-class structure for Engraulidae was drastically different between the stations in the back bay (1 and 2) and stations closer to the mouth of the bay (3 and 4). Total numbers were generally smaller and median size was greater in the back of the bay than towards the mouth. This seems to support the idea that a "corridor" of recruitment exists for these fish, which are most likely spawning in Corpus Christi Bay. The size differences seen between these two areas of the bay (the back bay and the mouth of the bay) also suggests that the outfall of the Nueces River and the power plant discharge, in conjunction with the numerous relict oyster reefs across from the river discharge location, affects water circulation patterns in ways that prohibit the smallest engraulids from being advected in large numbers to the back bay area. Spawning of *A. mitchilli* in the Port Aransas area has been reported from February to March and June to August, though considerable temporal differences are reported between this and other parts of the Texas coast (Pattillo et al. 1997). Since *A. hepsetus* is typically considered an offshore fish (Hoese and Moore 1977) and only a few identifiable adults were collected in this study, larval *Anchoa* sp. which appear in samples in March and April are probably attributable to spring spawning of *A. mitchilli*. Most *A. mitchilli* collected at an identifiable size (juvenile and adult) were probably spawned in the late summer/fall prior to spring sampling. The late occurrence of larval *Anchoa* sp. in 2002 indicates spawning occurred later than has been reported for this area, and may have also been attributable to the persistent cooler temperatures in the early spring of 2002.

Length-frequency differences between stations 1 and 2 are more difficult to resolve because these stations are more closely linked both spatially and hydrologically. Neither patterns of abundance nor length-frequency data seem to suggest that anchovies were proceeding downward along a salinity gradient with regard to these two stations; however, salinity differences between these two stations typically did not exceed 2 PSU during the year. The larger juvenile fish are far more motile than at the larval size, and probably have attained the ability to actively seek a favorable habitat/food source, and prevent advection away from such habitat. According to Pattillo et al. (1997) population densities of adult anchovies are primarily influenced by food supply in the water column, and the fish may be attracted to areas of high turbidity. Inspection of the engraulid collection data shows that highest juvenile-sized anchovy densities always occurred at the stations with the highest turbidity.

Length-frequency of gobies was also different among the stations, and median lengths show a trend similar to that of Engraulidae, with larger fish being captured towards the back bay Stations. While statistically significant differences were seen among a number of pair-wise comparisons of Stations (e.g., Station 1 had different length-frequencies than Station 3 and 4, but not Station 2; see Table 5), these differences need to be viewed in a biological context. The overall shapes of the distributions were very similar among all Stations (Fig. 10), with the majority of individuals falling within the 3-4 mm size class bins. Gobies were predominantly of the ubiquitously estuarine-resident genus *Gobiosoma*. If *Gobiosoma* were spawning throughout the bay, then the assertion of the river discharge zone acting as a recruitment barrier does not appear to hold for this genus. Alternatively, if this genus is spawning in higher numbers in the back bay and delta region, then the circulation patterns associated with any recruitment barrier of the river discharge zone may be acting as a retention mechanism, keeping higher numbers of larvae concentrated in the back bay Stations (Fig. 10).

According to Pattillo et al. (1997), *Gobiosoma* prefers intermediate to moderately high salinities, and spawning may require temperatures >19°C. Data from this study is in accordance with both of these assertions. Gobies were not collected in appreciable numbers until mid April in 2002, when water temperature began to increase, and the highest densities of gobies were collected at stations where salinity was generally between 25 and 32 PSU (Station 1 and 2).

