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Did the *Deepwater Horizon* oil spill affect growth of Red Snapper in the Gulf of Mexico?

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ABSTRACT

The explosion of the *Deepwater Horizon* (*DWH*) oil platform in 2010 released more than 200 million gallons of crude oil into the northern Gulf of Mexico (GoM). Elevated levels of carcinogenic polycyclic aromatic hydrocarbons (PAHs) were abundant in the upper water column throughout the event. Previous research suggests that PAHs may have negatively affected fishes in the northern GoM. Our objective was to test whether crude oil contamination from the *DWH* oil spill was correlated with changes in growth rates in adult Red Snapper, *Lutjanus campechanus*. We fit von Bertalanffy growth curves and back-calculated length-at-age using data collected from 2011–2013 during long-line surveys in the northern GoM and on the West Florida Shelf. No significant variation in von Bertalanffy growth parameters existed among the catch years; a combined-years model gave L_∞, k, and t_0 values of 82.91, 0.20, and 0.43, respectively. No significant difference existed between pre- (back-calculated) and post-*DWH* growth curves. However, annual widths of the fourth, fifth, and sixth increments (the dominant cohorts in the population) declined significantly post-*DWH* (2010–2012) by 13%, 15%, and 22%, respectively, and were significantly smaller than the mean width of each respective increment in pre-spill years (2006–2009). While the *DWH* event was related temporally to growth declines in the dominant adult age groups, other environmental factors (winds, temperature, and river discharge) may also affect growth. Accordingly, meridional (V) and zonal (U) winds, sea level height anomalies (a proxy for water temperature variation), and Mississippi River discharge were compared to increment widths but none of the factors were strongly correlated with variation in age-specific growth increments (maximum Pearson's $r = 0.47$). Therefore, we are unable to reject the hypothesis that the *DWH* resulted in growth rate declines as opposed to climatic variation.

1. Introduction

Red Snapper, *Lutjanus campechanus,* is an economically important, relatively long-lived reef fish (Patterson et al., 2001a; Wilson and Nieland 2001) supporting both commercial and recreational fisheries in the Gulf of Mexico (GoM; Gold and Saillant, 2007). Although Red Snapper was both overfished (depleted) and experienced overfishing (Goodyear, 1988), conservation efforts under the Gulf of Mexico Fishery Management Council's Reef Fish Fishery Management Plan have resulted in an improved population status (Fischer, 2007; GMFMC, 1981; Strelcheck and Hood, 2007). Red Snapper enter the directed hook and line fishery between the ages of 2–4 years old (Szedlmayer and Shipp, 1994). They tend to associate with artificial reefs, reef pinnacles, rock ledges, and shelf-banks (Gallaway et al., 2009). In the western GoM, where natural reef structures are less common, they often associate with shallow water oil infrastructure (Gitschlag et al., 2003; Stanley, 1994), where they are potentially vulnerable to crude oil contamination. Notably, while Red Snapper exhibit high site fidelity in the eastern GoM (east of the Mississippi River), site fidelity to individual man-made structures is less than 1% per year in the western GoM (Patterson and Cowan, 2003).

During the 2010 *Deepwater Horizon* (*DWH*) oil spill, polycyclic aromatic hydrocarbons (PAHs), an abundant class of carcinogenic compounds in crude oil (Eisler, 1987; Short, 2003), were found at elevated levels in the upper 100 m of the water column (McNutt et al., 2012; Watson, 2014). Consequently, fishes in the northern GoM may have been contaminated by PAHs through ingestion of PAH-laden food or water (Mackay, 1991; McKim, 1994), direct contact via gills, or by transdermal exposure to contaminated sediment (Murawski et al., 2014). Overwhelming evidence from laboratory studies of larval and juvenile life-stages indicates that PAH contamination can result in developmental and morphological abnormalities, reduced survival, growth declines, mutagenic

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effects, disrupted cardiac function, reproductive impairment, and increased mortality (Carls et al., 1999; Heintz et al., 2000; Incardona et al., 2014, 2011; Marty et al., 1997; Reynaud and Deschaux, 2006; Roy et al., 1999). Additionally, several studies have demonstrated that metabolism, somatic growth, and otolith growth are also highly sensitive to crude oil contamination (Brown-Peterson et al., 2015; Kerambrun et al., 2012; Moles and Norcross, 1998; Morales-Nin et al., 2007). Results of a 1995 study showed that Chinook salmon exposed to PAHs in an urban estuary had significantly altered concentrations of regulatory growth hormones suggesting that PAH exposure, through habitat or diet, affects growth by interfering with metabolic pathways (Casillas et al., 1995; Meador et al., 2006).

Field studies after the *DWH* on adult fish in the GoM found increased concentrations of *DWH*-associated PAHs in the bile of demersal fishes, increased prevalence of external skin lesions in northern GoM fishes, and aberrant protein expression in gill tissue of juvenile and adult estuarine fish (Murawski et al., 2014; Snyder et al., 2015; Whitehead et al., 2012). However none, to date, have evaluated growth effects. Evaluating the effects of PAH contamination on somatic growth of adult fishes is especially important as growth declines might lead to increased susceptibility to predation, decreased ability to find food and resources, and may be associated with reproductive impairment (Kime, 1995; Morales-Nin, 2000). Growth effects and reproductive impairment of the English sole have been found to co-occur at threshold levels of PAH contamination (Johnson et al., 2008). Moreover, reduced reproductive output may have significant implications for overall population productivity as Heintz et al. (2000) and Geiger et al. (1996) observed with pink salmon populations exposed to PAHs from the *Exxon Valdez* oil spill.

