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*Corresponding author

Adonis S Floren, Institute of Environmental and Marine Sciences, Silliman University, Dumaguete City 6200, Philippines

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Research Article

Distribution Patterns of Reef Fish Larvae in the Dipolog Srait, Philippines

Adonis S Floren[1]*, Angel C Alcala[2] and Olivia C Cabrera[3]

[1]*Institute of Environmental and Marine Sciences, Silliman University, Philippines*

[2]*Silliman University, Angelo King Center for Research and Environmental Management, Philippines*

[3]*Institute of Environmental Science and Meteorology, Dilliman, Philippines*

Abstract

The composition, abundance and distribution of reef fish were strongly influenced by the trends in salinity, temperature and mixing regimes of the water during the three oceanographic cruises conducted in the vicinity of the marine reserve networks of Dipolog Strait. Forty-seven families of reef fish larvae were identified. Carangidae, Labridae, Scaridae, Gobiidae and Apogonidae were the top five most abundant larvae comprising 64.7 % of the total number of reef fish larvae collected. Shifts in the dominance of the top five most abundant reef fish families occurred primarily between the northeast and southwest monsoons coinciding with the changes in the temperature profiles of the water column. Abundance of reef fish larvae showed variability across the three sampling periods due to the succession of the dominant species of reef fish larvae. Fluctuations in salinity brought about by the transition from Northeast to Southwest monsoon period could explain the variation. Density distribution of reef fish larvae significantly increased with the increasing depth of the mixed layer during northeast monsoon period. The downwelling off the coast of southern Negros in February and April cruises contributed to the high abundance of reef fish larvae in this part of the strait, while the uniform mixing of the water column in June 2010 at southwest monsoon resulted in the weakening of density gradient of reef fish larvae.The study demonstrated the variable responses of the reef fish larvae to the gradients of chlorophyll in the Dipolog Strait. A better understanding on the retention mechanism of reef fish larvae along the coast of southern Negros, where the main marine reserve networks exist, is provided by the present study.

Introduction

The pelagic larval phase of coral reef fishes is vital to the understanding of the adult reef fish population. Majority of the reef fish larvae move away from the vicinity of their natal reef for varying distances over more open seawater [1]. Reef fish larvae remain in the water column for several weeks where they are subjected to biological and environmental pressures before they settle on a suitable reef [2]. Environmental factors that are known to affect the fish larvae are light intensity [3], monsoon cycle [4,5], temperature [6], depth [7,8], climatic events [9], and oceanographic features such as upwelling or downwelling and fronts [10-14]. The common implication suggests that water movements play an important role on fish larval transport. Recent findings on the larval dispersal distances are on the scale of only tens of kilometers for a variety of reef fish species [15]. However, the mechanisms by which fish larvae are retained or dispersed from the natal site are generally unclear considering the complexity of factors that operate simultaneously in nature [16]. Vertical migration in the water column was indicated as one of the factors influencing the horizontal distribution of fish larvae (Muhling and Beckley, In Press) [6,17] demonstrated the vertical migration of coral reef fish larvae as a strategy to increase self-recruitment. Latest findings on the vertical distributions of reef fish larvae in the Straits of Florida however revealed that reef fish larvae were unaffected by the wide variety of environmental factors except only for the sampling depth [8]. Dissimilarities among findings might be related to the spatial and temporal scales of the actual investigation [12]. The difficulty in finding strong linkages between hydrography and the fish larvae was confounded by the fact that only a few environmental variables were examined simultaneously [18] and the effects of climatic events [9] and protection of habitats [19], were rarely assessed. Our main objective was to examine the spatio-temporal distribution of reef fish larvae in the Dipolog Strait in relation to hydrographic and environmental conditions. The study area is characterized by the presence of marine reserve networks, majority of which are located in the coastal part of southern Negros [20]. This condition makes the Dipolog strait an ideal venue for both oceanographic and conservation studies. The composition and distribution patterns of reef fish larvae were evaluated in relation to the fluctuations in temperature, salinity, chlorophyll, current patterns, and turbulent mixing (i.e. mixed layer depth or MLD) of the water column. Occurrence of the different developmental stages of reef fish larvae was used to assess the effect (if any) of water current to the horizontal distribution of reef fish larvae in the Dipolog strait.

