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Occurrence and Pelagic Habitat of Reef Fish Larvae in the Gulf of Mexico

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Abstract.—Examination of 3,560 ichthyoplankton samples taken during 15 years of annual Southeast Area Monitoring and Assessment Program (SEAMAP) resource surveys in the U.S. Gulf of Mexico (GOM), 1982–1996, yielded 208 holocentrid, 524 priacanthid, 6,606 labrid, and 2,609 scarid larvae. Larvae were found more frequently and in higher abundances over the continental shelf of the eastern GOM, where most reef fish habitat exists. Labrid and scarid larvae taken over the Texas–Louisiana shelf during 1992 and 1993 were consistently associated with higher salinity and clearer water on the mid- to outer shelf during all seasons. Increased river discharge in 1993 appears to have limited labrid and scarid larvae to the outer Texas–Louisiana shelf, as compared to their more widespread distribution over the shelf in 1992 when river discharge was near mean levels. Labrid and scarid larvae were found to consistently occur in the open GOM, at abundance levels comparable to those observed over the continental shelf. Abundances of labrid and scarid larvae examined in relation to dynamic sea surface height in winter and spring of 1993 revealed their apparent relationship with open GOM hydrography. In the western GOM, the highest abundances of labrid and scarid larvae were associated with the frontal boundary of a Loop Current (LC) anticyclone. In the eastern GOM, labrid and scarid larvae were found in higher abundances along the frontal boundaries of the Loop Current, LC/cyclonic eddy confluences, and within the interior of the LC. The consistent occurrence and relative abundance of labrid and scarid larvae with these features in the open GOM indicates potential local retention and/or exchange and transport of larvae between the continental shelf and open ocean, among reef systems throughout the GOM, and from upstream sources such as the Caribbean Sea.

Introduction

The U.S. Gulf of Mexico (GOM) is known for the richness and productivity of its salt marshes, estuaries, and broad continental shelf, especially west of the Mississippi River. Yet, areas of natural hardbottom and the diverse reef fauna that they support occur throughout the GOM (Ludwick and Walton 1957; Moe 1963; Smith et al. 1975; Rezak and Bright 1981; Rezak et al. 1983; Putt et al. 1986; Sager et al. 1992). Additionally, in the northwestern and north-central GOM, the presence of offshore oil and gas production structures, and the placement of artificial reefs, has increased the amount of hard substrate and available reef habitat (Gallaway 1984; Kasprizak 1998).

The biota associated with natural and artificial reef habitat is a mix of western Atlantic temperate and insular tropical species, which becomes increasingly tropical in the more offshore areas (Dennis and Bright 1988). The tropical nature of reef communities in the GOM is dependent upon geological characteristics of the substrate, regional and local hydrography, winter temperature minimum, riverine influence on salinity and turbidity, depth of substrate, and depth and thickness of the nepheloid layer (Smith 1976 and Rezak et al. 1990).

The majority of adult reef fishes are sedentary and have an obligate relationship with their habitat (Choat and Bellwood 1991). This relationship limits them to relatively small areas of suitable habitat. Since the adult phase of most species are sedentary, populations of reef fishes are established and maintained by the continuous settlement of pelagic larvae to reef habitat (Sale and Ferrell 1988; Leis 1991).

There is a noted lack of information on the planktonic and early life stages of reef fishes (Richards and Lindeman 1987; Sale 1991; Cowen and Sponaugle 1997). Richards et al. (1993) review the numerous ichthyoplankton studies from the broad range of marine habitats found in the GOM, but none focus on the larvae of reef fishes on a GOM-wide basis. Ichthyoplankton samples collected since 1982 during Southeast Area Monitoring and Assessment Program (SEAMAP) ichthyoplankton surveys provide a means to examine the pelagic habitat of reef fish larvae throughout the GOM (SEAMAP 2000). The data from these collections are summarized to describe the regional and GOM-wide distribution and abundance of pelagic larvae in four obligate reef fish families: Holocentridae (squirrelfishes), Priacanthidae (bigeyes), Labridae (wrasses), and Scaridae (parrotfishes). Additionally, we present data that reveals apparent relationships between larval reef fish distributions and hydrography in the northwestern and open GOM.

Methods

Plankton collections and environmental data were taken during four annual SEAMAP surveys of fishery resources in the U.S. Exclusive Economic Zone (EEZ) of the northern GOM (Figure 1; Table 1). The summer and fall groundfish surveys are conducted on the continental shelf between 10 and 110 m depth from Mobile Bay, Alabama to Brownsville, Texas in the months of June and July, and October and November, respectively. The fall plankton survey is conducted on the continental shelf between 10 and 200 m in late August to mid-October, but generally during the month of September. The spring plankton survey is conducted in open GOM waters between 200 m and U.S. EEZ in April, May, and occasionally into early June. Survey stations were located 56 km apart in a fixed grid pattern on the continental shelf and 112 km apart in the open GOM and were sampled at all times of the day or night. An additional set of plankton collections, taken during a marine mammals survey on *Oregon II* cruise 203, in January and February 1993, were examined in order to investigate possible associations between hydrographic features and larval fish distribution in the open GOM (Table 1). These samples were taken every 19 km during nighttime hours while the ship transited to the next day's starting position for marine mammals observations. All ichthyoplankton samples were taken with a 61-cm bongo net fitted with 0.333-mm mesh nets and fished in an oblique path from near bottom to surface following standard SEAMAP collection procedures (SEAMAP 2000). Fish larvae from the SEAMAP collections were sorted and identified at the Polish Sorting and Identification Laboratory in Szczecin, Poland.

Bongo net collections taken during the summer groundfish (SG), fall plankton (FP), and fall groundfish (FG) continental shelf surveys were partitioned by longitude as Texas–Louisiana (TX–LA: west of 89.25°W), Mississippi–Alabama (MS–AL: east of 89.25°W and west of 87.75°W), or Florida (FL: east of 87.75°W) shelf regions. Bongo net collections taken during the Spring Plankton (SP) open GOM surveys were partitioned by longitude as western (WEST: west of 89.25°W) or eastern (EAST: east of 89.25°W) regions. Frequency of occurrence, abundance (number of larvae/10 m^2), and standard error were calculated for the families Holocentridae, Priacanthidae, Labridae, and Scaridae for each year and region and for each survey time series and region.

Surface measurements of salinity and turbidity were taken with a SEABIRD SBE25 conductivity temperature depth (CTD) profiler. Surface salinity contours were generated for the 1992, 1993, and 1994 summer groundfish, fall plankton, and fall groundfish surveys. A salinity contour of 30 was used to delineate the westward and offshore extent of lower salinity shelf waters in those years. Surface turbidity (% water clarity) contours were generated for the summer and fall groundfish surveys in 1992 and 1993, and a turbidity contour of 60% was used to delineate the onshore extent of offshore waters. Contour plots were generated by Surfer 7 using a Kriging function with a linear variogram (Surfer 1999). Labrid and scarid distributions were plotted over composite salinity and transmissivity contours to examine possible relationships with these parameters.

TOPEX/ERS-1 merged dynamic sea surface height maps were obtained interactively from the GOM historical data server at the Colorado Center for Astrodynamics Research (CCAR) at http://www-ccar.colorado.edu/~realtime/gom-historical_vel/.

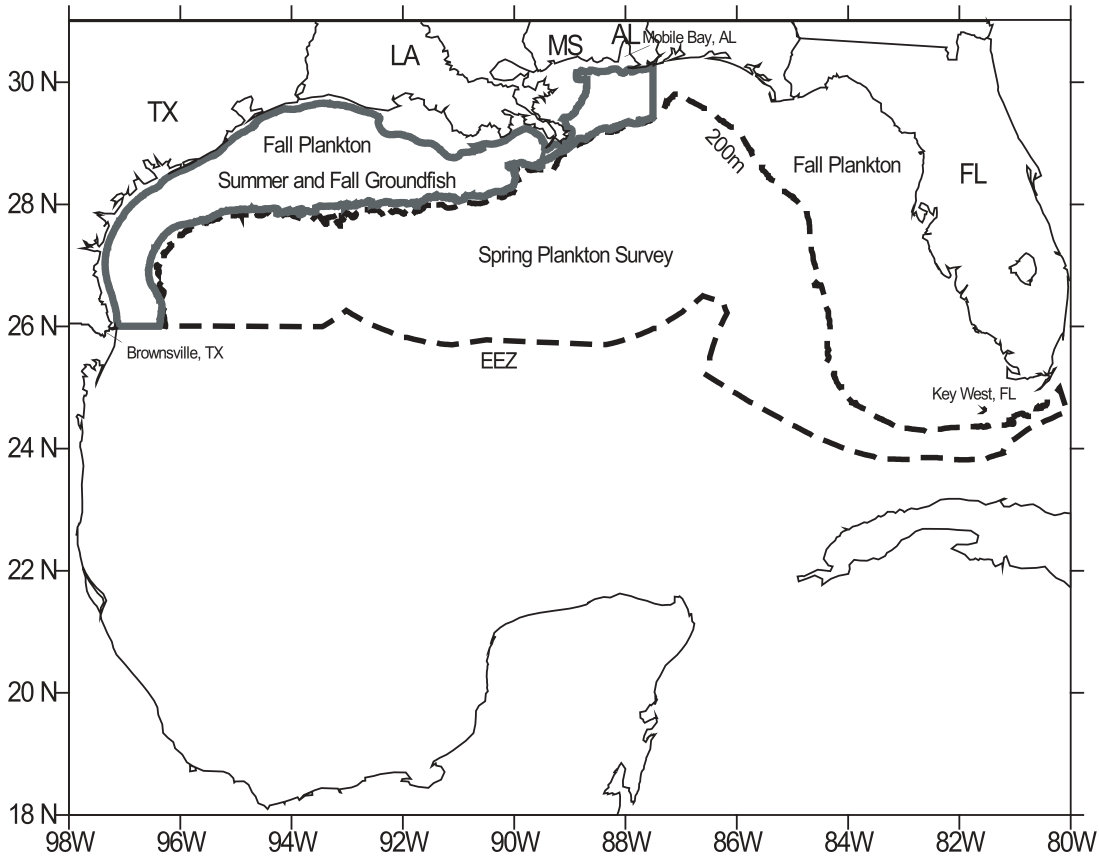

FIGURE 1. Southeast Area Monitoring and Assessment Program (SEAMAP) survey areas sampled during summer groundfish, fall plankton, fall groundfish, and spring plankton surveys.

Abundances of labrid and scarid larvae were plotted over dynamic sea surface height in order to examine relationships with open GOM hydrography. Abundance data were subset into 30-d periods and plotted over the sea surface height map corresponding to the midpoint of the 30-d sampling period.

