Invited Paper

Potential impacts of the Deepwater Horizon oil spill on large pelagic fishes

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ABSTRACT

Biogeographical analyses provide insights on how the Deepwater Horizon oil spill impacted large pelagic fishes. We georeferenced historical ichthyoplankton surveys and published literature to map the spawning and larval areas of bluefin tuna, swordfish, blue marlin and whale shark sightings in the Gulf of Mexico with daily satellite-derived images detecting surface oil. The oil spill covered critical areas used by large pelagic fishes. Surface oil was detected in 100% of the northernmost whale shark sightings, in 32.8 % of the bluefin tuna spawning area and 38 % of the blue marlin larval area. No surface oil was detected in the swordfish spawning and larval area. Our study likely underestimates the extend of the oil spill due to satellite sensors detecting only the upper euphotic zone and the use of dispersants altering crude oil density, but provides a previously unknown spatio-temporal analysis.

Keywords: Deepwater Horizon, oil spill, image analysis, satellite remote sensing, spawning, nekton, endangered species.

1. INTRODUCTION

Oil spill detection by satellite remote sensing is a reliable survey method when different sensors and satellites are combined [1] . Earlier use of satellite sensors for oil spill detection, including the 1979 *Ixtoc I* in Mexico [2], the 1989 *Exxon Valdez* in Alaska [3] and the 1991 Arabian Gulf War spill [4] , required extensive user input during image processing to make the oil spill visible [2] . Advances in the frequency of satellite passes, sensors, and dedicated software, have greatly improved oil spill detection using satellite remote sensing (2002 *Prestige* in Spain [5]).

The Deepwater Horizon (DWH) oil spill released crude oil from a depth of ~1500 m at an estimated rate of 68,000 barrels per day into the Gulf of Mexico during 87 days, from 20 April to 15 July 2010 [6] . Satellite images have been used for tracking and modeling the advance of the oil spill [7, 8] and changes in ocean surface productivity [9] . The aim of this study was to determine if satellite imagery, coupled with biological data, could detect surface oil spill presence in critical breeding and feeding areas of the Gulf's pelagic ecosystem.

Here we report that the spawning areas of giant predatory nekton (bluefin tuna and blue marlin) and feeding areas of giant plankton-feeding nekton (whale sharks) were covered with oil for a significant amount of time. These giant nekton species are either overfished, vulnerable or critically endangered (Table 1). Possible consequences in the pelagic ecosystems of the Gulf of Mexico may be profound ranging from impacts on endangered species recovery to fish stock management.

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Table 1. Basic life history parameters and population status for the giant nekton species shown in this study.

Species	Maximum Length (m)	Maximum Weight (Kg)	Spawning Season	IUCN Red List Status [10]
Whale Shark *Rhincodon typus*	12 - 20 [11]	12,000 [12]	Unknown [13] (Ovoviviparous)	Vulnerable
Bluefin Tuna *Thunnus Thynnus*	> 3 [14]	560 [14]	June to August [15]	Data deficient Critically endangered [16]
Swordfish *Xiphias gladius*	4.5 [17]	650 [17]	December to June [18]	Data deficient (needs updating)
Blue Marlin *Makaira nigricans*	5 [19]	636 [19]	May to September [19]	Unlisted

2. METHODS

2.1 NOAA-NESDIS Satellite-derived surface oil analysis products

Satellite derived oil analyses were produced as an experimental product of the NOAA Satellite Analysis Branch. The experimental imagery analysis provided, combined images from he following satellites: RADARSAT-1 (Canadian Space Agency), RADARSAT-2 (Canadian Space Agency & MacDonald Dettwiler and Associates Ltd), COSMO-SkyMed (Italian Space Agency), TerraSAR-X (German Aerospace Centre), ALOS (Japan Aerospace Exploration Agency & Japan Resources Observation System Organization), ENVISAT (European Space Agency), MODIS (NASA), AVHRR on NOAA-15,-17,-19 satellites (NOAA), Multispectral Imagery (The Disaster Monitoring Constellation), SPOT (SPOT Image & French Government Space Agency - CNES). Full geographical extend of the oil might not be detected if the oil sheen is too thin. Subsurface oil is generally not detected with the method. The experimental product was downloaded as layers to create a Geographic information System (GIS) database from the NOAA-NESDIS web site (http://www.ssd.noaa.gov/PS/MPS/deepwater.html). Daily satellite composites were not available or were corrupted for the 24 April to 25 August 2010 survey period. Specifically April 27, May 6-7, 9, 11-26, June 14, July 22, August 3-4, 9, 11-14, 16-17, 19-20 and 22-24 are missing in this analysis. Therefore, the total number of daily satellite composite samples is 87.