Materials and Methods

Study sites

There were three oceanographic cruises made in Dipolog Strait (between northern Mindanao and southern Negros, Philippines, Figure 1) on board the well-equipped, steel fishing vessel F/B J & P Romeo. The first two cruises were conducted on February 6 - 7, 2010 and June 26 - 27, 2010, coinciding with the northeast and southwest monsoon periods, respectively. Cruises started from the coast of Bacong in southern Negros Island towards the municipality of Zamboanguita (9° 15.10’ N, 123° 19.24’ E to 9° 05.90’ N, 123° 13.59’ E), and then across the Dipolog Strait towards the coast of Dapitan City in Zamboanga del Norte, Mindanao (8° 44.22’ N and 123° 27.34’ E). The third cruise was on April 2-3, 2011, conducted towards the end of the northeast monsoon period. It was extended along the east-west and north-south directions considering the distributional gradients of reef fish larval abundance and environmental conditions from the previous two cruises. The third cruise encompassed the whole coastline of the southern Negros Island, beginning from the east coast of Dumaguete City (9° 18.05’ N and 123° 19.96’ E) to the municipality of Siaton (9° 1.31’ N and 123° 4.83’ E) in the west, and then across the Dipolog Strait towards the coast of Manukan in Zamboanga del Norte (8° 35.10’ and 123° 5.53’). The final leg of the 3rd cruised commenced in Dipolog City (8° 37.28’ and 123° 16.07’) east of Manukan. There were 15 stations that were surveyed during the period February 2010, June 2010 and April 2011, with spacing distances between 4 kilometers (2.2 nautical miles) in the shallow coastal areas and up to 20 kilometers in the deep or open seas. This interval was within the spacing distance of the Marine Protected Areas (MPAs) in the Dipolog Strait and Bohol Sea that ranged from about 1 to 30 kilometers apart. Stations that were close to each other (< 3km) were grouped together according to the geo-political boundaries under which reef fisheries are currently managed. Sampling regimes were adopted in such a way that the present study would be able to collect fish larvae from the shallow and deep portions of the Dipolog Strait.

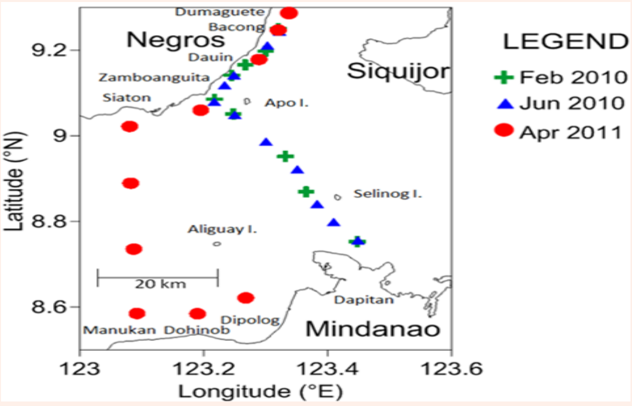

Figure 1: Map of stations during the three cruises on February 2010, June 2010 and April 2011.

Sampling

A Bongo gear (60.0 cm diameter, fitted with 300-micron mesh nets) was towed obliquely behind the vessel at a speed of 1-2 meters per second to a maximum depth of ~100 meters [9]. The depth of the oblique towing is the typical range limit of vertical migration of most fish larvae [21, 22]. A mechanical flow meter was attached across the mouth of the ring so that the volume of water filtered by the net can be determined. Fish larvae samples were preserved in 10% buffered formalin solution. The Conductivity-Temperature-Depth (CTD, Seabird USA) Profiler was deployed to depths 100-150 m per station and measured the variables temperature, conductivity (salinity), pressure (depth), and chlorophyll thru a fluorometer (Turner, USA) attached to the CTD. A holey-sock drogue with a GPS (Garmin, USA) was deployed to collect data on current patterns. The drogue was deployed at the stern of the boat and allowed to drift with the currents for one minute. The speed and direction of surface currents at each station was calculated using the coordinates recorded by the GPS within the time the drogue was deployed and retrieved. Satellite images of Chlorophyll were obtained from the Moderate Resolution Imaging Spectrometer or MODIS which determined the Chlorophyll distribution in Dipolog Strait. Precipitation data were obtained from the weather station of the Philippine Atmospheric, Geophysical and Astronomical Services (PAGASA), located ~1 km. from the first sampling station.

Data analyses

All fish larvae whose adults are associated with the coral reefs were identified to the family level using the well-known book of Leis and Carson-Ewart (2000) as main reference. Photomicrographs of fish larvae were taken in order to facilitate the identification of specimens whose characters and larval stages were not readily identifiable. Reef fish larvae were then sorted from the rest of the fish larvae samples using the photomicrographs. Density of reef fish larvae was computed by dividing the number of individuals by the volume of water filtered by the Bongo net. Values were multiplied by 100 in order to obtain a volume of 100m^{-3} of seawater, necessary especially in areas with very low larval densities. The total density of reef fish larvae (all species) was used to compare the abundances of reef fish larvae across the three sampling periods. In order to assess the effect of turbulent mixing in the water column to the spatio-temporal distributions of the reef fish larvae, the mixed layer depth or MLD (defined as the depth above which no gradient in CTD temperature or salinity measurement was apparent, [8] was evaluated against the density distribution of the reef fish larvae. Densities of the top two most abundant reef fish larvae (Carangidae and Labridae) and the total density of reef larvae were correlated (General Regression Models) to the MLD across the three sampling periods using the program STATISTICA (Version 7). Prior to parametric statistical analysis, MLD data were log transformed while the data on density were transformed by taking the square root [$\sqrt{(X + 1)}$] to ensure normality of values. The percentages of the top five most abundant reef fish larvae (i.e., species that had a total density of >10 individuals 100 m^{-3}) were used to determine the succession of species across the sampling periods. Occurrence of the different developmental stages of the reef fish larvae were used to determine whether or not the distribution of fish larvae are affected by the observed flow of surface current in the Dipolog Strait. Larval stages were mainly categorized into two groups (i.e. pre-flexion or post-flexion stage) based on the distinct flexion of the notochord tip and the formation of caudal rays. The flexion and near-settlement stage larvae were grouped to the post-flexion category due to their limited abundance. Only the top five most abundant reef fish families found along the southern coast of Negros (Dumaguete to Siaton) were included in the analysis since a great proportion of the reef fish larvae were found in this area.