TABLE 1. Sampling effort of SEAMAP surveys. Western Gulf of Mexico (West), Texas–Louisiana shelf (TX–LA), Mississippi–Alabama shelf (MS–AL), Florida shelf (FL), Western Gulf of Mexico (West) and Eastern Gulf of Mexico (East). (*) Indicates area not sampled.

			Number of samples by area					
Survey	Time frame	Years	West	TX–LA	MS–AL	FL	East	Total
Summer groundfish (SG)	June–July	1982–1996	*	330	39	*	*	369
Fall plankton (FP)	Aug.–Oct.	1986–1994, 1996	*	507	84	551	*	1142
Fall groundfish (FG)	Oct.–Nov.	1986–1995	*	607	95	*	*	702
Spring plankton (SP)	April–June	1982–1984, 1986–1996	511	*	*	*	836	1347
Winter plankton (WP)	Jan.–Feb.	1993	*	*	*	*	*	102

Results

Examination of 3,560 bongo net samples from annual SEAMAP resource surveys in the GOM, 1982–1996, yielded 208 holocentrid, 524 priacanthid, 6,606 labrid, and 2,609 scarid larvae (Table 1). Plots generated for each survey depict the pelagic distribution of these larvae throughout the GOM (Figures 2–5). Distinct differences in annual and regional occurrence and abundance of these larvae were revealed among five regions: TX–LA, MS–AL, and FL shelves, and the western and eastern open GOM. Since annual and regional patterns in frequency of occurrence and abundance were similar, only occurrence data are presented here for each year and region.

Among the targeted reef fish larvae captured in June and July during summer groundfish surveys, only the labrids were consistently taken in every year of the 15-year time series (Figure 6). Frequency of occurrence of labrid larvae was higher on the MS–AL shelf than the TX–LA shelf. Priacanthid larvae were captured almost exclusively in collections on the TX–LA shelf but never in more than 8% of the samples. Holocentrid and scarid larvae occurred only sporadically over the time series and usually on the TX–LA shelf.

Reef fish larvae were taken more often in late August to early October than during summer surveys in June and July probably because of the inclusion of stations off the FL shelf during fall plankton surveys (Figure 7). The larvae of both labrids and scarids were consistently taken over the 11-year time series with percent frequency of occurrence in some years reaching 83% for labrids and 50% for scarids. The larvae of both were generally more common on the FL shelf than in the other two GOM regions. Although more common during the fall plankton survey, holocentrid larvae were never taken in more than 10% of the samples, even off Florida. Priacanthid larvae were consistently taken throughout the survey area over the time series but were most common on the Florida shelf where, in some years, they were found in more than 20% of samples.

Reef fish larvae were infrequently taken in October and November during 9 years of fall groundfish surveys (Figure 8). Among the four families of reef fishes, labrid and scarid larvae were the most common, occurring in up to 11% and 13% of samples

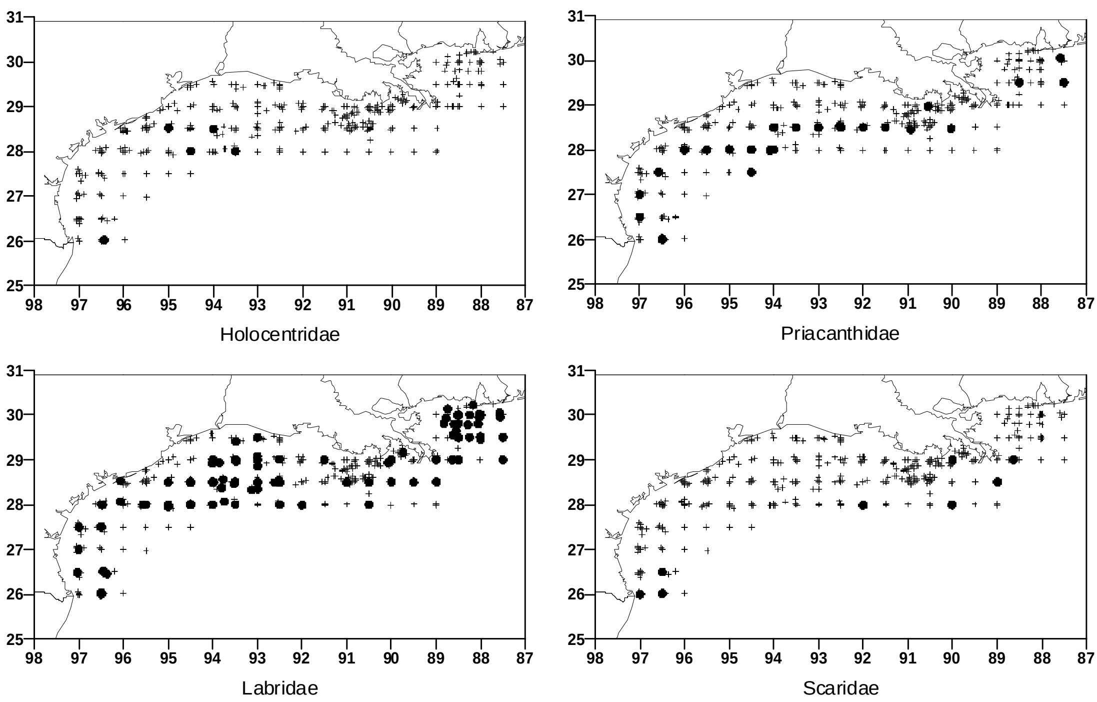

FIGURE 2. Occurrence of holocentrid, priacanthid, labrid, and scarid larvae taken during the 1982–1996 summer groundfish surveys. Filled circles (•) indicate positive catches of larvae, and plus signs (+) indicate zero catch.

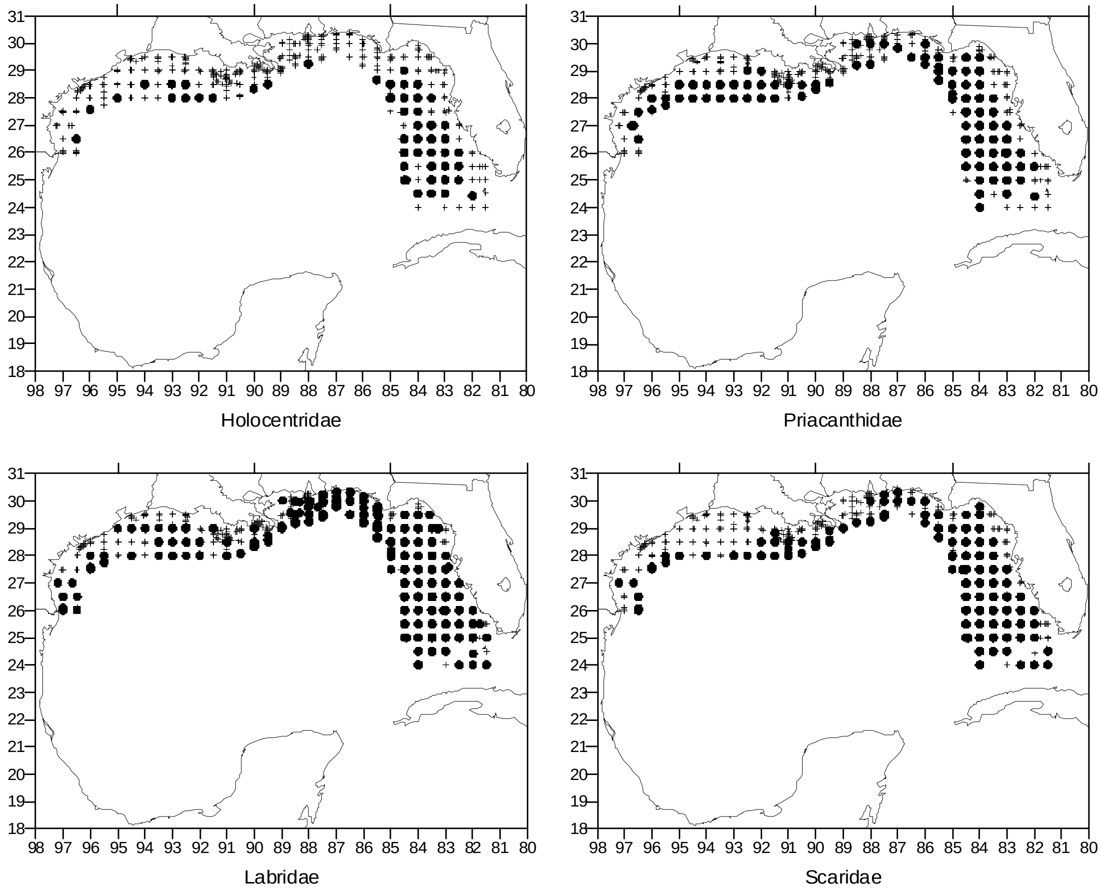

FIGURE 3. Occurrence of holocentrid, priacanthid, labrid, and scarid larvae taken during the 1986–1994 and 1996 fall plankton surveys. Filled circles (•) indicate positive catches of larvae, and plus signs (+) indicate zero catch.

from the TX–LA shelf and 33% and 20% of samples from the MS–AL shelf. Holocentrid larvae were never collected during this survey, and priacanthid larvae were collected in only 5 years.

The larvae of all the targeted reef fishes were consistently captured during the spring plankton survey of open GOM waters in April and May (Figure 9). Labrid and scarid larvae were taken in all 14 years of the time series in the eastern GOM but in only 11 and 13 years, respectively, in the western GOM. They consistently occurred at higher frequencies in the eastern than the western region where, in some years, they occurred in 40% or more of the samples. Holocentrid and priacanthid larvae were captured in each year of the time series in the eastern GOM but in only 6 and 9 years, respectively, in the western GOM. Their incidence in the west was usually less than 11% and, in the east, 18% or less.