2.2 Percent occurrence of surface oil and spatial statistical analysis

Based on the maximum oil surface coverage shown in the daily composite satellite-derived surface oil analysis, the area 23° N to 30.5° N latitude and 82° W to 94.5° W longitude was divided into a 0.5º x 0.5º grid, and the presence or absence of surface oil was recorded to calculate the percent of time each grid square had surface oil detection. We used the non-parametric Cochran's Q test in lieu of a parametric repeated measurements ANOVA, because we used a binary variable [20] . Here the "individuals" were each of the 349 squares in the 0.5° x 0.5° grid and the randomized blocks treatment were the days surveyed. Presence of surface oil was classified as a bad condition (assigned value "0"), absence of surface oil was classified as a good condition (assigned value "1"). We tested the null hypothesis (alpha = 0.01) that the proportion of 0.5° x 0.5° squares in good condition (free of surface oil) remained the same as the season progressed.

2.3 Mapping spawning and larval areas, and whale shark sightings

Spawning area mapping included ichthyoplankton surveys conducted by NOAA within the SEAMAP program, a fishery-independent gulfwide survey, including the entire northern Gulf of Mexico within the U.S. Exclusive Economic Zone, EEZ, since 1982. We used ichtyoplankton maps compiled from the 1982 through 1985 SEAMAP surveys [21,22,23,24] and data summaries [25,26] . We also used information on female ripeness and reproductive condition in blue fin tuna [15] and non-government surveys of swordfish [18] and blue marlin [19] . We mapped whale shark sightings from data in the published literature [27,28,29,30,31] .

3. RESULTS

The spawning and larval areas for bluefin tuna (*Tunnus thynnus*), swordfish (*Xiphias gladius*) and blue marlin (*Makaira nigricans*) were mapped based on approximately 5,000 historical ichthyoplankton samples collected over a 5 year period and published reports of female reproductive condition. Whale shark (*Rhyncodon typus*) sightings were mapped from reports dating back to 1957 (Fig.1). The extent and presence of the oil spill on the sea surface was mapped from NOAA-NESDIS daily satellite-derived surface oil analysis images from 24 April to 25 August 2010 (Fig 2A). Surface oil presence increased from the start of the sampling period (Cochran's Q test, a= 87, b = 349, d.f. = 86, $\chi2 = 119.41$, $P < 0.01$) and decreased after the well was capped on 15 July 2010 (Cochran's Q test, a= 27, b = 349, d.f. = 26, $\chi2 = 45.6$, $P < 0.01$). Analysis of the surface oil percent occurrence (Fig 2B) showed that 50-100 % of the days surveyed, the oil was present within latitude 28° N to 30° N and longitude 87.5° W to 90° W. Lower percent occurrences radiated from the epicenter reaching as far south as 23° N. Surface oil was detected in 100 % of the northernmost whale shark sigthtings, in 32.8 % (52,594.7 km2) of the bluefin tuna spawning area and 38 % (53,348.51 km2) of the blue marlin spawning and larval area (Fig 3). No surface oil was detected in the swordfish spawning and larval areas using the satellite derived data.