Results

Oceanographic conditions

The physical characteristics of the water column from surface to ~150m showed variability across the different sampling periods (Figure 2). Water temperature was coldest during February 2010 cruise while the warmest temperature was in June 2010. Although temperature during the February 2010 and April 2011 was close (surface average of 26.7°C and 27.3°C, respectively), the salinity was lower during the April cruise. Salinity showed increasing trend with latitude with the Dipolog side having lower salinity compared to the Negros side. Generally, November to April is the Northeasterly (NE) monsoon season, with cold winds blowing in a northeasterly direction while July to September is the southwesterly season. Our cruise in June 2010 was conducted at the later part of the month with prevailing winds from the southwest indicating the onset of the southwest monsoon period. May and October are transition months when the monsoon winds relax. During the February 2010 cruise, the northeasterly wind pattern was observed for most stations at speeds of 7 to 11 knots (3.8 to 6 m s^{-1}). The flow along the Negros coast were consistent during the February and April cruises which suggests that during the NE monsoon, winds may enhance the westward-flowing surface current along the southern coasts of Negros (Figure 3), promoting a downwelling in this part of the strait. Looking at section of temperature across the Dipolog Strait (Figure 4, Left panel), a >50-m thick, well-mixed layer is found off the coast of Negros (near Dumaguete) while sloping isotherms indicative of upwelling is found off the coast of Mindanao (near Dipolog). It should be noted that the downwelling at the Dumaguete side and upwelling at the Dipolog side during the February sampling was not observed during the June cruise (Figure 4, middle panel). During the April 2011 cruise, both the downwelling and upwelling is again evident from temperature section across the strait (Figure 4, right panel). Chlorophyll from coincident remotely sensed data (MODIS Aqua satellite) shows that low-chlorophyll waters were found to be present off the coast of Dumaguete across all sampling seasons while a high-chlorophyll area is evident off the coast of Zamboanga during both the February 2010 and Apr 2011 sampling (Figure 5). This finding is further supported by chlorophyll data taken in situ using a fluorometer sensor attached to the CTD (Figure 6). Chlorophyll was highest during the February 2010 cruise and lowest during the June 2010 cruise.

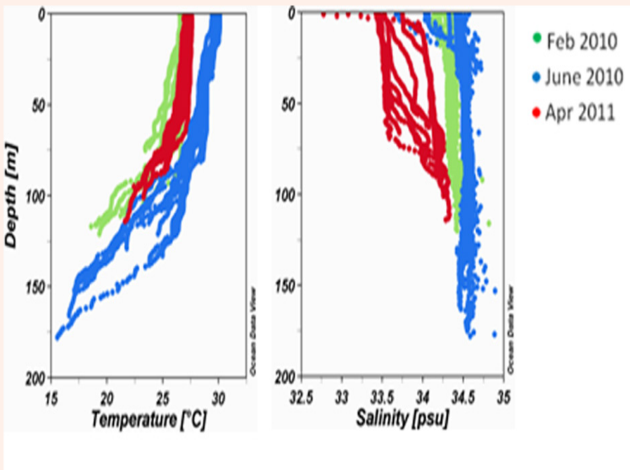

Figure 2: Profiles of temperature (T) and salinity (S) with depth during the three cruises across the Dipolog Strait.

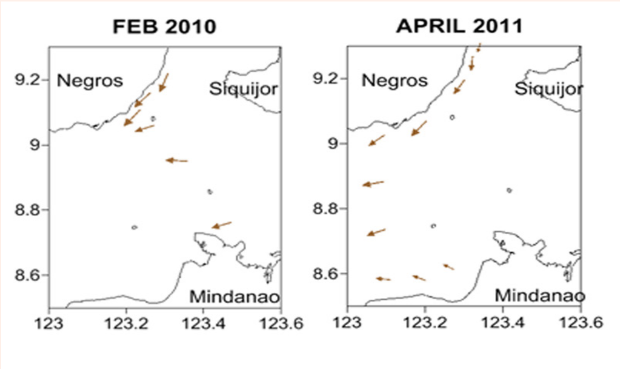

Figure 3: Vector plot of surface currents during the February 2010 and April 2011 sampling.

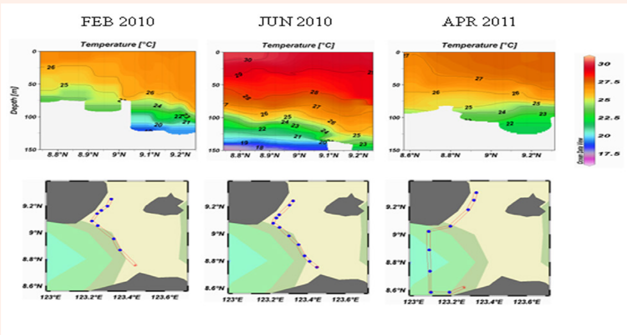

Figure 4: Sections of temperature from Dipolog to Dumaguete (increasing latitude).