Observations over the entire time series were combined by survey and region in order to compare regional differences in distribution and abundance (Figure 10 and Table 2). Overall frequency of occurrence and abundance of all four families of reef fishes was highest on the FL shelf. Labrid occurrence and abundance on the MS–AL shelf were comparable to observations on the FL shelf but were lower on the TX–LA shelf. The frequency of occurrence and abundance of holocentrids, priacanthids, and scarids was extremely low on the TX–LA and MS–AL shelves. Overall occurrence and abundance of all four taxa of reef fishes in the open GOM were higher in the eastern than the western GOM (Figure 10 and Table 2). The frequency of occurrence and abundance on the FL shelf and in the eastern GOM often exceeded occurrence on the TX–LA, MS–AL shelves, and in the western GOM by as much as 50%. The frequency of occur-

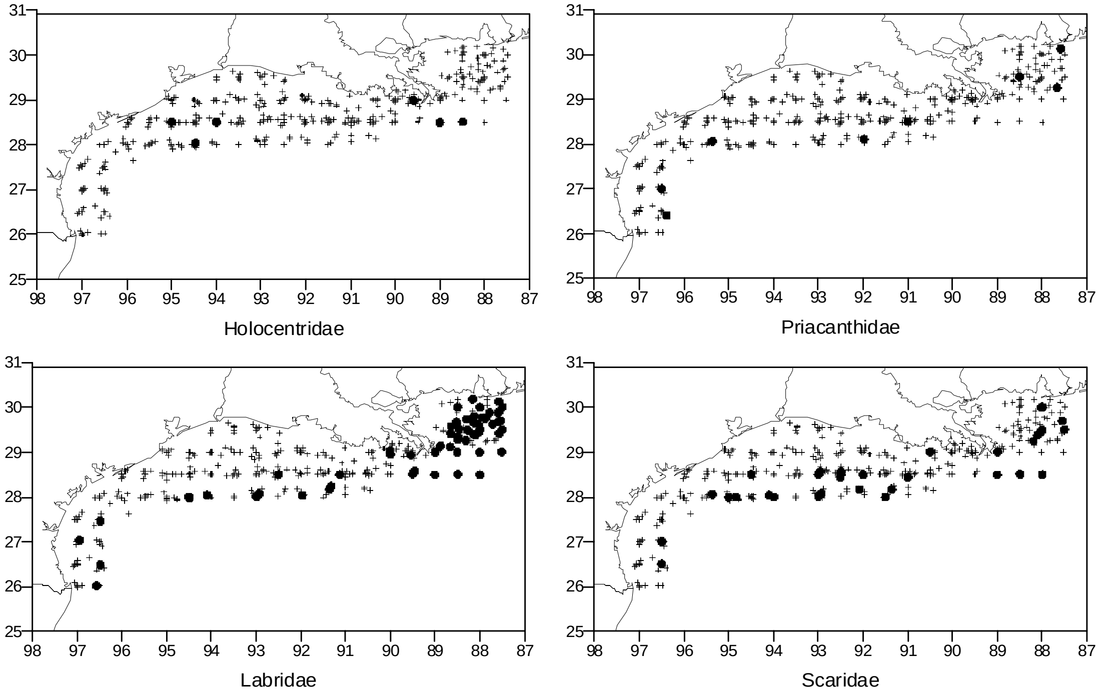

FIGURE 4. Occurrence of holocentrid, priacanthid, labrid, and scarid larvae taken during the 1986–1995 fall groundfish surveys. Filled circles (•) indicate positive catches of larvae, and plus signs (+) indicate zero catch.

rence and abundances of all families were similar in continental shelf and open ocean waters for both the western and eastern GOM.

Seasonality of larval reef fish occurrence could not be fully evaluated because of uneven regional sampling over the seasons. However, during the 6-month time period from early June to late November, the occurrence of labrids decreased on both the TX–LA and MS-AL shelves, while scarid occurrence generally increased.

Two hydrographic parameters, surface salinity and surface transmissivity, appeared to delineate the westward and offshore habitat of labrid and scarid larvae on the continental shelf west of Mobile Bay (Figures 11 and 12). Larvae were consistently associated with water of salinity greater than 30 and transmissivity of greater than or equal to 60%. The 30 isohaline generally defined the inshore limit of labrid and scarid occurrence. Annual variation in the area bounded by this isohaline was greatest during summer groundfish surveys and least during fall plankton and fall groundfish surveys in 1992–1994. Similarly, larval labrids and scarids were consistently associated with clearer offshore waters, as delineated by the 60% transmissivity contour during the 1992 and 1993 summer and fall groundfish surveys.

The occurrence of labrid and scarid larvae in open GOM waters appeared to be associated with Loop Current (LC) anticyclonic eddies in January and February 1993 (Figure 13). These larvae were seldom taken at stations along the 200-m isobath but were consistently taken farther offshore. Larvae were found more frequently and in higher abundances along the periphery of the anticyclonic Eddy Vasquez (Eddy “V”), a LC ring in the western Gulf, and in the confluence of the eastern eddy pair (EA and EC) off the mouth of the Mississippi River, than at locations away from these features.

Persistent association of labrid and scarid larvae with oceanographic features in the open GOM was observed during two, 30-d periods covering April, May, and June during the 1993 spring plankton survey (Figures 14 and 15). In the western GOM, labrid and scarid larvae were found more frequently and in higher abundances along the northern edge of the anticyclonic eddy or within the confluence of the Eddy “V”/WC pair. In the eastern GOM, labrid and scarid larve were more frequently found in higher

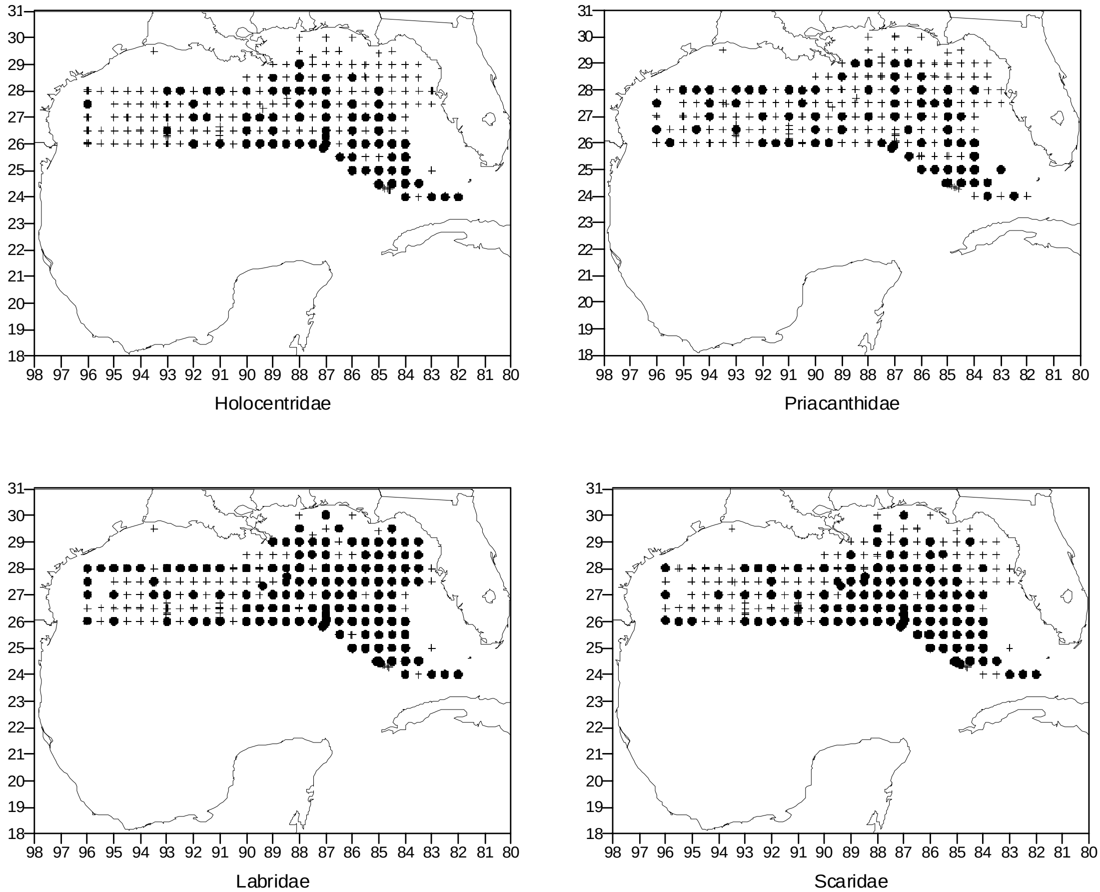

FIGURE 5. Occurrence of holocentrid, priacanthid, labrid, and scarid larvae taken during the 1982–1984 and 1986–1996 spring plankton surveys. Filled circles (•) indicate positive catches of larvae, and plus signs (+) indicate zero catch.

abundances along the frontal boundaries of the LC and cyclonic eddies (EC1 and EC2), within these features or the confluence of the LC/cyclone pairs.

Discussion

Larvae of the obligate reef fish families Holocentridae, Priacanthidae, Labridae, and Scaridae were the focus of our study and were chosen primarily for their distinct morphology and prolonged planktonic durations. Identification of fish larvae in the GOM is problematic. Fish larvae from nearly 200 families of fishes with more than 1,800 species may be found in the GOM; the larvae of approximately 27% of these species have been described and therefore may be identified (Richards 1990; Kendall and Matarese 1994). Currently, larval descriptions are available for one of the 11 holocentrid species, none of the 4 species of priacanthids, 13 of the 19 species of labrids, and 4 of the 15 species of scarids occurring in the western central north Atlantic (Richards 1990; Lyczkowski-Shultz et al. 2000; Powell 2000; D. L. Jones, University of Miami, personal communication). However, the distinct morphology of these larvae minimizes misiden-tification at least to the family level.