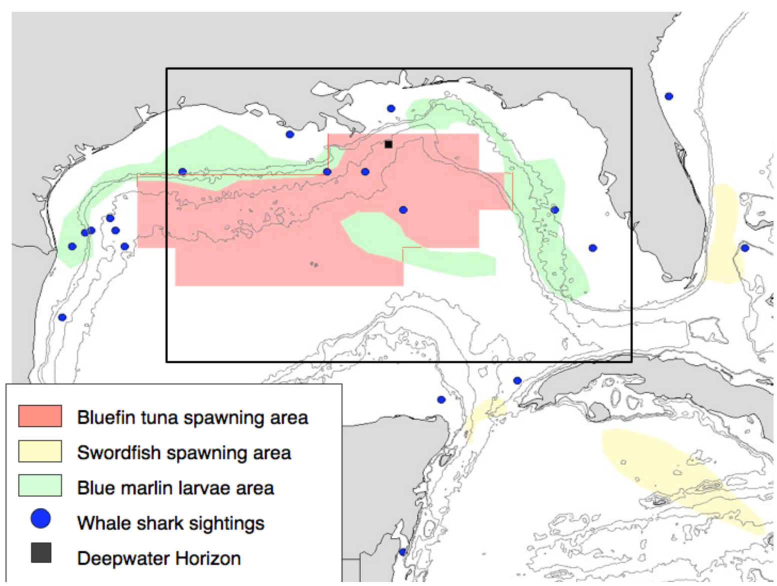

Figure 1. Map showing the location of whale shark sightings and spawning/larval areas of bluefin tuna, swordfish and blue marlin in the Gulf of Mexico. The black square indicates the area presented in Figure 2.