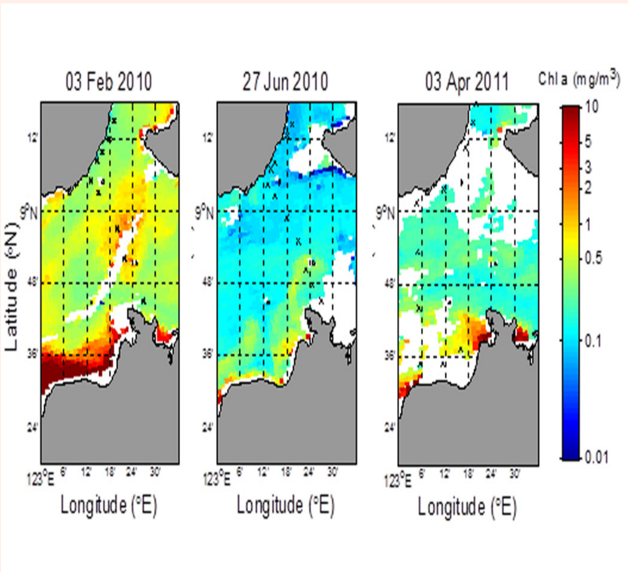

Figure 5: Satellite-derived concentrations of chlorophyll, a phytoplankton biomass indicator, across the Dipolog Strait. Images are from the US MODIS satellite, downloaded for dates coincident or as near to the sampling dates as possible.

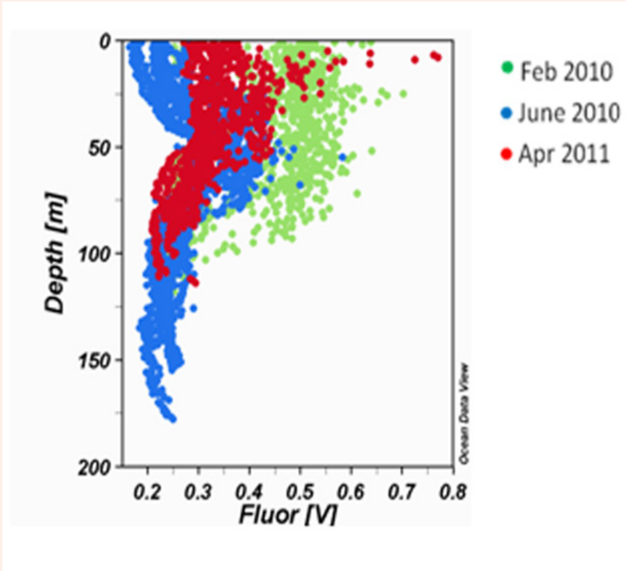

Figure 6: Profiles of in situ chlorophyll fluorescence during the three cruises.

Abundance and distribution patterns of reef fish larvae

Reef fish larval abundance in the Dipolog Strait ranged from 1.0-177.4 individuals 100m^{-3} (Figure 7). On the average, density of reef fish larvae during the February 2010 cruise was higher compared to the June 2010 and April 2011 cruises (77.5 individuals 100m^{-3}, 75.9 individuals 100m^{-3} and 43.6 individuals 100m^{-3}, respectively). However, the density of reef fish larvae in February 2010 was higher (by only 1%) compared to the June 2010 cruise but was 27.9 % higher compared to the April 2011 cruise. Density distribution of reef fish larvae in February and April cruises showed an increasing trend with latitude (Figure 7) with highest density recorded off Bacong (southern Negros) in February 2010 reaching up to 177.4 individuals 100m^{-3}. Lowest density of reef fish larvae was also recorded off Dipolog City in April 2011 with only ~1.0 individuals 100m^{-3}. Density distribution of reef fish larvae (all species) was correlated to the MLD of the water column (Figure 8). Significant positive correlations ($P < 0.05$) were found between the MLD and the densities of Carangidae, Labridae and the total density of reef fish larvae during the February 2010 cruise (Table 1). In June 2010 cruise, the total density of reef fish larvae and the densities of Carangidae and Labridae revealed no significant correlations ($P \geq 0.42$) with the MLD. During the April 2011 cruise, the total density of reef fish and the density of Carangidae indicated positive correlations ($P \leq 0.05$) with the MLD. However, there was no significant correlation ($P = 0.19$) between MLD and the density of Labridae during the April 2011 cruise.

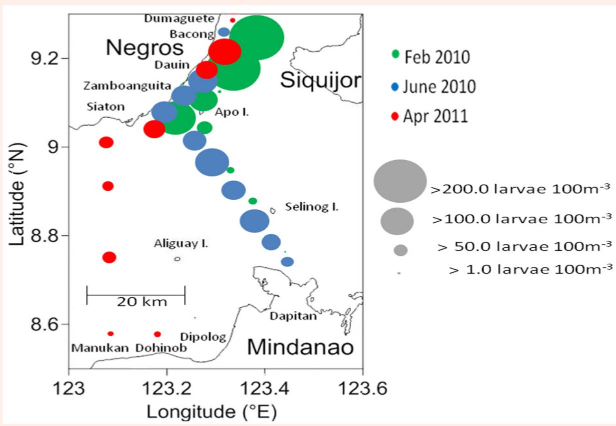

Figure 7: Density distribution of reef fish larvae along the Dipolog Strait on February 2010, June 2010 and April 2011 cruises.

Table 1: Summary of correlation analysis (General Regression Models) to assess the effects of mixed layer depth (MLD) on the density distribution patterns of reef fish larvae.