Distinct regional differences in the occurrence and abundance of holocentrid, priacanthid, labrid, and scarid larvae were revealed among the TX–LA, MS–AL, and FL continental shelves. Annual occurrence of larval holocentrids and priacanthids in the western GOM was highly variable compared to the occurrence of labrids and scarids in the same region. Although holocentrid and priacanthid larvae were never as abundant as labrid and scarid larvae, larvae of all four families consistently occurred in higher num-

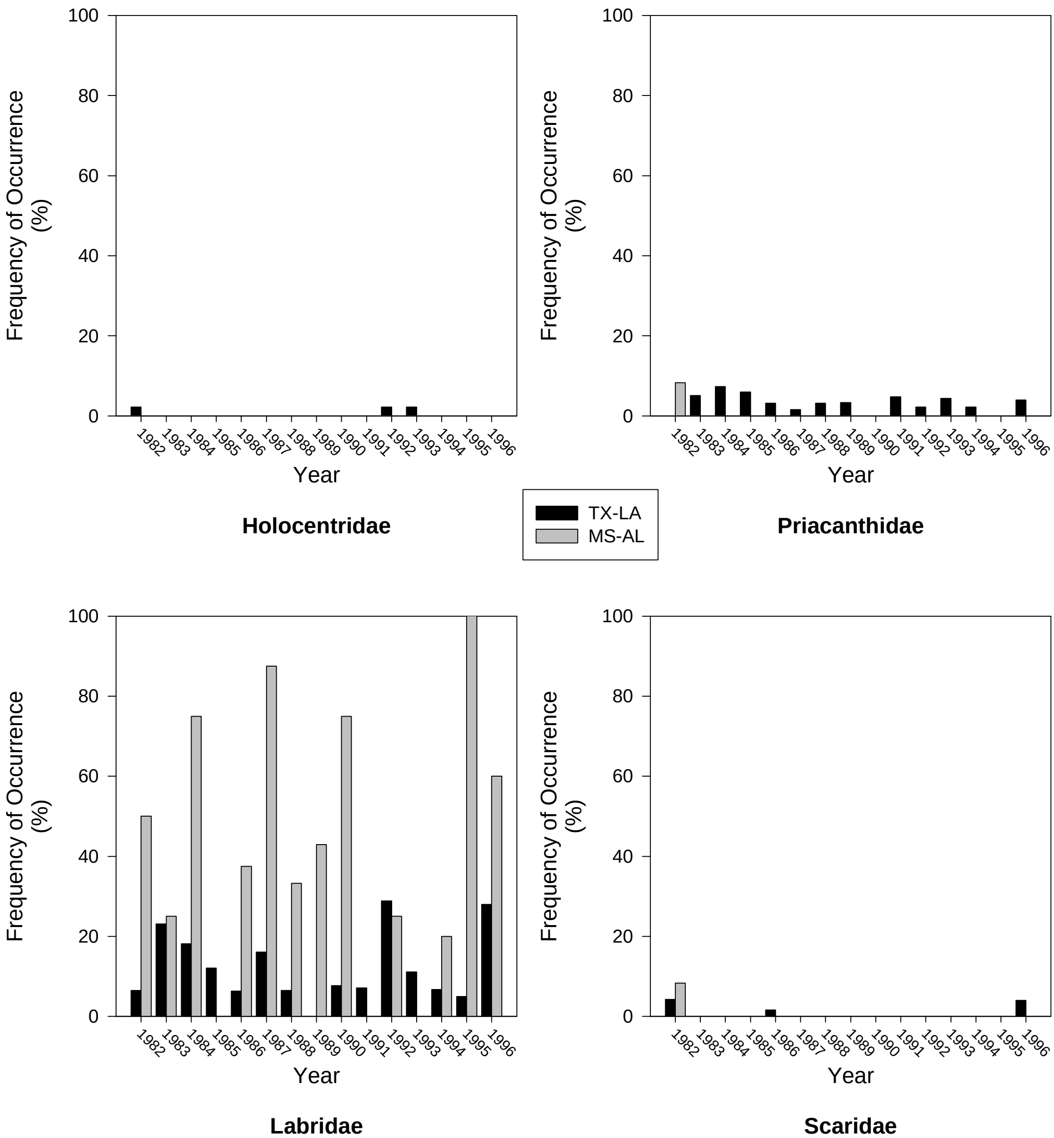

FIGURE 6. Annual frequency of occurrence (%) of holocentrid, priacanthid, labrid, and scarid larvae by year and region for the 1982–1996 summer groundfish surveys. Regional designations: Texas–Louisiana shelf (TX–LA), Mississippi–Alabama shelf (MS–AL).

bers in the eastern than in the western GOM. Labrid and scarid larvae occurred 4–6 times more frequently and were 3–10 times more abundant in the eastern than in the western GOM.

Reef habitat between 18 and 91 m in the U.S. GOM has been estimated to be 38% of the shelf area between Pensacola and Key West, Florida and 5% of the shelf between Pensacola, Florida and the Rio Grande River (Parker et al. 1983). The occurrence and abundance of larval reef fishes in the families Holocentridae, Priacanthidae, Labridae, and Scaridae taken during SEAMAP surveys reflected this pattern in GOM reef habitat. These larvae were taken throughout the SEAMAP survey area over continental shelf waters but occurred more frequently and in higher

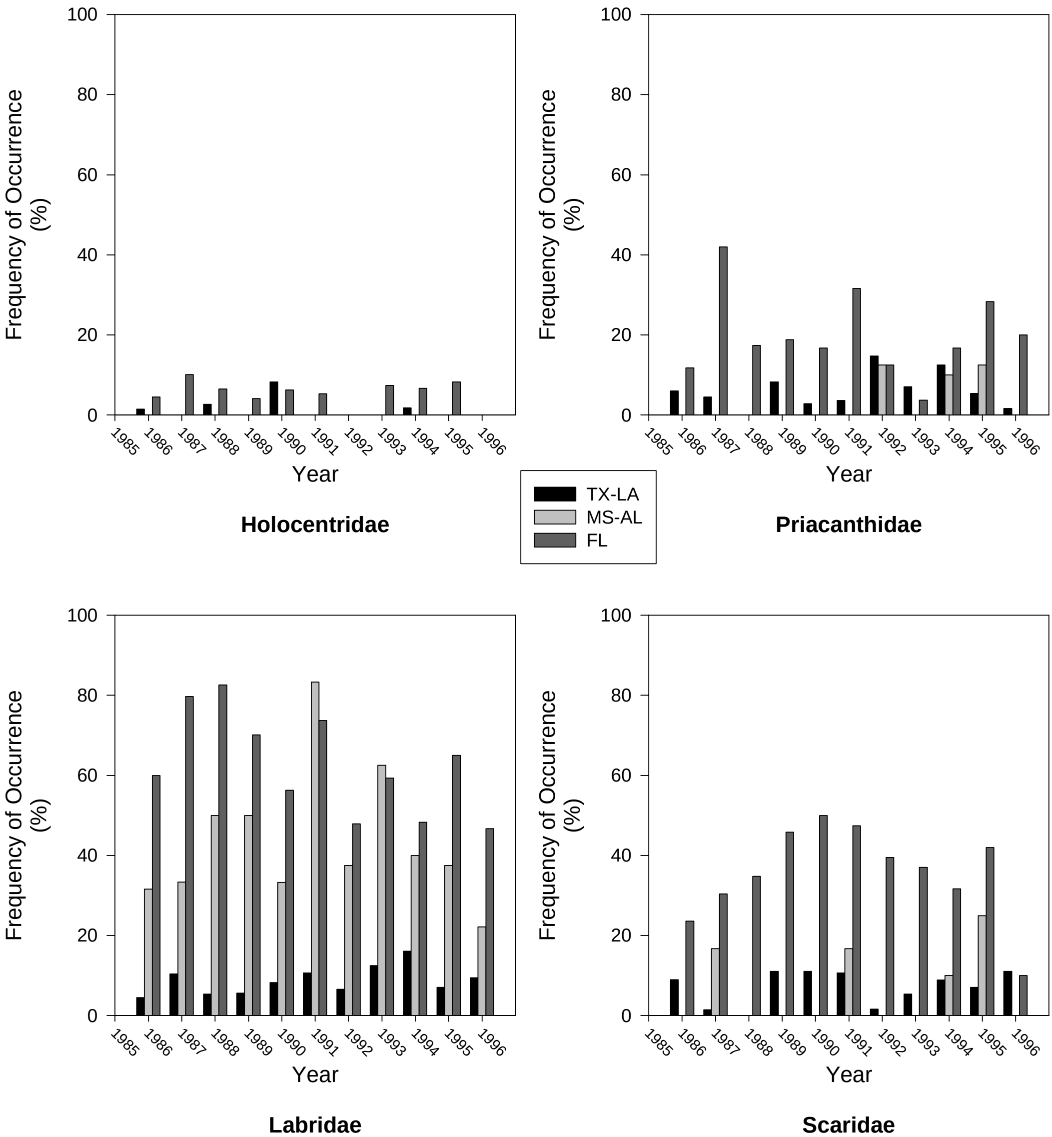

FIGURE 7. Annual frequency of occurrence (%) of holocentrid, priacanthid, labrid, and scarid larvae by year and region for the 1986–1994 and 1996 fall plankton surveys. Regional designations: Texas–Louisiana shelf (TX–LA), Mississippi–Alabama shelf (MS–AL), Florida shelf (FL).

numbers in the eastern than in the western GOM where more reef fish habitat exists.

Riverine influence on salinity and turbidity has been identified as an important biological control with regard to establishing and maintaining adult reef fish communities (Smith 1976; Rezak et al. 1990). The inflow of freshwater predominantly from the Atchafalaya, Mississippi and Mobile river drainages significantly alters salinity and turbidity gradients over the continental shelf of the northwestern and north-central GOM. This was seen in the summer of 1993 when discharge from the Atchafalaya and Mississippi rivers reached a 100-year flood stage (Dantin et al. 1993). In contrast, river discharge in 1992 was near historical means (Arcement et al. 1992). Increased river discharge in 1993 appears to have limited labrid and