Clupeidae larvae and juveniles (primarily *B. patronus*) appear to be actively seeking out the back bay Stations, with abundance increasing along the transect through the Nueces Bay estuary (Fig. 11). Length-frequencies also support the idea of a recruitment corridor for this taxa, with the largest proportion of larvae (<19 mm SL) being collected at Station 4. The proportion of juveniles increased across the bay up to Station 2, with the greatest number of clupeids collected at the delta Station. Because this taxa spawns well offshore beginning in the fall (Pattillo et al. 1997), the size ranges of individuals collected in the spring were that of transforming juveniles and as such, they were competent swimmers and less likely to be affected by passive transport mechanisms. By the spring sampling period, this taxa appears to be able to overcome any recruitment barrier at the river discharge zone and actively seek out the back bay portions of the estuary. This could be in response to food availability associated with the high turbidity zone of the back bay. Larval *B. patronus* feed on larger phytoplankton and some zooplankton, with the phytoplankton being replaced in importance by larger zooplankton, such as copepods, tintinnids, and invertebrate eggs, as they transform into juveniles (Ahrenholz 1991). If the differences in *B. patronus* abundances are due to primary productivity and food availability, and thus freshwater inflow, then their distributions reinforce the idea of the back bay locations as preferred nursery habitat.

In a one year study (bi-monthly sampling) of larval fish immigrating into the Aransas-Corpus Christi Bay Complex via Aransas Pass and the associated channels, Allshouse (1983) reported Engraulidae, Sciaenidae and Clupeidae as the three most dominant families, comprising 49, 25 and 18% of the catch, respectively. The three most dominant sciaenids (*Micropogonias undulatus*, *Cynoscion arenarius*, and *Leiostomus xanthurus*) collected during the spring months are all offshore spawning fishes with estuarine-dependent early life history stages. A strong presence of these species compared to this study would be expected due to the proximity of the Gulf pass. The lower abundances and larger sizes of these species found in this study may indicate that the majority of their larvae either disperse and settle out of the plankton soon after being transported through the pass and into the immediate bays or are lost to mortality. The peak period of occurrence reported for *B. patronus* by Allshouse was November through March. The presence and timing (through April and into May) of *B. patronus* in this study, particularly at the back bay stations (and especially Station 1), suggests that the river and delta areas are actively sought by this species. Though Allshouse consistently encountered gobies throughout the year, they did not occur in the relative abundances as found in this study. The assertion that the majority of larval gobies caught in this study belong to the genus *Gobiosoma* is supported by the fact that they are considered estuarine-resident, and they were not encountered in such high abundances in the Allshouse (1983) study.

Taxa which were commonly encountered in this study but not in the Allshouse (1983) study include *Elops saurus*, Diodontidae (larval descriptions are lacking but this is probably the striped burrfish, *Chilomycterus schoepfi*) and *Gobiesox strumosus*. *E. saurus* is reported to spawn throughout the year, with a possible peak in fall (Jones et al. 1978). Specimens captured in this study were mostly Stage I leptocephali and were encountered in February, March and April exclusively at the back bay stations. *G. strumosus* inhabits areas associated with structure (rocks, oyster shells, sponges, etc.) in inshore areas. Various aspects of early life history stages as reported by Martin and Drewery (1978) may need to be updated for this area based on the occurrence of *G. strumosus* in this study. The presence of larvae in this study suggests that spawning probably begins as early as February and extends into at least May, and larvae hatched at ~1.5 mm (or less). Martin and Drewery (1978) had reported a spawning season of April through August with a peak in late April or early May, and hatch size of 2.4-2.8 mm (experimental).

VI. CONCLUSIONS

Larval abundance of many of the species occurring in the study (particularly those that spawn outside the bay and in the Gulf) appears to be positively affected by freshwater inflow. Though a strong salinity gradient is not always present in the bay, fish appear to be selectively recruiting to the more productive areas of the bay associated with the delta. It is postulated that pulsed freshwater inflow events that provide flushing of the highly productive delta marsh area may be more important for larval fish recruitment than lower flows that bypass the delta.

CITED REFERENCES

Ahrenholz, D.W. 1991. Population biology and life history of the North American menhadens, *Brevoortia* spp. *Marine Fisheries Review* 53(4)3-19.

Allshouse, W.C. 1983. The distribution of immigrating larval and postlarval fishes into the Aransas-Corpus Christi Bay complex. M. S. Thesis. Corpus Christi State University. 120 pp.

Armstrong, N.E. 1981. Responses of Texas estuaries to freshwater inflows, p. 103-120. In V. S. Kennedy (ed.), Estuarine Comparisons: Proceedings of the Sixth Biennial International Estuarine Research Conference, Gleneden Beach, Oregon.

