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Are hydrographic mesoscale structures associated with the mass nesting behavior of the olive ridley sea turtle?

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Abstract

The olive ridley sea turtle is a species that presents an exclusive and extremely gregarious mass nesting behavior termed “arribada”, which has only been documented in a few countries around the world. Based on satellite observations we assess the presence of hydrographic mesoscale structures and chlorophyll-*a* concentrations at three nesting sites (La Escobilla in Mexico, Ostional in Costa Rica, and Gahirmatha in India) in order to determine whether their presence is linked to the olive ridley sea turtle “arribada” events. The results showed the persistence of cold cores and high chlorophyll-*a* concentrations associated with mesoscale eddies at nesting zones suggesting their utilization by the turtles and might also indicate an ability of the sea turtles to adapt to each nesting site. The results presented here help to locate regional satellite observations of chlorophyll variability within a global perspective and contribute towards a better understanding of the complex “arribada” events and helps to identify foraging areas that play a pivotal role in species conservation.

Keywords: Arribada, chlorophyll-*a, Lepidochelys olivacea*, mesoscale eddies, sea surface temperature.

INTRODUCTION

The olive ridley sea turtle (*Lepidochelys olivacea*, Eschscholtz, 1829) is classified by the International Union for Conservation of Nature as vulnerable with a population trend as decreasing [1]. This sea turtle is a widely-distributed species that presents an exclusive and extremely gregarious behavior called "arribada" documented in only a few countries around the world. The most important sites along the Pacific coasts of the American tropics are La Escobilla, Oaxaca in Mexico and Ostional in Costa Rica. Another site where thousands of turtles synchronously emerge is Gahirmatha, India, in the Bay of Bengal of the Indian Ocean (Fig. 1). Nesting aggregates of over 130,000 turtles have been reported at La Escobilla [2, 3], and up to 140,000 nests have been recorded at Ostional [4, 5]. Mass-nesting events in both sites occur almost every month of the year with a peak during August. Meanwhile more than 150,000 nesting turtles were estimated to be present at Gahirmatha with a peak season during February [6, 7].

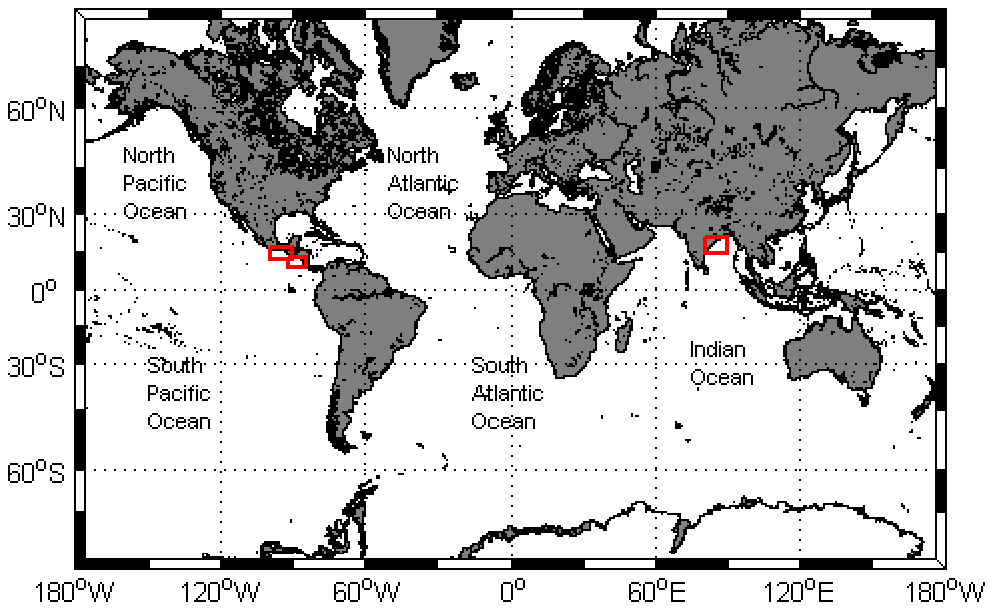

Fig. 1. Location where the most important nesting sites for the olive ridley sea turtle occur represented as red rectangles. Along the Pacific coasts of the American tropics are La Escobilla, Oaxaca in Mexico and Ostional in Costa Rica, as well as Gahirmatha, India, in the Bay of Bengal of the Indian Ocean.

