Observations for Climate: Satellite Observations and Fisheries for Climate Studies

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Spatial and temporal distributions of larval fishes have been related to environmental conditions and mesoscale oceanographic structures, with subsequent effects on larvae growth and survival and, thus, recruitment to adult populations. Using satellite altimetry and *in situ* larval fish densities a methodology was developed to study the effect in larval distributions of six fish taxa of the variability in the circulation in the Gulf of Mexico (GOM), during the spring months from 1993 to 2007. Results indicate that the northward penetration of the Loop Current (LC) tended to increase during spring and reach maximum values in summer. Frontal positions, northward excursions of the LC, and other mesoscale features in the GOM were important for determining larval distributions, with generally higher larval abundances during years of high northward penetration. Our results showed that larvae of bluefin tuna (*Thunnus thynnus*), little tunny (*Euthynnus alleteratus*), *Auxis* spp., and snappers (*Lutjanidae*) were preferentially located within the boundaries of anticyclonic features (generally between 140-150 cm of sea surface height), and within GOM common waters. Our findings suggest that the position and strength of mesoscale features in the GOM is likely to dictate the temporal and spatial distribution of larval fish assemblages, possibly by influencing the area and persistence of habitat favorable for adult spawning. These results are important because they highlight the relationship between the upper ocean dynamical and thermal conditions and larval recruitment. Any long-term variability of these conditions will be probably linked to changes in recruitment. In the GOM, a long term variability of the upper ocean conditions has been observed using both sea surface temperature and sea surface height. Results presented here stress the need for a sustained observing system able to resolve mesoscale features, which are important for the upper ocean temperature response to the changing climate, and continuous sampling of larvae of economically important species.

GULF OF MEXICO DYNAMICS

The mesoscale circulation in the GOM is dominated by the Loop Current (LC) and the rings shed by the LC (Figure 1). The LC extends northward into the GOM from the Yucatan Channel. The current forms an intense anticyclonic flow, which can extend as far north as 29.1°N and can come within close proximity to the Mississippi River delta or the Florida Panhandle coast. The LC intrusion may occur in any season and with periods varying from 6 to 17 months, with an average period of 10-11 months. The LC returns to its southern location by slowly pinching off its northern extension to form large, warm-core anticyclonic rings that then propagate westward at speeds of 2-5 km/day, and have lifetimes of days to approximately a year. These large anticyclonic rings shed by the LC with radii of approximately 150 km, swirl speeds of 1.8-2 m/s, and around 800 m depth are generated aperiodically, with an average shedding time of 9.5 months and a range of 3 to 21 months between consecutive sheddings.

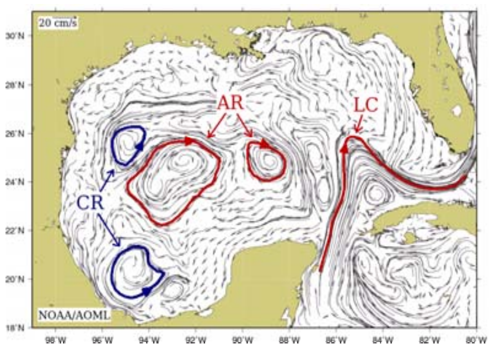

Figure 1. Example of general circulation through the GOM. Gray arrows in the background represent satellite-derived geostrophic currents with red contours highlighting anticyclonic movements (mainly Loop Current, LC, and anticyclonic regions, AR) and blue contours for cyclonic movements (cyclonic regions, CR).

DATA AND METHODOLOGY

Data of abundances of captured larvae standardized to larval densities (number of larvae per m^3 of sea water filtered) collected in the GOM north of 23°N, during spring months between April 1993 and June 2007 [1] were combined with satellite derived sea surface temperature (SST) [2] and sea surface height (SSH, obtained from altimetry derived sea height anomaly [3] by adding the mean dynamic height [4]) in order to asses the influence of mesoscale ocean features on the distribution patterns of fish larvae spawned in the GOM.