Blaber, S.J.M. and T.G. Blaber. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology* 17:143-162.

Boehlert, G.W. and B.C. Mundy. 1988. Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. *American Fisheries Society* 3:51-67.

Boesch, D. and R. Turner. 1984. Dependence of fishery species on salt marshes: The role of food and refuge. *Estuaries* 7:460-468.

Bureau of Reclamation. 2000. Concluding Report: Rincon Bayou Demonstration Project. Volume II: Findings. United States Department of the Interior, Bureau of Reclamation, Oklahoma-Texas Area Office, Austin, Texas.

Buskey, E.J. 1993. Annual pattern of micro- and mesozooplankton abundance and biomass in a subtropical estuary. *Journal of Plankton Research* 15:907-924.

Christmas, J.Y., J.T. McBee, R.S. Waller and F.C. Sutter III. 1982. Habitat suitability index models: Gulf menhaden. U. S. Dept. Int. Fish Wildl. Serv. FWS/OBS-82/10.23. 23 pp.

Clarke, K.R. and R.M. Warwick. 1994. Changes in Marine Communities: An Approach to Stastical Analysis and Interpretation. Plymouth. Plymouth Marine Laboratory. 144 pp.

Cushing, D.H. 1975. Marine Ecology and Fisheries. Cambridge University Press, Cambridge, Massachusetts.

Dando, P.R. 1984. Reproduction in Estuarine Fish, p. 155-170. In G. Potts and R. Wootton (eds.), Fish Reproduction: Strategies and Tactics. Academic Press, Orlando, Florida.

Darnell, R.M. and J.D. McEachran. 1989. Larval recruitment of estuarine-related fishes and invertebrates of the Texas coast. Report to Texas Parks and Wildlife Department, by Department of Oceanography and Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX. 107 pp.

Ditty, J.G. and R.F. Shaw. 1994. Preliminary guide to the identification of the early life history stages of sciaenid fishes from the western central Atlantic. NOAA Tech. Mem. NMFS-SEFSC-349. 118 pp.

Espey, Huston & Associates. 1981. Nueces marsh development: A feasibility study of the introduction of river flows. Document #81328. EH&A, Austin, Texas.

Farooqi, T., R.F. Shaw, and J.G. Ditty. 1995. Preliminary guide to the identification of the early life history stages of anchovies (Family Engraulidae) of the western central Atlantic. NOAA Tech. Mem. NMFS-SEFSC-358. 65 pp.

Freund, R.A. and J.A. Dodson. 1995. Freshwater releases and salinity monitoring in Nueces Bay, Texas, p. 43-52. In Texas Water '95. Proceedings of the Texas Section of the American Society of Civil Engineers, San Antonio, Texas (USA), 16-17 August 1995.

Fritzsche, R.A. 1978. Development of Fishes of the Mid-Atlantic Bight: An atlas of egg, larval, and juvenile stages. Volume V. Chaetodontidae through Ophidiidae. U.S. Department of the Interior, Biological Services Program. 340 pp.

Gamble, J.C. and S.J. Hay. 1989. Predation by the scyphomedusan Aurelia aurita on herring larvae in large enclosures: Effects of predator size and prey starvation, p. 366-375, In The Early Life History of Fish. The Third ICES Symposium, Bergen (Norway), 3-5 October 1988.

Grange, N., A.K. Whitfield, C.J. de Villiers and B.R. Allanson. 2000. The response of two South African east coast estuaries to altered flow regimes. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:155-177.

Hardy, Jr., J.D. 1978. Development of Fishes of the Mid-Atlantic Bight: An atlas of egg, larval, and juvenile stages. Volume II. Anguillidae through Syngnathidae. U.S. Department of the Interior, Biological Services Program. 458 pp.

HDR Engineering, Inc. 1991. Regional Wastewater Planning Study – Phase I, Nueces Estuary. Austin, Texas.

Henley, D.E. and D.G. Rauschuber. 1981. Freshwater needs of fish and wildlife resources in the Nueces-Corpus Christi Bay area, Texas: a literature synthesis. FWS/OBS-80/10. U.S. Fish and Wildlife Service, Washington, D.C.