In general, little is known about the factors that influence nest density of sea turtles across regional scales [8, 9]. Therefore, the conditions associated with the beginning of the "arribada" remain unclear. Some hypotheses have been proposed, including specific sand granulometric characteristics at the nesting site [10], behaviors to avoid predation [11] and a reproductive specific strategy to prevent collapse on the populations [12]. Recently, Coria-Monter and Durán-Campos [3] suggested that the presence of mesoscale eddies and strong currents could be related to the beginning of the “arribada” events at La Escobilla, Oaxaca, Mexico because although sea turtles are strong swimmers, proximity to mesoscale eddies and favorable currents might provide energy savings, and accumulated chemical compounds and food availability in the water column. Similarly, Putman et al. [13] suggested that proximity to propitious ocean currents in the proximity of the Gulf Stream System (North Atlantic) strongly influences sea turtle nesting distribution, then natural selection may help reproduction in areas near ocean currents that facilitate migratory movements.

Mesoscale eddies with radii in the range 10–100 km are physical structures that play a pivotal role in biogeochemical production in the ocean and they can change the rate of nutrients from the deep to the euphotic layer [14, 15]. There are at least three classes of mesoscale eddies in the open ocean: anticyclonic, cyclonic and mode-water eddies. Cyclonic and mode-water eddies are characterized by divergent movements that lead to a rise of cold water and a shallower thermocline [16]. The core of cyclones and mode-water is enriched with nutrients, and produces a fertilization in the euphotic zone that induces an accumulation of phytoplankton biomass to accumulate, which can be observed as a region of high chlorophyll-*a* concentration. Anticyclonic eddies induce convergent movements, sinking surface waters below the euphotic zone [16]. These structures support a good fishery for small, pelagic fishes like clupeids, engraulids, leiognathids, and also associated with larval transport, and have been considered as recruitment sites for several species such as crabs, shrimps, and squids, among others [17, 18]. The influence of mesoscale eddies on turtles was assessed by Gaube et al. [19]. They reported that juvenile loggerhead sea turtles are significantly more likely to be located in the interior of anticyclonic eddies in the Brazil-Malvinas Confluence region, suggesting that these turtles may be feeding on prey items. The authors emphasize the high degree of biological activity in these structures and the challenges that are inherent in understanding how marine animals use oceanographic features, such as eddies.

So, could mesoscale eddies be related to the mass nesting behavior of the olive ridley sea turtle in the most important sites around the world? In order to explore this hypothesis we applied the following strategies: a) selected the sites where extremely gregarious nesting have been documented: La Escobilla (Mexico); Ostional (Costa Rica); and Gahirmatha (India); and b) we used satellite observations derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) in order relate the reproductive synchrony to oceanographic cues such as the presence of eddies and filaments.

MATERIALS AND METHODS

Study sites. La Escobilla is located on the Pacific coast of Oaxaca, Mexico and is characterized by a long beach of 22 km length with a nesting zone of 8 km. The beach has been monitored by the Mexican authorities since 1967, and now is considered as a

National Sanctuary protected area [20]. Ostional is an 86 km^2 coastal wildlife refuge located on the northern Pacific Peninsula of Costa Rica, extending 200 m inland from the high tide line and approximately 5.5 km offshore [21]. Gahirmatha is a Marine Wildlife Sanctuary bounded by the Bay of Bengal on the east with a coastline extending over 35 km. The continental shelf is shallow and does not exceed 20 m even at an off-shore distance of 7 km [22].

Data analyses. In order to assess the variability of the oceanographic conditions in the selected sites, we used daily data of sea surface temperature (SST) and chlorophyll-*a* (Chla) during August 2014-2017 in La Escobilla and Ostional, and during February 2014-2017 in Gahirmatha. The selected months correspond to the peak in the nesting season in these sites reported in the literature [2, 3, 4, 5, 6, 7]. The SST and Chla signatures with a spatial resolution of 1 km/pixel were obtained daily for the months mentioned above from the Moderate Resolution Imaging Spectroradiometer (MODIS-AQUA, https://oceancolor.gsfc.nasa.gov/), processed at Level 1 and 2, using SeaDas 7.4 and standard algorithms. The processing method was as follows: first, using Level 2 (before mapping), values of SST and Chla were extracted. In order to screen poor or low quality data when generating the images, LAND, CLDICE, HILT and STRAYLIGHT flags/masks were applied. LAND and CLDICE were raised, then a mask pixel was applied to MODIS L2 products. HILT was flagged if any of the bands or detectors reached the physical saturation, whereas STRAYLIGHT indicated the influence of the brightness of adjacent pixels on the pixels' reflectance value [23]. Once extracted, data were average for each month, and then maps of both variables were generated. The algorithms used return the near-surface concentration of Chla (in mg m^{-3}), calculated using an empirical relationship derived from *in-situ* measurements of Chla and remote sensing reflectance in the blue-to-green region of the visible spectrum; the algorithm employs the standard OC3/OC4 (OCx) band ratio algorithm merged with the color index (CI) of Hu et al. [24]. As a great proportion of sea surface chlorophyll-*a* variation occurs at small scale, its concentration is sufficiently stable to be tracked by monthly satellite observations, even if chlorophyll at the sea surface is not a conservative tracer.