	Feb-10			Jun-10			Apr-11		
	R_2 adj	F	P	R_2 adj	F	P	R_2 adj	F	P
Carangidae Density	0.68	6.23	0.04	-0.003	0.705	0.42	0.302	4.899	0.05
Labridae Density	0.85	19.32	0	-0.035	0.691	0.42	0.101	2.014	0.19
Total Density	0.71	7.26	0.03	-0.053	0.546	0.48	0.445	8.22	0.02

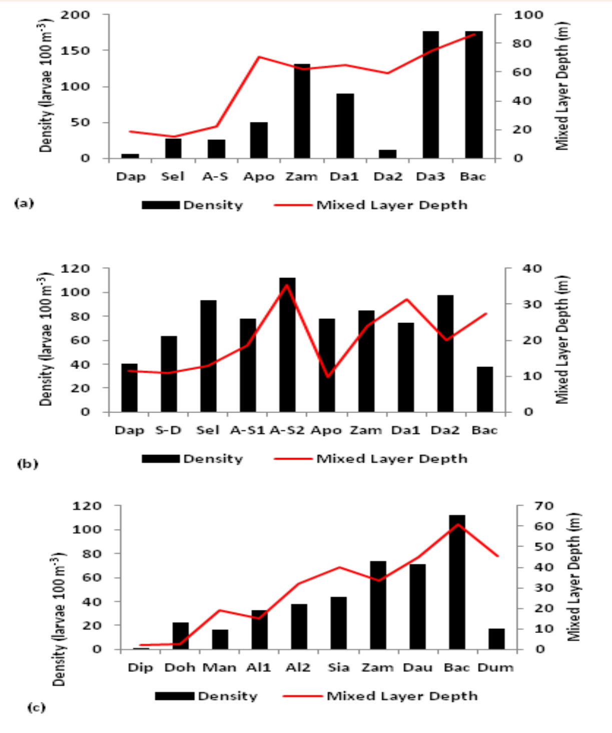

Figure 8: Total density of reef fish lavae and mixed layer depth (MLD) on (a) February 2010, (b) June 2010, and (c) April 2011. Dap=Dapitan, Sel=Selinog, A-S=Apo-Selinog, Apo=Apo Is., Zam=Zamboangita, Da1=Dauin station 1, Da2= Dauin station 2, Da3= Dauin station 3, Bac=Bacong , S-D= Selinnog-Dapitan, A-S1=Apo-Selinog station 1, A-S2=Apo-Selinog station 2, Dip=Dipolog, Doh=Dohinob, Man=Manukan, Al1=Aliguay station 1, Al2=Aliguay station 2, Dum=Dumaguete.

Taxonomic structure of reef fish larvae

A total of 47 families were identified from the 1,545 reef fish larvae collected from the Dipolog strait (Table 2). The percentages of the top 5 most abundant reef fish larvae are Carangidae (22.6), Labridae (16.9), Scaridae (10.2), Gobiidae (9.2) and Apogonidae (5.6). Together, these larvae comprised 64.5% of the total number of reef fish collected from the Dipolog Strait. The remaining reef fish larvae were characterized by low larval densities with <10 individuals 100m^{-3}. In addition, the percent composition of each family was ≤5.5 % of the total number of reef fish larvae collected from the Dipolog Strait. Shifts in the dominance of the top 5 most abundant larvae occurred across the three sampling periods (Figure 9). Carangidae was the most abundant reef fish larvae during the February 2010 comprising 46.9% of the top five most abundant reef fish larvae (Figure 9a). Adults of Carangidae are also commonly observed in the coral reefs of central Philippines (Alcala et al., 2005; Russ and Alcala, 1989). Carangidae was followed by Labridae and with a combined percent composition of 75.7%. In June 2010, Labridae occupied the topmost abundant reef fish larvae comprising 40.1% (Figure 9b). Labridae was followed by Scaridae and with a combined percent composition of 67.4%. In April 2011 cruise, Carangidae again dominated among the top five most abundant larvae, but unlike the February cruise, it was followed closely by Gobiidae (Figure 9c). The combined percent composition of Carangidae and Gobiidae in April 2010 cruise was 57.4%.