Hettler, W.F., Jr., D.S. Peters, D.R. Colby, and E.H. Laban. 1997. Daily variability in abundance of larval fishes inside Beaufort Inlet. *Fishery Bulletin* 95:477-493.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. *U.S. Bureau of Fisheries Bulletin*, Vol. 43:1-388.

Hoese, H.D. and R.H. Moore. 1977. Fishes of the Gulf of Mexico. Texas, Louisiana, and Adjacent Waters. Texas A&M University Press. College Station.

Johnson, G.D. 1978. Development of Fishes of the Mid-Atlantic Bight: An atlas of egg, larval, and juvenile stages. Volume IV. Carangidae through Ephippidae. U.S. Department of the Interior, Biological Services Program. 314 pp.

Jones, P.W., F.D. Martin, and J.D. Hardy, Jr. 1978. Development of Fishes of the Mid-Atlantic Bight: An atlas of egg, larval, and juvenile stages. Volume I. Acipenseridae through Ictaluridae. U.S. Department of the Interior, Biological Services Program. 366 pp.

Kneib, R.T. 1997. Early life stages of resident nekton in intertidal marshes. *Estuaries* 20:214-230.

Knox, G.A. 1986. Estuarine Ecosystems, Vol. I. CRC Press, Boca Raton, Florida.

Lange, U. and W. Greve. 1996. (How) Does temperature determine the spawning time and the distribution of fish? Council Meeting of the International Council for the Exploration of the Sea, Reykjavik (Iceland), 27 Sep-4 Oct 1996.

Laprise, R. and P. Pepin. 1995. Factors influencing the spatio-temporal occurrence of fish eggs and larvae in a northern, physically dynamic coastal environment. *Marine Ecological Progress Series* 122:73-92.

Lee, W.Y., P.E. Eldridge, D. Buzan, and W.M. Pulich. 2001. Freshwater Inflow Recommendation for the Trinity-San Jacinto Estuary of Texas. Technical Report. Texas Parks and Wildlife Department, Resource Protection Division, Coastal Studies Program, Austin, Texas.

Livingston, R.J. 1997. Trophic response of estuarine fishes to long-term changes of river runoff. *Bulletin of Marine Science* 60:984-1004.

Longley, W.L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.

Lowe, J.A., D.R.G. Farrow, A.S. Pait, S.J. Arenstam and E.F. Lavan. 1991. Fish Kills in Coastal Waters 1980-1989. National Oceanic and Atmospheric Administration, Rockville, Maryland. 69 pp.

Lyczkowski-Shultz, J., D.L. Ruple, S.L. Richardson, and J.H. Cowan, Jr. 1990. Distribution of fish larvae relative to time and tide in a Gulf of Mexico barrier island pass. *Bulletin of Marine Science* 46:563-577.

Martin, F.D. and G.E. Drewery. 1978. Development of Fishes of the Mid-Atlantic Bight: An atlas of egg, larval, and juvenile stages. Volume VI. Stromateidae through Ogcocephalidae. U.S. Department of the Interior, Biological Services Program. 416 pp.

McHugh, J.L. 1976. Estuarine fisheries: Are they doomed? In M. Wiley (ed.), Estuarine Processes, Vol. I. Academic Press, New York.

Newstead, D. 2003. Larval fish recruitment to isolated nursery grounds in Nueces Bay, Texas. M. S. Thesis, Texas A&M-Corpus Christi University. 61 pp.

Norcross, B.L. and R.F. Shaw. 1984. Oceanic and estuarine transport of fish eggs and larvae: a review. *Transactions of the American Fisheries Society* 113:153-165.

Palmer, T.A., P.A. Montagna and R.D. Kalke. 2002. Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA. *Estuaries* 25:1448-1456.

Pattillo, M.E., T.E. Czapla, D.M. Nelson and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. 377 pp.

Powell, G.L. and J. Matsumoto. 1994. Texas estuarine mathematical programming model: a tool for freshwater inflow management, p. 401-406. In K. R. Dyer and R. J. Orth (eds.), Changes and Fluxes in Estuaries. Olsen & Olsen: Fredensborg, Denmark.