RESULTS

Particularly, the intertropical convergence zone around the equator is marked by high convection and energy fluxes, resulting in persistent cloudy conditions and only some weeks of clear sky throughout the year. Although the presence of clouds creates some gaps in the data, satellite observations revealed a clear signal for SST and Chla in the selected sites of this study.

The results showed the presence of cold cores and large numbers of Chla filaments as common features in the three sites, associated with the presence of mesoscale eddies. At La Escobilla, Oaxaca, Mexico, the presence of cold cores and SST cold tongues were consistent during August along the four years period analyzed (Figs. 2A-D) as well as high Chla concentrations (> 5 mg m^{-3}) were observed extending out from the coast (Figs. 3A-D). These structures are closely related with the presence of mesoscale eddies and upwelling processes, which induce nutrient pumping, fertilizing the euphotic zone, and in turn facilitating the availability of food and chemical compounds in the water column. These kinds of structures have been documented throughout the year in this area, so due to their persistence these mesoscale structures could be assumed to be recurrent. At Ostional, Costa Rica, the monthly composite images in August were also consistent with the presence of cold cores (Figs. 2E-H) and high Chla concentrations (> 9 mg m^{-3}) (Figs. 3E-H), indicative of the presence of mesoscale eddies, and filaments were observed extending from the coast and reaching more than 500 km. At Gahirmatha, India, the monthly composite images during February also showed evidence of strong mesoscale variability with the presence of cold cores (Figs. 2I-L) and strong pulses of fertilization close to the coast, in particular close to the nesting beach. The Chla concentration in these zones reached values of ≈ 5 mg m^{-3} (Figs. 3I-L).