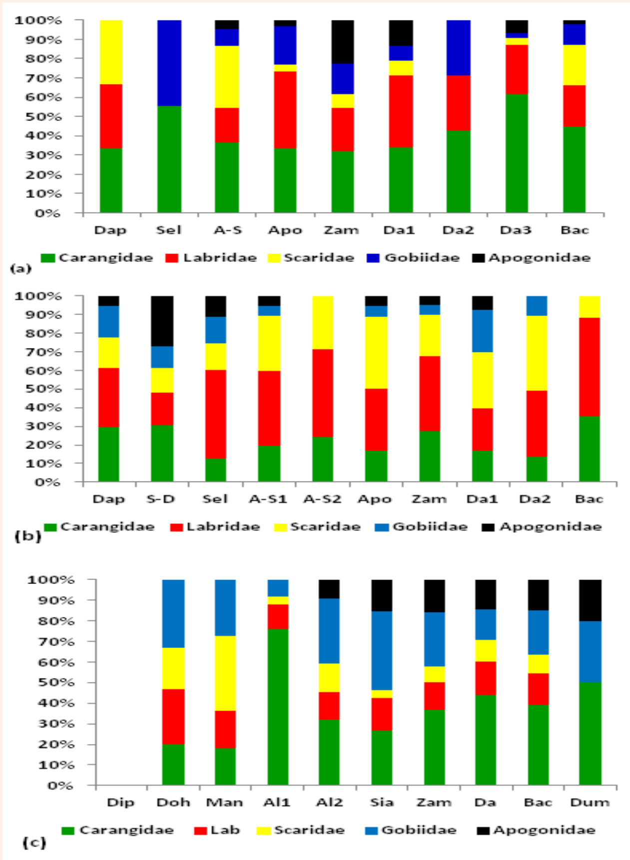

Figure 9: Percent composition of the top five most abundant reef fish larvae per station collected from the Dipolog strait on (a) February 2010, (b) June 2010, and (c) April 2011. Dap=Dapitan, Sel=Selinog, A-S=Apo-Selinog, Apo=Apo Is., Zam=Zamboangita, Da1=Dauin station 1, Da2= Dauin station 2, Da3= Dauin station 3, Bac=Bacong , S-D= Selinnog-Dapitan, A-S1=Apo-Selinog station 1, A-S2=Apo-Selinog station 2, Dip=Dipolog, Doh=Dohinob, Man=Manukan, All=Aliguay station 1, Al2=Aliguay station 2, Dum=Dumaguete.

Table 2: Average density (larvae 100m-3) and percent composition of the reef fish larvae collected from the 15 stations of Dipolog strait during the three oceanographic cruises in February 2010, June 2010 and April 2011.

	Feb-10		Jun-10		Apr-11	
Taxon	Density	Percent Com.	Density	Percent Com.	Density	Percent Com.
Carangidae	21.71	28	10.61	13.99	11.36	26.08
Labridae	12.61	16.27	18.9	24.91	4.25	9.76
Serranidae	6.78	8.74	1.23	1.62	0.85	1.96
Pomacentridae	4.69	6.05	2.8	3.69	1.65	3.78
Gobiidae	5.15	6.64	4.54	5.99	6.57	15.08
Lethrinidae	3.21	4.14	1.2	1.59	1.04	2.39
Acanthuridae	3.46	4.47	3.12	4.12	0.95	2.17
Apogonidae	4.04	5.22	3.29	4.33	3.22	7.38
Lutjanidae	1.6	2.07	3.14	4.14	4.51	10.35
Scorpaenidae	1.98	2.55	1.84	2.43	0.43	0.98

Bleniidae	0.9	1.16	1.66	2.19	1.07	2.46
Mullidae	0.68	0.87	0.52	0.69	1.33	3.06
Synodontidae	1.19	1.54	1.89	2.49	0.31	0.7
Scaridae	4.99	6.44	13.42	17.69	2.92	6.71
Balistidae	0.26	0.33	1.82	2.39	0	0
Ostraciidae	0.34	0.44	0	0	0	0
Opistognathidae	0.17	0.22	0	0	0.11	0.24
Terapontidae	0.69	0.89	0.64	0.84	0.62	1.41
Nemipteridae	0.17	0.22	0.81	1.06	0.24	0.55
Monacanthidae	0.42	0.54	0.38	0.5	0.1	0.22
Priacanthidae	0.3	0.39	0.14	0.19	0.42	0.97
Drepanidae	0	0.13	0.29	0.38	0	0
Cirrithidae	0	0	0.28	0.37	0	0
Berycidae	0	0	0.16	0.21	0	0
Holocentridae	0	0	0.49	0.64	0.21	0.49
Platycephalidae	0	0	0.16	0.21	0.46	1.06
Antennariidae	0	0	0.49	0.65	0.22	0.51
Schindleriidae	0	0	0.27	0.35	0	0
Carapidae	0.13	0.17	0.15	0.2	0	0
Centricidae	0	0	0.08	0.11	0	0
Siganidae	0	0	0.27	0.36	0	0
Chaetodontidae	0.49	0.64	0.26	0.34	0.3	0.69
Tetraodontidae	0.13	0.17	0.3	0.39	0.11	0.24
Soleidae	0.25	0.32	0.1	0.13	0	0
Fistulariidae	0.25	0.32	0	0	0	0
Tripterygiidae	0.25	0.32	0.28	0.37	0	0
Muraenidae	0.16	0.21	0	0	0	0
Pomacanthidae	0.14	0.17	0	0	0	0
Haemulidae	0.27	0.35	0	0	0	0
Uranocospidae	0.11	0.14	0	0	0	0
Bythiidae	0	0	0.1	0.13	0	0
Trichonotidae	0	0	0.1	0.14	0	0
Scatophagidae	0	0	0.14	0.18	0	0
Plesiopidae	0	0	0	0	0.11	0.25
Eleotridae	0	0	0	0	0.08	0.19
Ophiidae	0	0	0	0	0.13	0.3
Total	77.52		75.87		43.56	

Developmental stages of the reef fish larvae

Occurrence (No. of individuals per station) of the pre- and post-flexion stage reef fish larvae belonging to the top five most abundant reef fish larvae, along the coast of southern Negros (Dumaguete to Siaton), indicated that 82.2% of the larvae were in the pre-flexion stage while the remaining 17.8% were in the post-flexion stage (Figure 10). Occurrence of the pre-flexion stage larvae during the February 2010 cruise reached up to 85 larvae per station while post-flexion stage larvae were only between 0 - 5 larvae per station (Figure 10a). In June 2010 cruise, the post-flexion stage larvae were absent on the eastern part of southern Negros (e.g. off Bacong and Dauin) while it reached a peak in station close to Apo Island, as exemplified by the fish larvae Labridae (Figure 10b). During the April 2011 cruise, the pre-flexion stage reef fish larvae were still markedly higher compared to the post-flexion stage larvae, although the latter were present in all of the stations (Figure 10c).