__________, J. Matsumoto, W.L. Longley, and D.A. Brock. 1997. Effects of Structures and Practices on the Circulation and Salinity Patterns of the Corpus Christi Bay National Estuary Program Study Area. Corpus Christi Bay National Estuary Program Publication No. 19. 169 pp.

Pulich, W.M., Jr., W.Y. Lee, P.E. Eldridge, C.L. Loeffler, and J.M. Hinson. 1998. Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas. technical Report 98-01. Texas Parks & Wildlife Department, Resource Protection Division, Austin, TX. 101 pp.

__________, J. Tolan, W.Y. Lee and W. Alvis. 2002. Freshwater Inflow Recommendation for the Nueces Estuary. Technical Report. Texas Parks and Wildlife Department, Resource Protection Division, Coastal Studies Program, Austin, Texas.

Raynie, R.C. and R.F. Shaw. 1994. Ichthyoplankton abundance along a recruitment corridor from offshore spawning to estuarine nursery ground. *Estuarine, Coastal and Shelf Science* 39:421-450.

Richards, W.J. and K.C. Lindeman. 1987. Recruitment dynamics of reef fishes: planktonic processes, settlement and demersal ecologies, and fishery analysis. *Bulletin of Marine Science* 41:392-410.

Riley, G.A. 1967. The plankton of estuaries, pp. 316-326. In G. H. Lauff (ed.) Estuaries. American Association for the Advancement of Science Publication No. 83. Washington, D. C.: AAAS.

Roberts, C.M. 1991. Larval mortality and the composition of coral reef fish communities. *Trends in Ecology and Evolution* 6:83-87.

Ruth, B.F. 1990. Establishment of estuarine faunal use in a salt marsh creation project, Nueces River Delta, Texas. Center for Coastal Studies. Corpus Christi State University, Corpus Christi, Texas. CCSU-9001-CCS.

Sale, P.F. 1990. Recruitment of marine species: Is the bandwagon rolling in the right direction? *Trends in Ecology and Evolution* 5:25-27.

Schelske, C.L. and E.P. Odum. 1961. Mechanisms maintaining high productivity in Georgia estuaries, p. 75-80. In Clean Water for the Nation's Estuaries. Proceedings of the Georgia Public Meeting, Jekyll Island, Georgia.

Shaw, R.F., B.D. Rogers, J.H. Cowan, Jr., and W.H. Herke. 1988. Ocean-estuary coupling of ichthyoplankton and nekton in the northern Gulf of Mexico. *American Fisheries Society Symposium* 3:77-89.

SYSTAT. 1992. SYSTAT for Windows: Statistics, Version 5 Edition. SYSTAT Inc., Evanston, Ill. 750 pp.

Taggart, C.T. and W.C. Leggett. 1987. Wind-forced hydrodynamics and their interaction with larval fish and plankton abundance: A time-series analysis of physical and biological data. *Canadian Journal of Fisheries and Aquatic Sciences* 44:438-451.

Texas Department of Health. 2002. 2001-2002 Red Tide Event in Texas. Texas Department of Health, 1100 W. 49th Street, Austin, Texas 78756.

Texas Department of Water Resources. 1982. Nueces and Mission-Aransas Estuaries: An Analysis of Bay Segment Boundaries, Physical Characteristics, and Nutrient Processes. (LP-83) Texas Department of Water Resources, Austin, Texas.

Underwood, A.J. and P.G. Fairweather. 1989. Supply-side ecology and benthic marine assemblages. *Trends in Ecology and Evolution* 4:16-20.

United States Geological Survey. 1984. Corpus Christi, Texas Quadrangle Map. 27097-E1-TB-100.

Valesini, F.J., I.C. Potter, M.E. Platell, and G.A. Hyndes. 1997. Ichthyofaunas of a temperate estuary and adjacent marine embayment. Implications regarding choice of nursery area and influence of environmental changes. *Marine Biology* 128: 317-328.