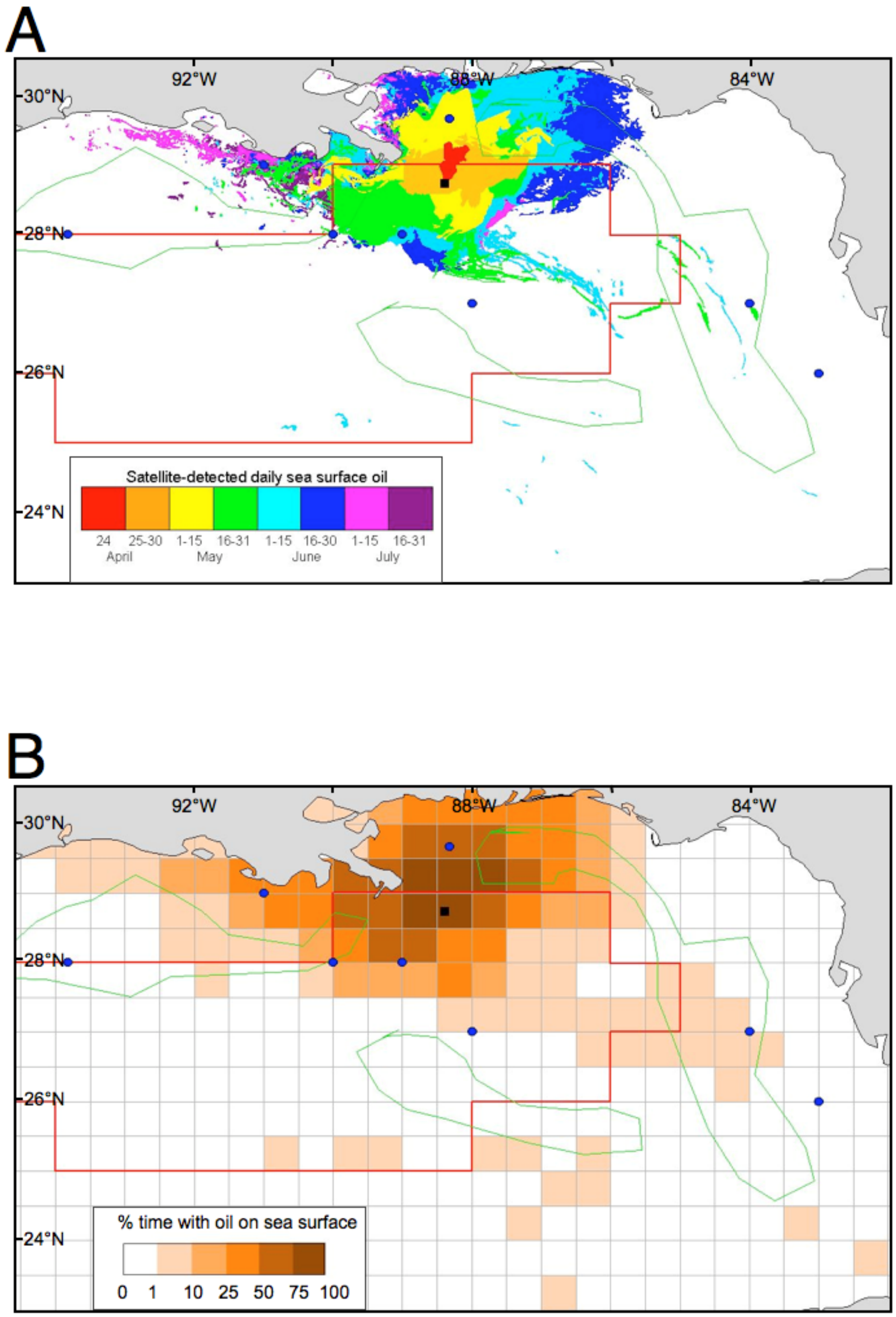

Figure 2. The extent of the Deepwater Horizon oil spill. (A) Daily multi-sensor satellite detected surface oil (August is not shown). (B) Percent time oil was present within a 0.5º x 0.5º geographical grid.

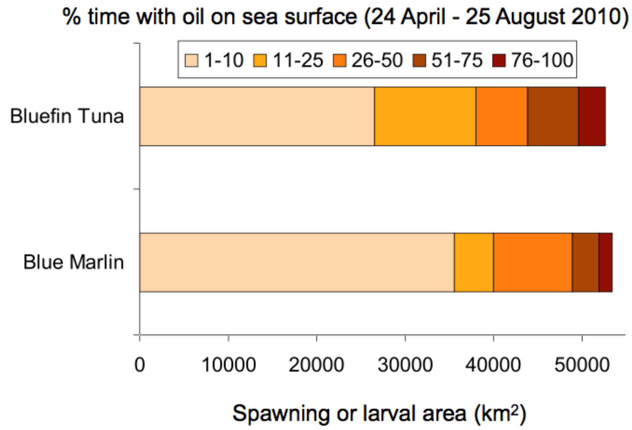

Figure 3. Percent time of oil presence and total surface covered in spawning areas of bluefin tuna and blue marlin

4. DISCUSSION

Oil presence on the sea surface and the timing of its occurrence likely impacted the developing eggs and larvae of bluefin tuna and blue marlin. Pelagic eggs and larvae concentrate at the sea surface microlayer, SML (upper 0-1 mm), the boundary between the atmosphere and the ocean [32] . The SML also concentrates petroleum, petroleum-derived hydrocarbons, tar, pesticides, polychlorinated biphenyls (PCBs), heavy metals and plastics [33] .Exposure to oil and oil dispersants causes acute toxicity, narcosis and eventual death in marine fish larvae [34] .

Sea surface oil might have affected whale sharks in a different way. Whale sharks do not have a plankton phase homologue to that of giant predatory nekton. The species is ovoviviparous, with females giving birth to live pups [13] . Pupping areas are unknown. Whale sharks have dense filtering screens in their modified gill rakers for feeding on dense aggregations of plankton and small nekton [11] . The oil spill and oil-dispersant complex could clog the filtering system of whale sharks, resulting in chronic starvation or even asphyxia.

Our satellite derived biogeographical analysis likely underestimates the extend of the oil spill and its ecological impacts on large pelagic fish. First, some satellite sensors only detect the ocean microlayer, the first millimeters of the sea surface, without detecting subsurface oil. Other sensors only detect the relatively thin well mixed euphotic zone near the water surface. Second, the use of dispersants on the sea surface may have disrupted the integrity of the oil sheen microlayer that is detected by satellite sensors. Third, although it has been suggested that most of the oil spill accumulated on the sea surface [35] based on the low density of Louisiana crude oil, the injection of dispersants directly at the submerged well head might have altered the density of the crude oil to a yet unknown amount, reducing its tendency to accumulate at the sea surface and thus remaining submerged in small oil-dispersant droplets.

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