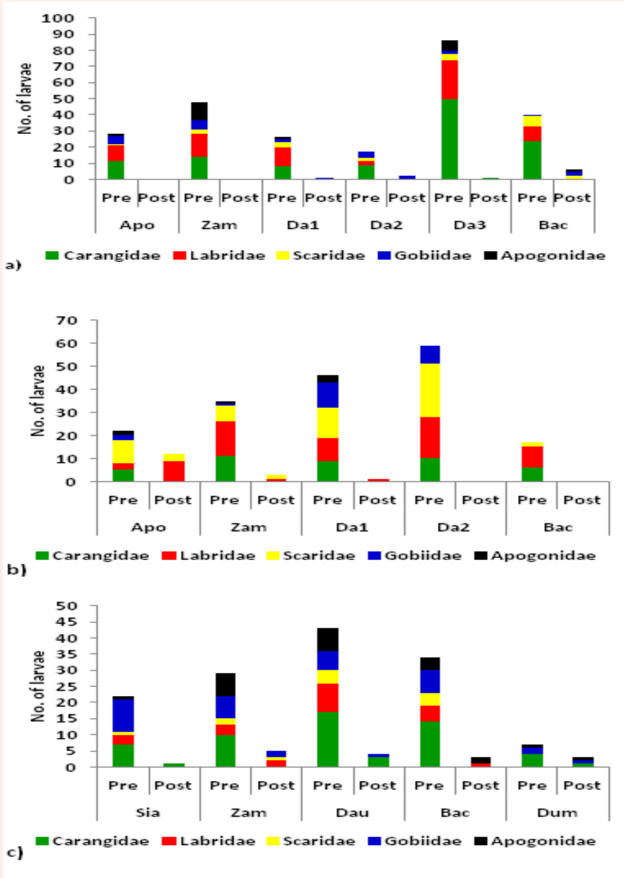

Figure 10: Occurrence of the pre- and post-flexion stage reef fish larvae (top five most abundant larvae) along the southern coast of Negros on (a) February 2010, (b) June 2010 and (c) April 2011. Pre=Preflexion stage, Post=Postflexion stage, Apo=Apo Is., Zam=Zamboangita, Da1=Dauin station 1, Da2=Dauin station 2, Da3=Dauin station 3, BAC=Bacong, Sia=Siaton, Dum=Dumaguete.

Discussion

Factors contributing to reef fish larval dynamics

Result from the present study indicates that the reef fish larval composition and abundance in the Dipolog strait was strongly influenced by a combination of temperature and salinity. Major shifts in the dominance of the top five most abundant reef larvae across the sampling periods corresponded to the change in the temperature profiles of the water column. For example, the remarkable similarity of the temperature profiles between the February 2010 and April 2011 cruises (Figure 2) could explain the dominance of the reef fish larvae of Carangidae during the northeast monsoon period while the highest temperatures recorded in June 2010 cruise could have favored the dominance of the fish larvae of Labridae. Recruitment patterns of Labridae also peaked during the southwest monsoon in the reefs of central Philippines [23] while Carangidae was indicated as the dominant fish larvae in southwestern Australia when temperature differentiation across the shelf was weaker in summer than in the winter [22]. During the prolonged period of rainy conditions prior to the April 2011 cruise (Figure 11), extreme rainfall pattern could have favored the promotion of the fish larvae Gobiidae which are known to thrive in low saline environments. These larvae could have been spawned several days earlier than the April 3 cruise considering the pelagic larval duration of Gobiidae of up to 15 days [24]. A similar finding was indicated in the southern Gulf of Mexico where an increase in the abundance of Gobiidae was significantly linked to the rainy period in the area [25]. The significant positive correlations between the abundance of reef fish larvae and the MLD during the February 2010 and April 2011 cruises would indicate that the patterns observed were brought about by the northeast monsoon period. Conversely, the absence of positive correlation between the MLD and the densities of reef fish larvae in June 2010 was a result of the reversal of the northeasterly winds in February-April to the southwesterly direction in June. However, the failure of the larvae of Labridae to correlate with the MLD in the April 2011 cruise was likely due to the decreasing abundance of this species during this period (Figure 9c). Nevertheless, the total density of reef fish larvae positively correlated with the MLD, indicating a community response of the reef fish larval population to the mixing regimes rather than by the individual species. The positive correlations between the fish larvae and the depth of mixed layer the MLD was also documented in East China Sea and SE Australia, wherein the mixed layer gave the best explanation for variability in the assemblage and distribution of fish larvae [26,27].