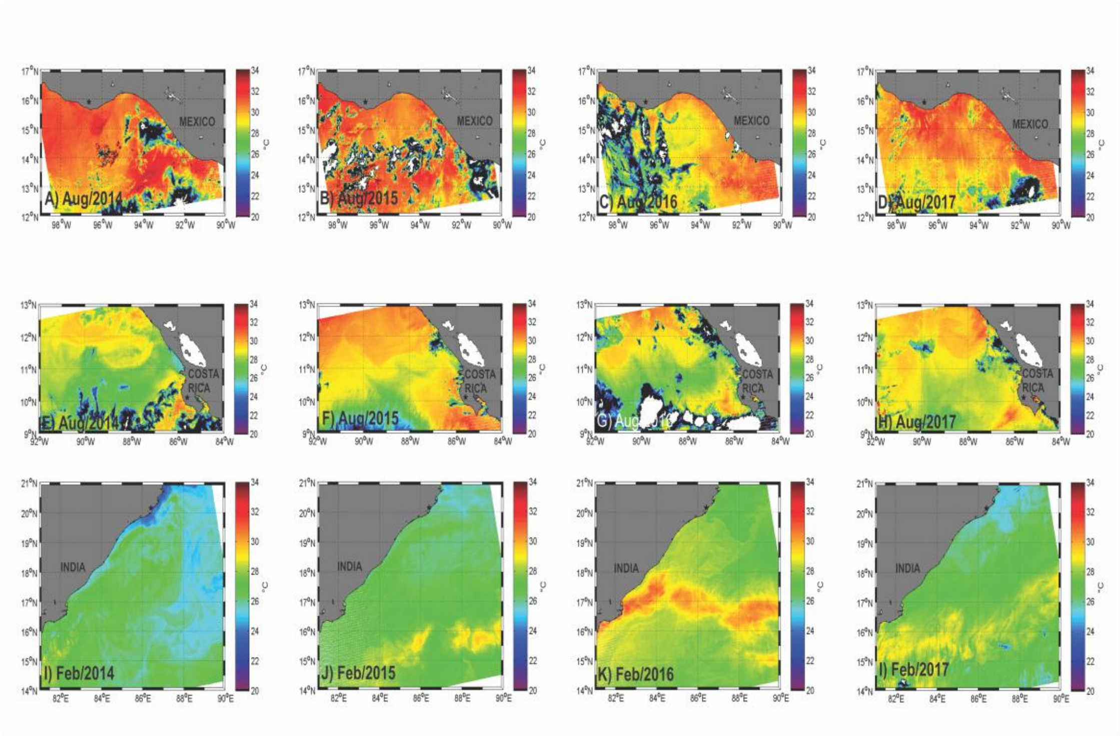

Fig. 2. Satellite images of Sea Surface Temperature (ºC): (**A**) La Escobilla, Oaxaca, Mexico (August 2014); (**B**) La Escobilla, Oaxaca, Mexico (August 2015); (**C**) La Escobilla, Oaxaca, Mexico (August 2016); (**D**) La Escobilla, Oaxaca, Mexico (August 2017); (**E**) Ostional, Costa Rica (August 2014); (**F**) Ostional, Costa Rica (August 2015); (**G**) Ostional, Costa Rica (August 2016); (**H**) Ostional, Costa Rica (August 2017); (**I**) Gahirmatha, India (February 2014); (**J**) Gahirmatha, India (February 2015); (**K**) Gahirmatha, India (February 2016); (**L**) Gahirmatha, India (February 2017). The symbol * represents the location of a nesting beach.

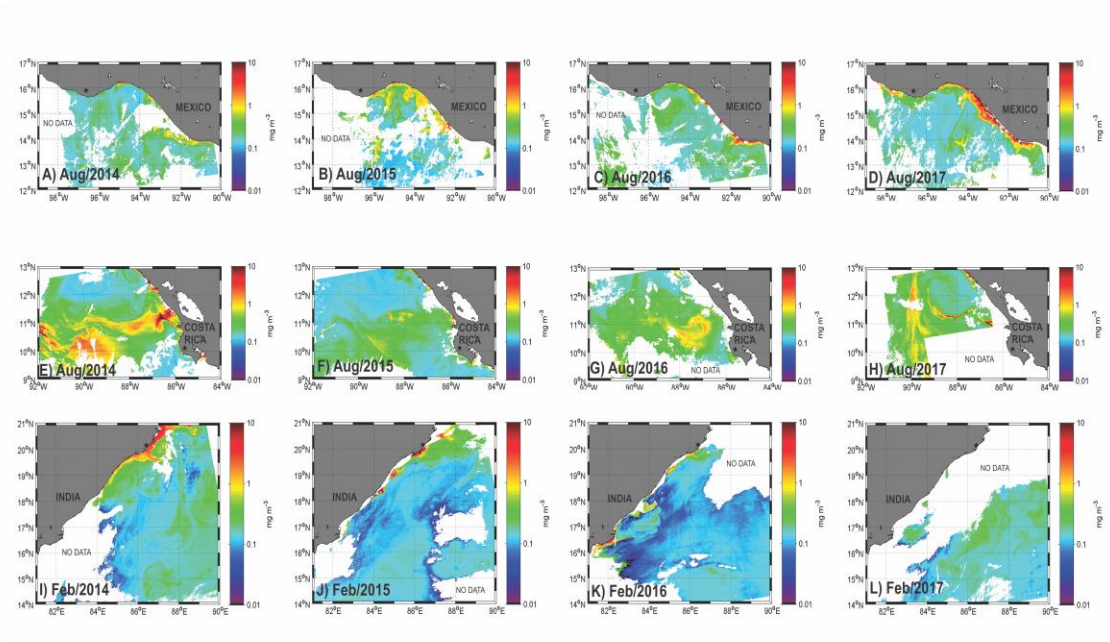

Fig. 3. Satellite images of chlorophyll-*a* (mg m^{-3}): (**A**) La Escobilla, Oaxaca, Mexico (August 2014); (**B**) La Escobilla, Oaxaca, Mexico (August 2015); (**C**) La Escobilla, Oaxaca, Mexico (August 2016); (**D**) La Escobilla, Oaxaca, Mexico (August 2017); (**E**) Ostional, Costa Rica (August 2014); (**F**) Ostional, Costa Rica (August 2015); (**G**) Ostional, Costa Rica (August 2016); (**H**) Ostional, Costa Rica (August 2017); (**I**) Gahirmatha, India (February 2014); (**J**) Gahirmatha, India (February 2015); (**K**) Gahirmatha, India (February 2016); (**L**) Gahirmatha, India (February 2017). The symbol * represents the location of a nesting beach.