In order to link the mesoscale features to captures of fish larvae, the GOM was characterized depending on its dynamic as cyclonic or anticyclonic regions, cyclonic or anticyclonic boundaries, or common waters, according to the following methodology, based on the analysis of *SSH* and grad(*SSH*) values:

- an anticyclonic region (AR) when:

$$SSH > SSH_{max} - n \cdot \sigma(SSH)$$

- a cyclonic region (CR) when:

$$SSH \leq SSH_{min} + p \cdot \sigma(SSH)$$

- an anticyclonic boundary (AB) when:

$$SSH \geq m \cdot SSH_{max} \quad \text{and} \quad \text{grad}(SSH) \geq r \cdot \sigma(\text{grad}(SSH))$$

- a cyclonic boundary (CB) when:

$$SSH \leq q \cdot SSH_{min} \quad \text{and} \quad \text{grad}(SSH) \geq r \cdot \sigma(\text{grad}(SSH))$$

- or common waters (CW) if none of these conditions are satisfied

with $m = 0.91$; $n = 3.30$; $p = 0.60$; $q = 1.08$ and $r = 0.67$ (optimized for better results).

RESULTS

The LC northward penetration was seasonal, with maximum values in early summer (Figure 2) and high year-to-year variability (Figure 3). This variability was reflected in larval fish distributions, with generally higher larval abundances during years of high northward penetration (Figure 4). This could be due to a biological response by either adults or larvae to the LC feature, but also to purely physical mechanisms of northward displacement of larvae carried out by the LC. Further analysis showed that larvae appeared to be less abundant in the core regions of both cyclonic and anticyclonic mesoscale features, and more abundant at the boundaries and frontal areas. This suggests that the observed association between larval abundances and the LC excursions might be due to higher abundances within the LC frontal zone, rather than abundances within the main body of the current.

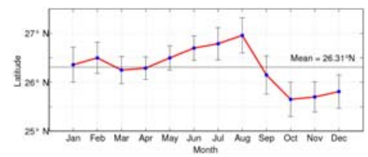

Figure 2. Monthly mean location of the LC northward penetration (blue circles). Black bars indicate one standard deviation over the 16 years of data analyzed, from January 1993 to December 2008.

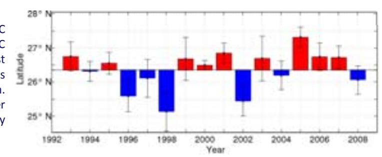

Figure 3. Annual mean location of the LC northward penetration. Blue bars indicate LC locations north of the mean northernmost position, and red bars indicate LC locations south of the mean northernmost position. Black bars indicate one standard deviation over the 16 years of data analyzed, from January 1993 to December 2008.

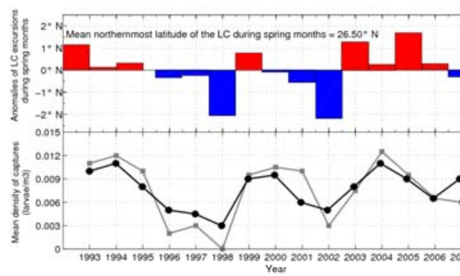

Figure 4. Anomalies of the mean northernmost location of the LC in relation to spring mean density of captures. Black line shows mean larval density of captures of bluefin tuna, little tunny, *Auxis*, *Thunnus*, snappers, and dolphin-fishes, from May 1993 to June 2007. Grey line illustrates spring mean larval density of captures of *Thunnus* species, from May 1993 to June 2007. The mean northernmost location of the LC during spring was found to be 26.5°N. Positive red bars indicate LC locations north of the mean northernmost position during spring, and negative blue bars indicate LC locations south of the mean northernmost position during spring. The sub-area of study of larval fish captures is a square bin of 2° centered at 87°W and 26.5°N.