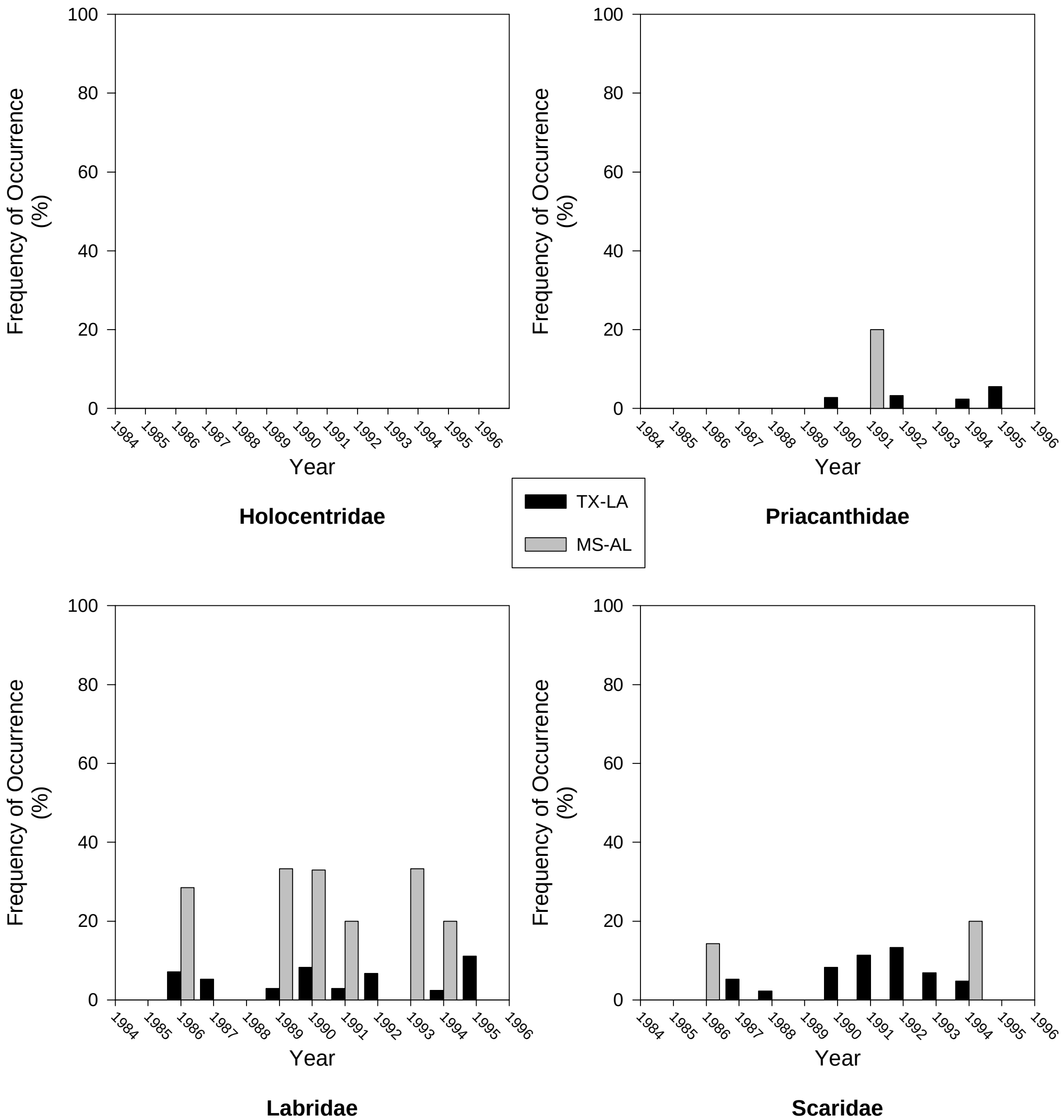

FIGURE 8. Annual frequency of occurrence (%) of holocentrid, priacanthid, labrid, and scarid larvae by year and region for the 1986–1995 fall groundfish surveys. Regional designations: Texas–Louisiana shelf (TX–LA), Mississippi–Alabama shelf (MS–AL).

scarid larvae to the outer shelf as compared to their more widespread distribution on the shelf in 1992. Labrid and scarid larvae were consistently associated with higher salinity and clearer water on the mid- to outer shelf during all seasons. Salinity and turbidity distributions are useful indicators of outer shelf and oceanic water masses on the shelf and, therefore, may be used to delineate the pelagic habitat of larval labrid and scarids.

The families Holocentridae and Pricanthidae are known to have a protracted juvenile pelagic stage, and specimens of 12–48 mm and 20–48 mm in length, for holocentrids and priacanthids respectively, have been reported in plankton collections (McKenney, 1959; Leis and Rennis 2000a, 2000b; Powell 2000). The protracted juvenile stage of these families indicate a potential for their long–range transport. Unfortunately, holocentrid and priacanthid lar-

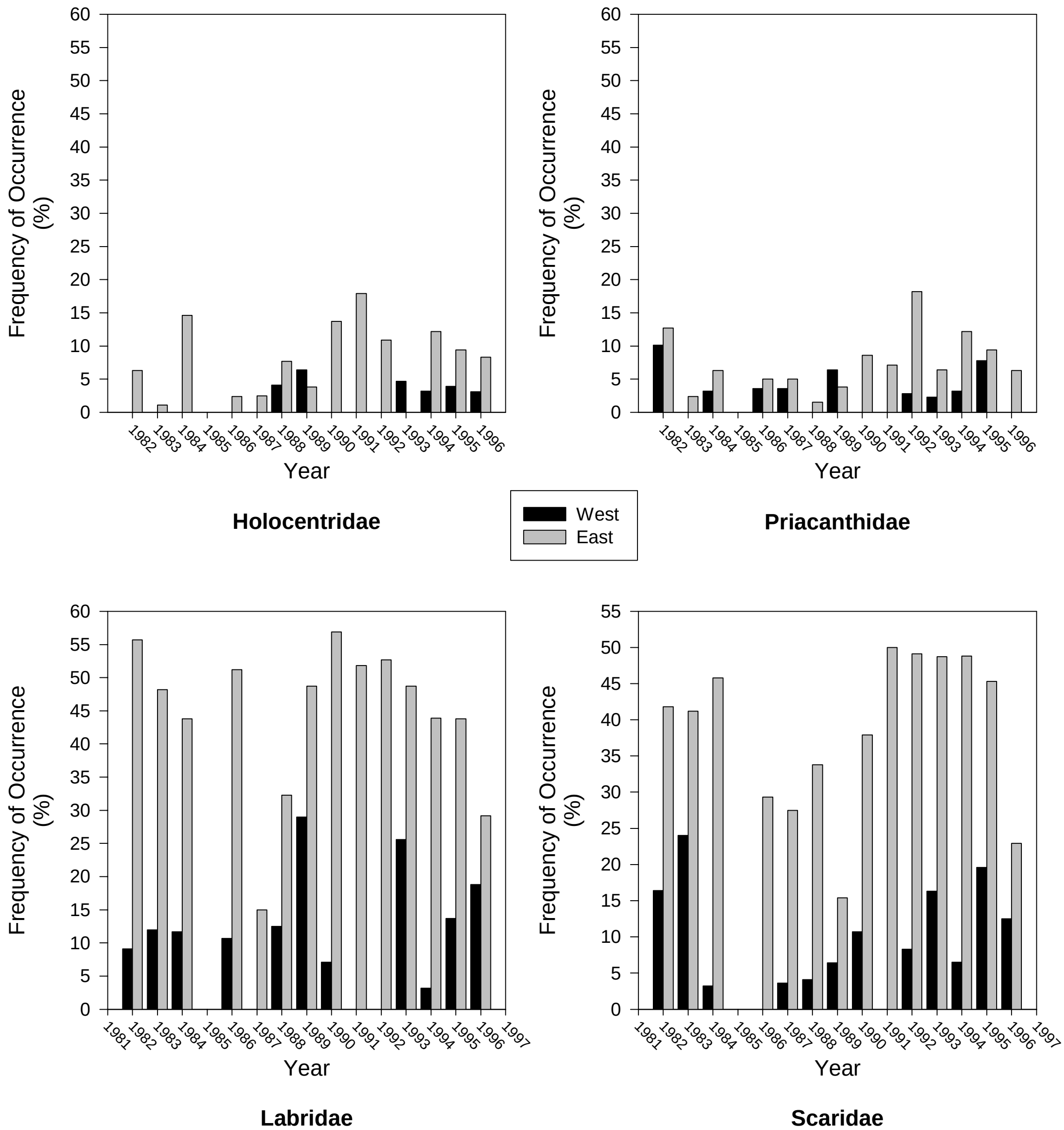

FIGURE 9. Annual frequency of occurrence (%) of holocentrid, priacanthid, labrid, and scarid larvae by year and region for the 1982–1984 and 1986–1996 spring plankton surveys. Regional designations: western Gulf of Mexico (WEST) and eastern Gulf of Mexico (EAST).

vae were not taken frequently enough in SEAMAP collections to examine their relationship with open GOM hydrography.

The pelagic larval durations of labrids and a single scarid species are shown to range from 22 to 55 d (Schultz and Cowen 1994; Sponaugle and Cowen 1997). Furthermore, some labrids (e.g., *Thalassoma bifasciatum*) may further extend the pelagic larval duration by delaying metamorphosis if suitable habitat is not found when competent to settle (Victor 1986). Labrid and scarid larvae were found to consistently occur in the open GOM at abundance levels comparable to those observed over the continental shelf. The occurrence of these larvae in the open GOM would place them under the influence of physical processes, such as the Loop Current and associated eddies. The

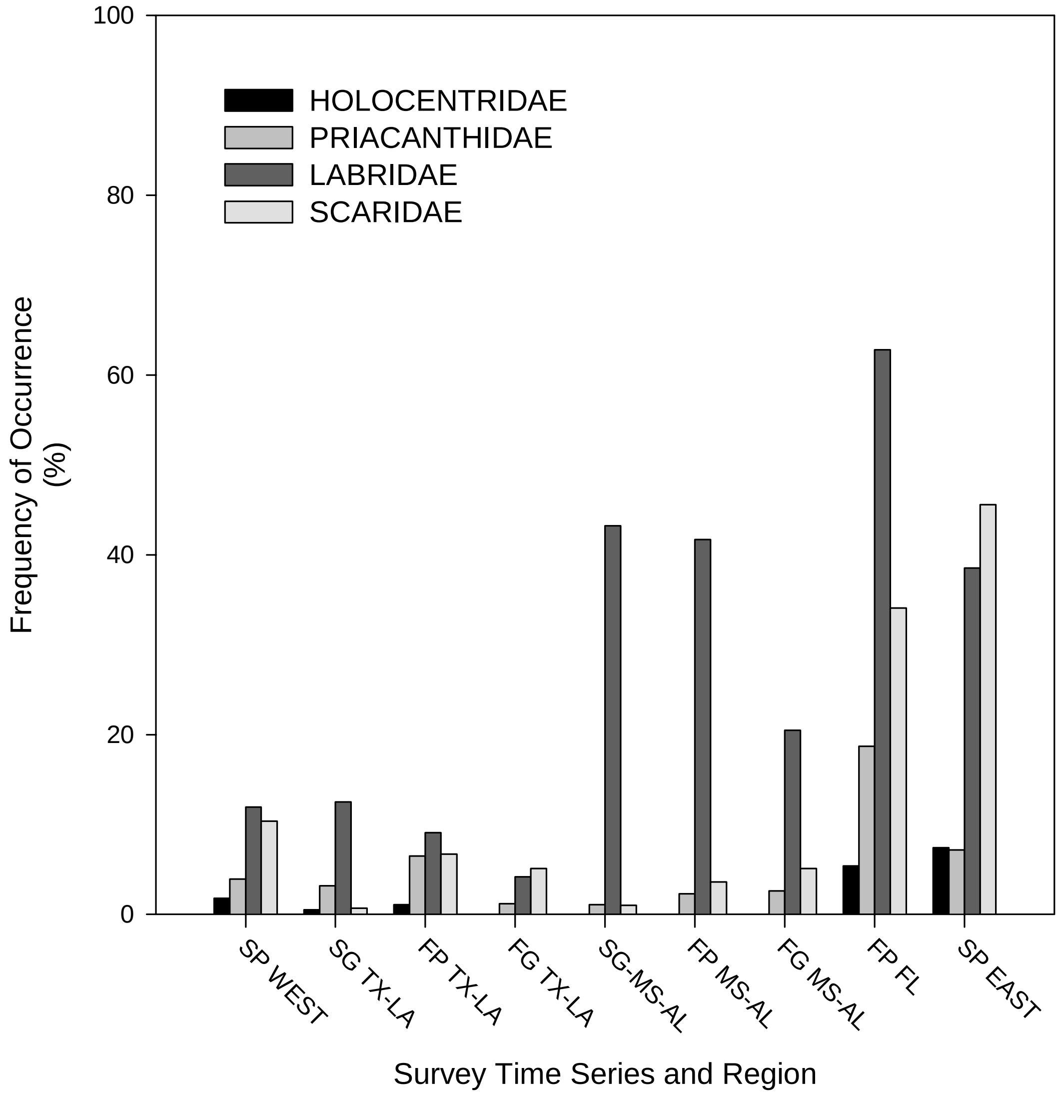

FIGURE 10. Regional frequency of occurrence (%) of the larvae of reef fish families by SEAMAP survey time series and region. Plankton survey designations: summer groundfish (SG), fall plankton (FP), fall groundfish (FP), and spring plankton (SP). Regional designations: Texas–Lousiana shelf (TX–LA), Mississippi-Alabama shelf (MS–AL), Florida shelf (FL), open Gulf of Mexico western (WEST), and open Gulf of Mexico Eastern (EAST).

consistent occurrence and the approximate 1-month or greater pelagic larval durations of labrids and scarids made them good candidates for exploring their relationship with the physical oceanography of the open GOM.