DISCUSSION

Mesoscale eddies are ubiquitous and highly energetic features of ocean circulation with a strong influence on biological and biogeochemical processes, acting as a "hotspot" of biodiversity [16].

Based on this evidence presented here, the mechanisms controlling the "arribada" events could be strongly related with the presence of 'hot spots' of biological activity associated with mesoscale eddies. The turtles may modify their behavior to take advantage of suitable foraging conditions around eddies, regions that may be also used as potential reproductive areas from which offspring have difficulty emigrating [13]. The pelagic organisms trapped by these structures could ensure the availability of food for the females of turtles close to the nesting zone. Recently, Chambault et al. [25] using satellite telemetry and remote sensing data (SST and sea surface height) examined the influence of mesoscale features, such as eddies, off French Guiana in the behavior of the olive ridley sea turtles, showing that the hunting time within a dive increased with water temperatures typical of cyclonic eddies. In a collateral study, Chambault et al. [26] investigated the use of mesoscale eddies by the olive ridley sea turtle during migration off French Guiana, showing evidence that the turtles moved away from the nesting beach, performed deeper and longer dives to later remain in optimal waters to forage, mainly crustaceans and fishes. Particularly in La Escobilla, Mexico, recent information suggest that the presence of mesoscale eddies (either cyclonic or anticyclonic) and strong currents could be close related with the begging of the arribada events in the olive ridley population of the region by three potential mechanisms: 1) the strong ocean currents clearly affect turtle movements by producing powerful forces that advect swimming turtles, 2) the occurrence of rotatory drifts of water, which can affect the sea turtle movements, and 3) changes in the biogeochemical properties of the water column by the presence of eddies which ensure the availability of food for sea turtles [3].

The use of mesoscale eddies by turtles, particularly the Loggerhead (*Caretta caretta,* Linnaeus, 1758), was also pointed out by Gaube et al. [19] who showed observational evidence of an affinity of the turtles to be close or in association with the centers of anticyclonic eddies located in the Brazil-Malvinas Confluence region, as a result of two mechanisms: 1) turtles were passively advected in the interiors of anticyclones, and 2) turtles were actively seeking out water masses trapped within anticyclones, possibly because of suitable foraging conditions, decreased predation and elevated temperatures. Using satellite transmitters to neonate loggerhead turtles, Mansfield et al. [27] observed migrations of thousands of kilometers off the coast; with individuals swimming around mesoscale eddies into the Gulf Stream region. Foley et al. [28] evaluated the postnesting migratory behavior of loggerhead turtles from the Gulf of Mexico, identifying migratory corridors associated with open-ocean eddies, suggesting suitable conditions for forage in those areas.

Not only sea turtles benefit from mesoscale eddies, recently the use of these structures by top predators, such as withe sharks, in the Gulf Stream and Sargasso Sea region was noticed by Gaube et al. [29]. They showed evidence that two mature female white sharks exhibited extensive use of the interiors of anticyclonic eddies, characterized by positive (warm) temperature anomalies, making prey more accessible and energetically profitable to adult white sharks in the region by reducing the physiological costs of thermoregulation in cold water. Additional evidence suggest that adult fishes also benefit from mesoscale eddies, for example, cyclonic eddies into the Gulf of Mexico appear to be home of Atlantic bluefin tuna populations there [30].

Nonetheless, there are two important aspects to consider 1) the "arribada" that means the arrival of the turtles to the nesting sites at a given time, and 2) the massive gregarious nesting of the turtles in a wide range of time as discussed by Eckrich and Owens [31]. So the persistence of the mesoscale eddies observed would set the stage for different ecosystem responses leading to the beginning of the “arribada” or maintaining and supporting it. Another important aspect to kept in mind, is the temporal synchronization in nesting activity associated with moon phases as reported by Márquez and Van Dissell [32]), by Kar and Dash [33], among others; in this regard, the moon phases could induce the sea turtles arrivals to the nesting zones, while the oceanographic processes, such eddies, could set the necessary conditions to establish the gregarious process.

The results presented here help to locate regional satellite observations of chlorophyll variability within a global perspective and contribute towards a better understanding of the complex "arribada" events and helps to identify foraging areas that play a pivotal role in species conservation; however, further studies are required, including *in-situ* and satellite observations as well as numerical modeling, in order to improve knowledge of the sea turtle ecology.

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