Larvae may be more common in mesoscale feature boundaries because:

1) they are concentrated by oceanographic processes;
2) feeding conditions are more favorable in convergence zones, which can concentrate planktonic fish larvae, and so larval survival is higher; and
3) adult fishes detect frontal features where they are able to spawn.

We may therefore hypothesize that adult spawners of some taxa might exhibit a preference to spawn in the boundaries of anticyclonic features and in common waters. Our results also suggest that larval abundances were often highly spatially autocorrelated, i.e., if one station contained larvae of particular taxa, the neighboring stations were likely to as well. This result is consistent throughout the various years of observations, and may suggest large-scale spawning when conditions are suitable for a particular taxa.

Larvae of bluefin tuna, little tunny, *Auxis* and snapper were preferentially located within the boundaries of anticyclonic features, and in GOM common waters (Figure 5). In contrast, *Thunnus* larvae were distributed more broadly, being collected in different regions and boundaries of mesoscale structures.

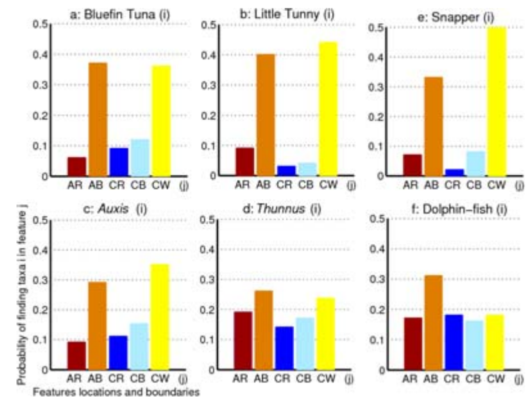

Figure 5. Probability of finding larvae of bluefin tuna (a), little tunny (b), *Auxis* (c), *Thunnus* (d), snappers (e) and dolphin-fishes (f) in anticyclonic regions (AR, red bar), anticyclonic boundaries (AB, orange bar), cyclonic regions (CR, dark blue bar), cyclonic boundaries (CB, light blue bar), and common waters (CW, yellow bar). Calculated from altimetry derived fields and spring sampling from 1993 to 2007.

The small size and age of larvae of the six fish taxa studied suggest that larval fish collected were likely to be captured in the same water mass in which they were spawn. This indicates that year-to-year variability of the LC might also be reflected in adult recruitment, with possibly higher adult recruitment of bluefin tuna, little tunny, *Auxis*, *Thunnus*, and dolphin-fish during years of high northward penetration of the LC. Also, we could infer that adult spawning habitat of bluefin tuna, little tunny, and *Auxis* spp. were preferentially located within the boundaries of anticyclonic features, and in GOM common waters.

CONCLUSIONS

Our findings illustrate that the position and strength of mesoscale features in the GOM are likely to dictate the area and persistence of habitat favorable for larvae distribution. Interestingly, variability of the LC excursions was reflected in larval fish distributions, and larvae of some taxa were associated with anticyclonic boundaries and common water regions. The larval fish distributions in the GOM common waters regions may be investigated in future research by using other sources of satellite data to overlay on the altimetry. Tracing frontal zones from SST and ocean color data to overlay on the SSH fields, for instance, would give more detail on the 'closeness' of larvae to the features, and would complement present altimetry results. The present study and related future investigations have high potential to improve the management of iconic fish species in the GOM. For example, global climate-model simulations forced by future greenhouse warming have recently used the fisheries database handled in this study, projecting that upper-ocean temperatures in the main western Atlantic spawning ground, the GOM, will increase substantially, potentially altering the temporal and spatial extent of bluefin tuna spawning activity [5].

REFERENCES

[1]. Larval fish data were available from the National Marine Fisheries Service Southeast Area Monitoring and Assessment Program (SEAMAP) database.

[2]. Microwave optimally interpolated SST fields from TMI and AMSR-E radiometers onboard the TRMM and Aqua satellites: *http://www.ssmi.com/*.

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