The Loop Current (LC) is the major driving force of circulation in the open GOM. Large anticyclonic (clockwise rotation) eddies detach from the LC, migrate to the western GOM where they eventually decay (Vukovich and Crissman 1986; Hamilton 1992). Associated with these large LC eddies are smaller anticyclonic and cyclonic (counter-clockwise rotation) eddies and rings that form, by the degradation of larger eddies, interaction with other eddies and/or the continental slope and shelf (Vukovich and Crissman 1986; Vidal et al. 1992; Hamilton 1992). Eddies in

TABLE 2. Regional mean abundance (A) expressed as larvae/10m^2 and standard error (SE) of the larvae of reef fish families by SEAMAP survey time series and region. Survey designations: summer groundfish (SG), fall plankton (FP), fall groundfish (FP), and spring plankton (SP). Regional designations: Texas–Lousiana shelf (TX–LA), Mississippi-Alabama shelf (MS–AL), Florida shelf (FL), open Gulf of Mexico western (WEST), and open Gulf of Mexico Eastern (East).

Survey and	Holocentridae		Priacanthidae		Labridae		Scaridae	
region	A	SE	A	SE	A	SE	A	SE
SP West	0.180	0.212	0.329	0.089	1.582	0.273	0.916	0.161
SG TX–LA	0.039	0.023	0.264	0.063	2.422	0.542	0.104	0.055
FP TX–LA	0.099	0.042	0.549	0.102	1.423	0.408	1.669	0.469
FG TX–LA	*	*	0.125	0.074	0.605	0.241	0.577	0.161
SG MS–AL	*	*	0.076	0.063	29.401	10.661	0.380	0.380
FP MS–AL	*	*	0.285	0.174	31.257	8.155	0.467	0.230
FG MS–AL	*	*	0.112	0.112	1.775	0.707	0.357	0.162
FP FL	0.605	0.147	2.862	0.384	35.636	3.999	10.315	1.268
SP East	1.011	0.213	0.772	0.169	9.158	0.679	9.920	0.905

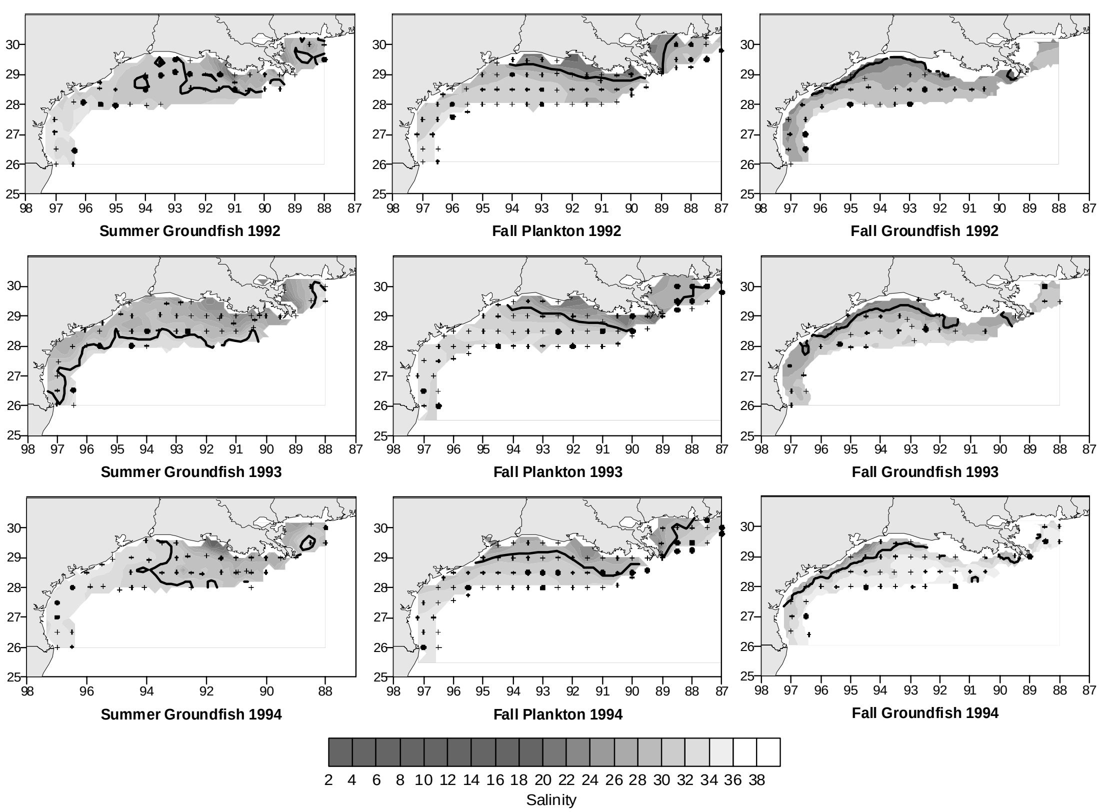

FIGURE 11. Occurrence of labrid and scarid larvae in relation to surface salinity for the 1992–1994 summer groundfish, fall plankton, and fall groundfish surveys. Solid black line delineates a salinity of 30. Filled circles (•) indicate positive catches of larvae, and plus signs (+) indicate zero catch.

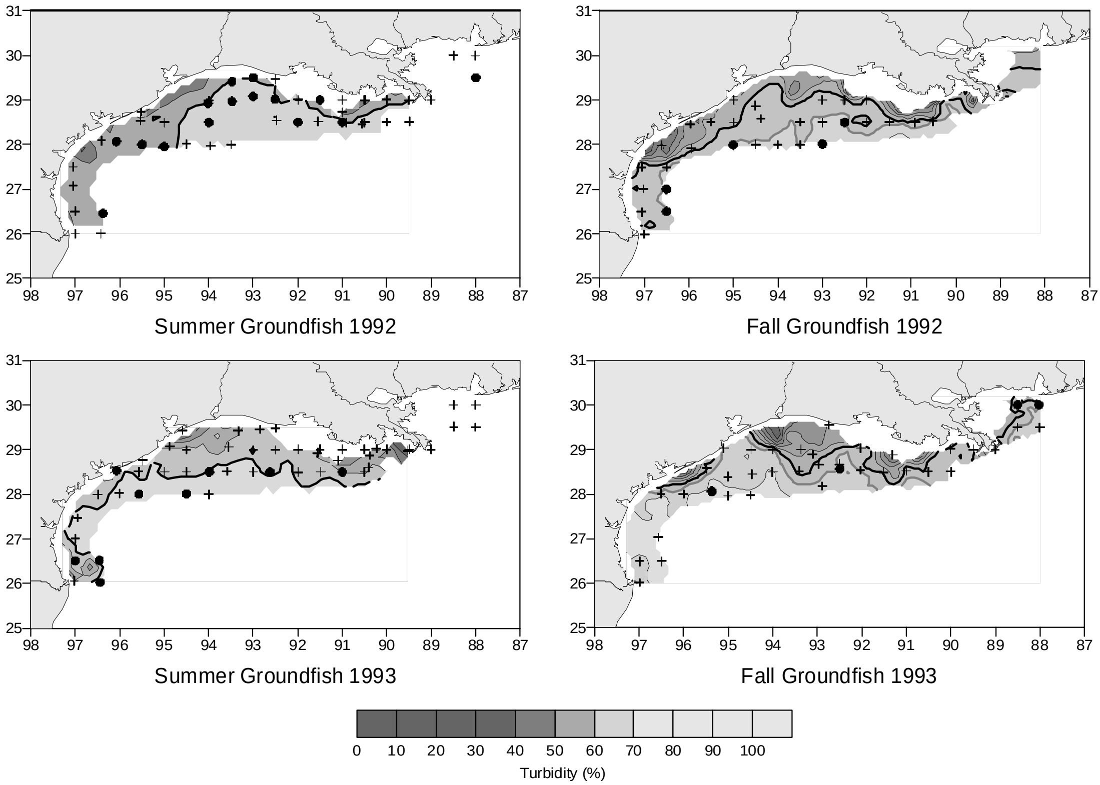

FIGURE 12. Occurrence of labrid and scarid larvae in relation to surface transmissivity for the 1992–1993 summer and fall groundfish surveys. Solid black line delineates a transmissivity of 60%. Filled circles (•) indicate positive catches of larvae, and plus signs (+) indicate zero catch.

the western GOM drive shelf edge currents and affect shelf waters through exchanges of mass, energy, and water properties. (Nowlin et al. 1998a). The major mechanism for this exchange between the shelf and slope is the interaction of counter-rotating eddies (Berger et al. 1996). These eddy pairs episodically impact the inner shelf, and during such episodes, the exchange between the shelf and open gulf can be substantial (Nowlin et al. 1998a).

In January and May of 1993, SEAMAP plankton sampling coincided with two episodic intrusions by LC "Eddy V" on the Texas shelf (Nowlin et al. 1998a, 1998b). Eddy "V" and its associated cyclonic ring persisted off the south Texas shelf and slope from December through the summer of 1993 and was well studied by oceanographers (Berger et al. 1996; Sahl et al. 1997; Nowlin et al. 1998a, 1998b and Hamilton et al. 1999). Sahl et al. (1997) describes the transport and exchange of shelf waters with the open GOM and the continental shelf during the April/May intrusion of Eddy "V." Texas/Mexico shelf waters were transported offshore by the convergence of the cyclone (WC)/anti-cyclone (WA) ring pair located near 23°N and 96°W (Figure 15). Shelf waters were then transported around the southeastern quadrant of the cyclone and transported onto the Texas shelf by the convergence of the cyclone and Eddie "V." The water mass then rotated around the northern portion of Eddy "V" and was transported offshore across the shelf slope break on the eastern side of Eddy "V." The January episode was not as well studied, but the eddy system was in a similar configuration (Figure 13).