Warlen, S.M., P.A. Tester and D.R. Colby. 1998. Recruitment of larval fishes into a North Carolina estuary during a bloom of the red tide dinoflagellate, *Gymnodinium breve*. *Bulletin of Marine Science* 63:83-95.

Weinstein, M.P., S.L. Weiss, R.G. Hodson, and L.R. Gerry. 1980. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. *Fishery Bulletin* 78:419-435.

__________ and H.A Brooks. 1983. Comparative ecology of nekton residing in a tidal creek and adjacent seagrass meadow: Community composition and structure. *Marine Ecology Progress Series* 12:15-27.

Whitledge, T.E. 1993. Enhanced hydrographic survey for CPL discharge in Nueces Bay. Technical Report No. TR/93-008. The University of Texas Marine Science Institute, Port Aransas, Texas.

Wilber, D.H. and R. Bass. 1998. Effect of the Colorado river diversion on Matagorda Bay epifauna. *Estuarine, Coastal and Shelf Science* 47:309-318.

Worthington, D.G., D.J. Ferrell, S.E. McMeill, and J.D. Bell. 1992. Effects of the shoot density of seagrass on fish and decapods: Are correlations evident over large spatial scales? *Marine Biology* 112:139-146.

SOURCES OF UNPUBLISHED INFORMATION

United States Geological Survey. USGS discharge data for station #08211500 Nueces River at Calallen, Texas (November 1998 – October 2002).

Website: http://tx.waterdata.usgs.gov/nwis/uv/?site_no=08211500.

Wagner, T. personal communication. Texas Parks and Wildlife Department, Coastal Fisheries Division, Corpus Christi Bay Ecosystem Office, 702 Navigation Circle, Rockport, Texas 78382.

APPENDIX

Taxonomic list of species collected (mean densities (fish $100m^{-3}$) by Station) during spring season, 2002, ichthyoplankton sampling in Nueces Bay, Texas.

Taxa	STATION			
	1	2	3	4
O. Clupeiformes				
F. Clupeidae				
Dorosoma sp.	0	0	0	0.13
Brevoortia patronus	65.86	44.78	55.25	23.75
F. Engraulidae				
Anchoa hepsetus	0.15	0	0	3.5
Anchoa mitchilli	27.48	26.85	4.32	10.35
Anchoa sp.	4.59	18.4	28.4	1049.69
O. Aulopiformes				
F. Synodontidae				
Synodus foetens	0	0	0	0.03
O. Gobiesociformes				
F. Gobiesocidae				
Gobiesox strumosus	0.28	0.52	0.13	0.49
O. Atheriniformes				
F. Atherinidae				
Menidia sp.	0.09	0.53	0.02	0.03
O. Gasterosteiformes				
F. Syngnathidae				
Hippocampus zosterae	0	0	0.03	0.06
Syngnathus scovelli	1.22	1.73	0.11	0.33
O. Beloniformes				
F. Belonidae				
Strongylura marina	0.04	0	0	0.03
O. Perciformes				
F. Carangidae				
Oligoplites saurus	0	0	0	0.02
F. Sparidae				
Lagodon rhomboides	0.9	0.62	0.33	0.86
F. Sciaenidae				
Micropogonias undulatus	0.2	0.05	0	0
Cynoscion nebulosus	0	0	0	0.95

Appendix (cont.)

F. Sciaenidae				
Leiostomus xanthurus	0.1	0.25	0	0
Bairdiella chrysoura	0	0.1	0	7
F. Blenniidae	0.33	1.77	0.44	0.63
F. Eleotridae				
Dormitator maculatus	0	0.04	0	0
F. Gobiidae	202.25	225.75	45.62	16.3
Gobiosoma bosc	0.04	0	0	0
Microgobius sp.	0.1	0	0	3.47
Gobionellus oceanicus	0	0.04	0	0
Gobionellus boleosoma	0.4	0.02	0	0.08
O. Tetraodontiformes				
F. Tetraodontidae	0	0.06	0.18	0
Sphoeroides parvus	0	0	0	0
F. Diodontidae	0	0	0	0.29
UNIDENTIFIED FISH	0.04	0	0	0
TOTAL	304.22	321.57	134.86	1117.99