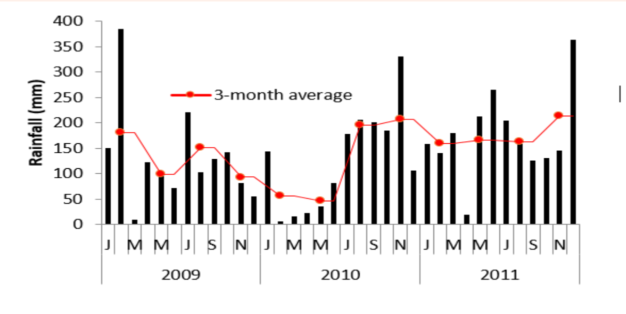

Figure 11: Rainfall patterns for the period 2009-2011 from the Philippine Atmospheric, Geophysical and Astronomical Services (PAGASA).

Mechanisms promoting local retention

The mechanism(s) by which reef fish larvae are retained or dispersed from the spawning site have received considerable attention in recent years due to the vertical migration ability of the fish larvae [17]. However, vertical migration of fish larvae in the water column was associated with several environmental and biological factors, including the orientation of the fish larvae to the maximum chlorophyll depth or to the vertical stratification of currents, avoidance to visual predators, physiological advantages of certain developmental stage or species to range in temperatures, and preferences for specific hydrostatic pressure [16, 28, 17, 29]. Our present study revealed that the high chlorophyll concentrations in the upwelling area off Zamboanga del Norte did not match with the low abundance of reef fish larvae. Likewise, the low concentrations of chlorophyll off the coast of southern Negros did not match with the high abundance of reef fish larvae in the area. This suggests that the distribution patterns of the reef fish larvae in the Dipolog strait could not be attributed to the primary productivity alone or to the bottom depth. Regarding the potential influence of the developmental stages (preflexion and postflexion) of reef fish larvae on the vertical migration of the reef fish larval community, this aspect was minimal since majority (> 80%) of the reef fish larvae were in the pre-flexion stage. On the possibility that young pre-flexion stage reef fish larvae could utilize the eastward-moving undercurrent at depths ~80m-100 m [30], this aspect was considered unlikely considering that the average mixed layer depth in southern Negros area was less than 50 meters. In fact, majority of the early-stage fish larvae do not stay at the deep portions of water column due to limitations in light intensity [31]. In addition, the issue on mortality of the reef fish brought about by predation was also rejected since most the adult pelagic fish predators off Zamboanga del Norte were found at much deeper water (~36 - 72 m) compared to the mixed layer depth (~ 0-20 m), as observed during the cruise. The high abundance of reef fish larvae along the southern coast of Negros may be explained by other hydrographic and biological factors operating in the Dipolog Strait. Strong NE monsoon winds from November to April through Dipolog Strait drives Ekman drift towards the coast of Negros creating a downwelling. This downward flow of water would inevitably transport planktonic prey and younger reef fish larvae, leading to their retention in this part of the Strait. As indicated in SE Australia, deepening of the mixed layer in response to strong downwelling favorable winds would encourage mixing between the surface and interior and could entrain some larvae [26]. In the nearby Bohol Sea, the very shallow mixed-layer depths were related to the above average rainfall during the La Niña year [32]. On the other hand, the upwelling event off the coasts of Zamboanga del Norte [33] would lead to offshore transport of water, particularly during the SW monsoon when the wind pattern reversed. However, this transport pattern could not be likely accompanied by the reef fish larvae since coastal fishes avoid reproduction during vigorous upwelling events to prevent offshore transport of their offspring due to mortality [34]. In addition, there appears to be limited coral reefs in the Dipolog area as compared to the Negros side [20], which may further explain the low abundance of reef fish larvae in the Dipolog side. The simultaneous occurrence of downwelling and upwelling events in Dipolog Strait resembles to what was observed in Georges Bank [35] except that the latter was conducted in a temperate continental margin where upwelling occurred on the mixed side of the front and the downwelling on the stratified side.

Conclusion

The present study, albeit with some limitations in sampling frequency, was able to demonstrate the variable responses of reef fish larval community to the trends and gradients of environmental conditions unique to Dipolog strait. In particular, the significant correlation between the distribution patterns of reef fish larvae and the depths of the mixed layer was in accordance to the findings of [17, 31], although these studies were conducted over a monsoon period with limited trends or gradients of environmental conditions. The same can be implied in the study conducted in the Straits of Florida where reef fish larvae in the area were collected from a fixed station based on the single environmental variable (ocean current). The high abundance of reef fish larvae in areas with a well-mixed water column (e.g. deep MLD), particularly during northeast monsoon, could be attributed to the downwelling brought about by Ekman drift and by the elevated Chlorophyll during the February cruise (Figures 5 and 6). As indicated in Western Australia, a deep mixed layer depth favored a large diatom population in warm-core eddy while the cold-core eddy was persistently stratified with a shallower mean mixed-layer depth [36]. An increasing number of studies have documented the correspondence of fish larval distribution to the patterns of adult fish distributions [10, 37, 38]; including sites close to the protected areas [39]. Our study provides a better understanding on the varying responses of the reef fish larvae to the trends and gradients of oceanographic conditions unique to Dipolog strait. In addition, the mechanism by which reef fish larvae are retained close to the marine reserve networks of southern Negros are also discussed in the present study. Rigorous sampling regime may be required to ascertain the role of each marine reserve in the maintenance of the reef fish larval community of Dipolog Strait [40-44].

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