This exchange between the open ocean and the TX–LA shelf is a potential mechanism for the transport and/or retention of larvae spawned on reefs located on the mid- and outer shelf. The highest abundances of labrid and scarid larvae during winter and spring SEAMAP collections in 1993 were associated with the frontal boundary of Eddy "V" and its com-

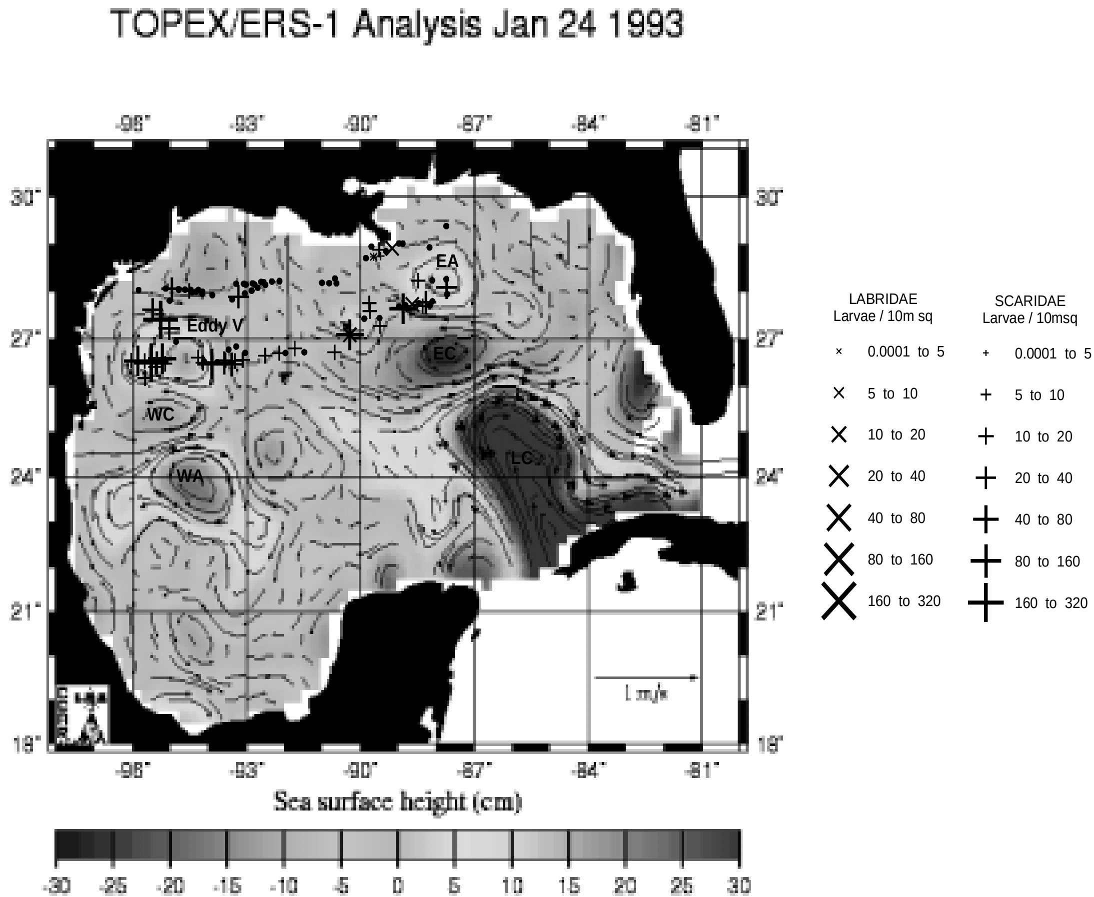

FIGURE 13. Distribution and abundance of labrid and scarid larvae during Oregon II, Cruise 203 in relation to the 24 January 1993 TOPEX/ERS-1 sea surface height analysis. Black vectors are relative geostrophic currents. Dominant features are labeled Eddy "V," western cyclone (WC), western anticyclone (WA), eastern anticylcone (EA), eastern cyclone (EC), and the Loop Current (LC). TOPEX/ERS-1 merged dynamic sea surface height maps were obtained from the GOM historical data server at the Colorado Center for Astrodynamics Research: http://www-ccar.colorado.edu/~realtime/gom-historical_vel/.

panion cyclone (Figures 13 and 15). The Texas-Louisaina shelf circulations and transport processes study's (LATEX) satellite-tracked surface drifting buoy #06938 was released near the shelf edge on 2 May 1992 and was transported off the shelf and entrained by Eddy "V" (Figure 16). Labrid and scarid larvae associated with Eddy "V" were likely transported onto/off the Mexico, Texas, and Louisiana shelves in a 'conveyor-belt' fashion by geostrophic flow and/or entrained by the Eddy "V" system in a similar manner.

Entrainment of larvae within a shelf edge anticylonic eddy, such as Eddy "V," could also serve as retention mechanism to keep larvae on or near the shelf edge. The mean rotational period for LC eddies in the northwestern GOM is 10–11 d (Hamilton et al. 1999). A broad survey of 25 reef families indicated that the pelagic larval duration of most ranged between 20 and 60 d (Richards and Lindeman 1987). Therefore, entrainment and subsequent transport along an eddy periphery could result in the return of larvae to shelf edge reefs as they reach settlement stage (Figure 16).

In the eastern GOM, labrid and scarid larvae were found in much higher abundances along the frontal boundaries of the LC, cyclonic eddies, within these features or within the confluence of LC/cyclone pairs than in areas not dominated by these features (Figures 14 and 15). These oceanographic features, as in

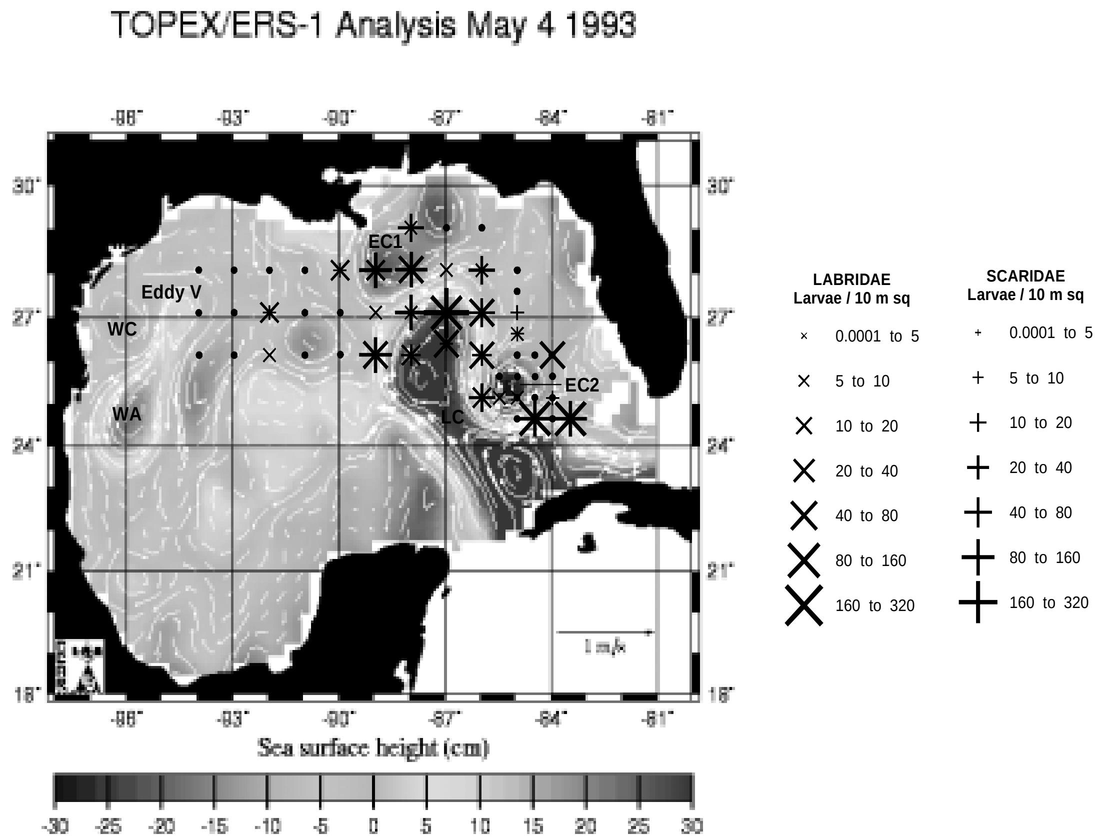

FIGURE 14. Distribution and abundance of labrid and scarid larvae during the spring plankton survey from 19 April to 19 May 1993 in relation to the 4 May 1993 TOPEX/ERS-1 sea surface height analysis. White vectors represent relative geostrophic currents. Dominant features are labeled Eddy "V," western cyclone (WC), western anticyclone (WA), eastern cyclones one and two (EC1 and EC2) and the Loop Current (LC). TOPEX/ERS-1 merged dynamic sea surface height maps were obtained from the GOM historical data server at the Colorado Center for Astrodynamics Research: http://www-ccar.colorado.edu/~realtime/gom-historical_vel/.

the western GOM, are mechanisms for the potential exchange of larvae between the continental shelf and open GOM (Vukovich and Maul 1985; Kelly 1991; Vastano et al. 1991; Muller-Karger et al. 1998).

In the northern and eastern GOM, the LC and LC spin-off eddies may intrude as far north as 29°N and directly influence the outer continental shelf (Maul 1977; Kelly 1991; Hamilton et al. 1999). Kelly (1991) indicated that the shelf break region of the MS-AL shelf is influenced by the LC 40% of the time. However, the TOPEX/ERS-1 analyses of 4 May 1993 and 3 June 1993 did not indicate a direct influence of the LC or a shed LC eddy on the continental shelf. However, high abundances of labrid and scarid larvae were found in association with the EC1 and EC2 cyclonic eddies (Figures 14 and 15). The cyclonic eddies were located near the shelf break of the MS-AL and FL shelf and may have transported larvae on/off the shelves in those two regions or functioned as a retention mechanism for larvae, as in the case of the anticyclone Eddy "V" in the western GOM. Conversely, the EC1 and EC2 cyclones may be have indirectly transported labrid and scarid larvae associated with the LC onto the continental shelf.

Larval transport from the LC may be initiated by minor, short-lived rings, pools of LC water produced by the advection associated with cold core cyclones, which are found on the boundary of the LC, or shallow pools of LC water dragged from the LC by strong winds (Vukovich 1998). Vukovich (1998) analyzed the frequency at which these events occurred over a period from 1976 to 1997 to determine how often

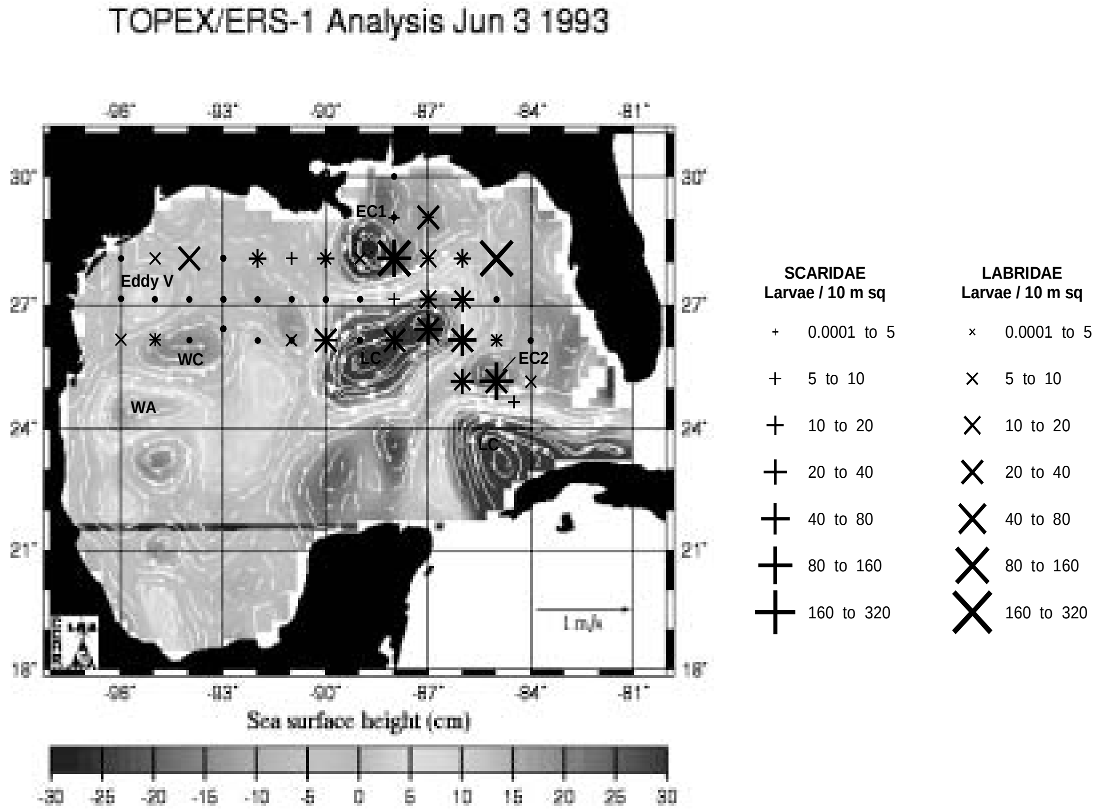

FIGURE 15. Distribution and abundance of labrid and scarid larvae during the spring plankton survey from 20 May to 19 June 1993 in relation to the 3 June 1993 TOPEX/ERS-1 sea surface height analysis. White vectors represent relative geostrophic currents. Dominant features are labeled Eddy "V," western cyclone (WC), western anticyclone (WA), eastern cyclones one and two (EC1 and EC2) and the Loop Current (LC). TOPEX/ERS-1 merged dynamic sea surface height maps were obtained from the GOM historical data server at the Colorado Center for Astrodynamics Research; http://www-ccar.colorado.edu/~realtime/gom-historical_vel/.

LC water not directly associated with the LC and/or major ring reaches the shelf break of the northeastern GOM. The analysis indicated a region centered at 28.75°N and 87.25°W, which extends northward toward the shelf break in the northeastern GOM at which LC water not directly associated with the LC and/or a LC eddy occurred at a frequency of 4–5%. The eastern edge of the EC1 cyclone was near this center and may have initiated such an exchange (Figures 14 and 15). A similar exchange with a frequency of 2–4% could also occur for the EC2 cyclone near the south Florida shelf. A frequency of 4% indicates an event approximately once every 2 years (Vukovich 1998). High numbers of labrids and scarids were observed within the LC boundary and exchanges of this type may be an important mechanism for larval exchange between the LC and other water masses.

The LC and associated eddies and rings exert a coherent and dynamic influence not only in the open GOM but on the continental shelf and slope as well. The dominant mechanism for water mass exchange between the shelf/slope and open GOM are the geostrophic currents generated by the Loop Current and its associated systems of eddies and rings. Locally produced reef larvae entrained in eddy systems throughout the GOM could either be retained to recruit locally or be transported into the open gulf and exported to other reefs systems. Survival and return to favorable reef habitats may still be possible for reef fish larvae exported into the open GOM, depending on species-specific duration of the precompetent stage and the position of larvae relative to circulation of an eddy or ring. The high abundance of labrid and scarid larvae present within the interior of the LC also sug-

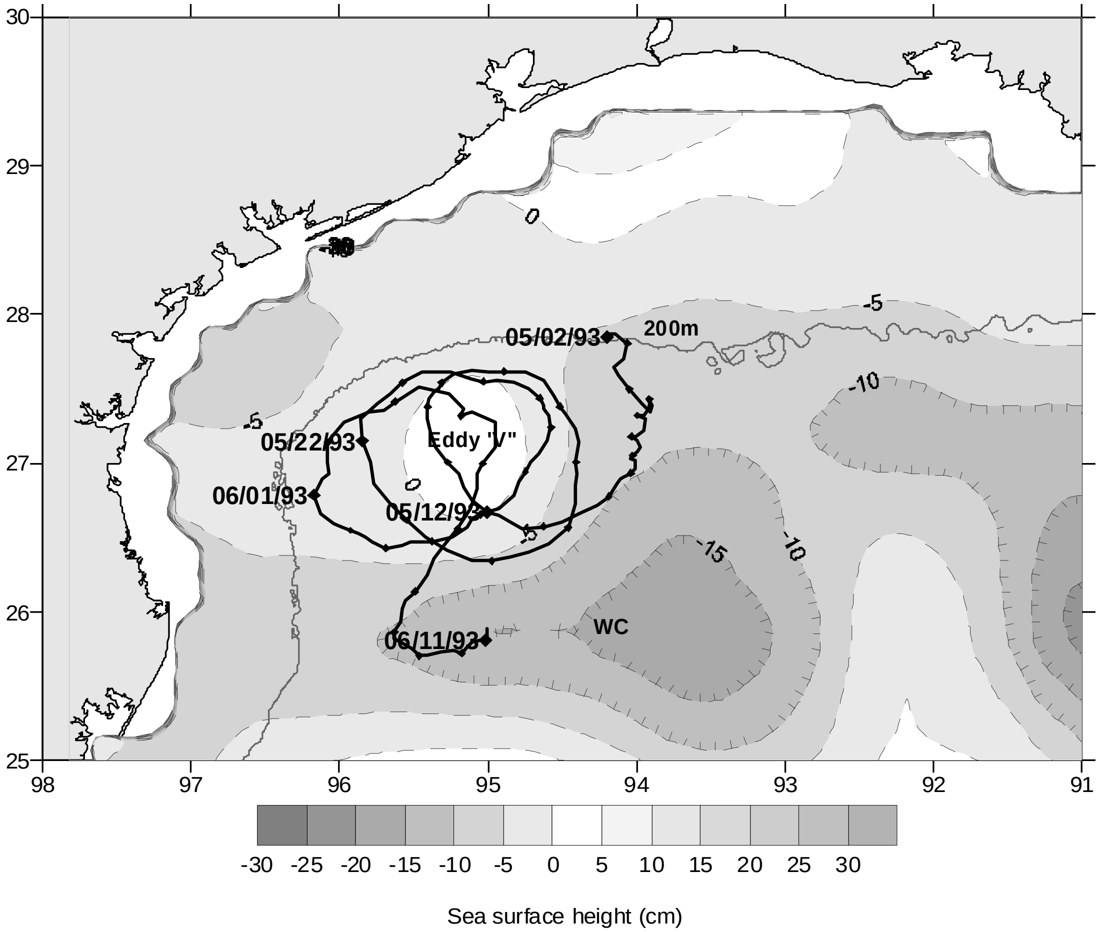

FIGURE 16. Path of the Texas–Louisiana shelf circulation and transport processes study's (LATEX) satellite-tracked surface drifting buoy #06938 from 2 May 1993 to 11 June 1993 in relation to the 3 June 1993 TOPEX/ERS-1 sea surface height analysis. Drifter was released near the shelf edge on 2 May 1993. Solid black line shows the drifter path, small diamonds designate daily drifter position, and large diamonds designate drifter position every 10 days. Dominant features are labeled: Eddy "V" and western cyclone (WC). LATEX drifter #06938 data was obtained from the National Oceanographic Data Center. TOPEX/ERS-1 merged dynamic sea surface height maps were obtained from the GOM historical data server at the Colorado Center for Astrodynamics Research, http://www_ccar.colorado.edu/~realtime/gom_historical_vel/.

gests that larvae produced from upstream sources such as the Yucatan Peninsula and Caribbean Sea could supply recruits to reefs in the northern GOM and on the West Florida shelf.

We undertook this examination of the SEAMAP ichthyoplankton database in an attempt to identify patterns in larval reef fish production and potential 'sources and sinks' of recruits to GOM reefs. Initial data summaries have shown that the larvae of at least two major groups of reef fishes, the wrasses and parrotfishes, are transported throughout the open GOM. Species level identifications are needed to provide a more detailed examination of the distribution of labrid and scarid larvae. Differences in spawning times and larval durations among GOM and Caribbean reef systems may yield further insights into the origin of reef fish larvae found in the open GOM. We will, therefore, reexamine and attempt species-level identifications of labrid and scarid larvae from SEAMAP collections. Otolith analysis and age determination of archived specimens will also be undertaken. Together, these new data may yield a less ambiguous depiction of the source and fate of reef fish larvae. Finally, we plan to utilize Geographic Information Systems (GIS) to examine the SEAMAP time series in relation to hydrographic features in the open GOM to provide more detailed data on the coupling between biophysical processes and variations in larval labrid and scarid recruitment.

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