Red Snapper are a fishery management priority in the Gulf of Mexico, and evaluating the effects of potential oil contamination on population-level growth of adults is important to inform rebuilding strategies (GMFMC, 2013). The objective of this study was to determine whether growth rates in Red Snapper changed during the three years post-*DWH* using annual growth increment data and fitted von Bertalanffy growth functions (VBGFs). Using sclerochronology techniques (Jones, 1983) and increment width analysis (Campana and Thorrold, 2001), we estimated age-specific, annual growth variation in Red Snapper among years 2006–2009 (pre-oil spill) and 2010–2012 (post-oil spill). This provided direct comparison of age-specific growth rates pre- and post- oil spill as well as back-calculated length data necessary to estimate a VBGF applicable to the length-at-age relationship in Red Snapper immediately before the event. Because exogenous environmental variables can also affect growth in fishes, we tested the relative influences of meridional (north-south) and zonal (east-west) winds in the Gulf of Mexico (Black et al., 2011), temperature, and the influence of river outflow (a proxy for nutrient enrichment), in comparison to the timing of the *DWH* oil spill on annual growth in Red Snapper.

2. Materials and methods

2.1. Field sampling procedures

Demersal long-line sampling was conducted during the summers of 2011–2013 along pre-defined transects on the shelf and shelf edge of the northern GoM and the west Florida shelf (WFS). Sampling in 2011 occurred from June-August aboard chartered commercial fishing vessels following methods described in Murawski et al. (2014). Sampling in 2012 consisted of two sampling cruises, one occurring from June-July aboard a commercial, long-line fishing vessel (F/V *Pisces*) and the other in August aboard the R/V *Weatherbird II.* Sampling in 2013 occurred in August also aboard R/V *Weatherbird II.* Sampling occurred within the distribution of the surface oil contamination from the *DWH* as well as west of the Mississippi River mouth. Red Snapper have the potential to move great distances (>100 km; Patterson et al., 2001b) so it is possible that Red Snapper collected west of the Mississippi River had originated from more oiled areas. Otoliths from the WFS were included in this analysis because there is evidence that hydrocarbons from the *DWH* were present on the west Florida continental shelf in June of 2010 (Weisberg et al., 2014).

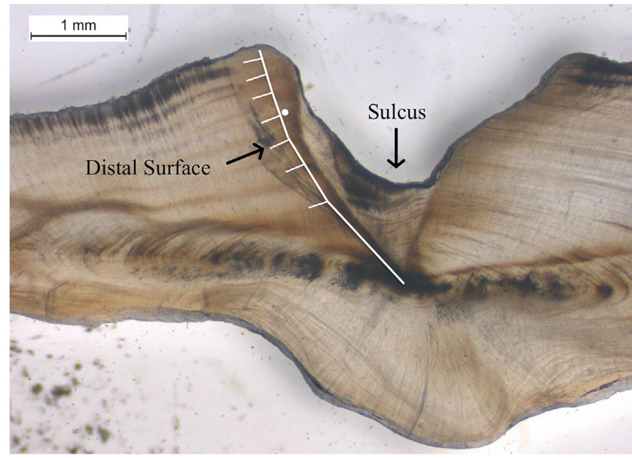

Fig. 1. Dorsal half of a thin-sectioned Gulf of Mexico Red Snapper sagittal otolith as viewed under transmitted light. The axis of measurement is shown along with increment width boundaries indicated by the horizontal white dash marks. The month of June 2010 is shown as a single white dot. Catch date was August 2013.

Morphometric data including fork length and standard length (nearest cm), as well as weights (g), were obtained from all captured samples using a Marel® motion-compensated scale or a hand scale for animals larger than the measurement range of the Marel (6 kg). Left and right sagittal otoliths were excised and cleaned of the endolymphatic fluid and placed in individual envelopes.

2.2. Otolith aging

A total of 822 Red Snapper sagittal otoliths were used for age analysis. Of these, 327 otoliths were collected across 84 sampling stations in 2011, 387 otoliths were collected across 34 sampling stations in 2012, and 108 otoliths were collected across 16 sampling stations in 2013. Left otoliths were thinly sectioned (0.4 mm) along the transverse plane using a Buehler Isomet® low speed saw equipped with four, 10 centimeter impregnated diamond cutting blades (VanderKooy and Guindon-Tisdel, 2009). Left otoliths were chosen to be consistent with aging methods followed by Florida Fish and Wildlife Research Institute's (FWRI) Age and Growth Lab (J. Carroll, pers comm.). Right otoliths were only used if the left otoliths were incomplete, unavailable, or deformed as alternating between left and right otoliths can potentially cause discrepancies in the ageing process (VanderKooy and Guindon-Tisdel, 2009). The three resulting cross sections were mounted on glass slides with Flo-Texx®, a permanent toluene-based mounting medium, and viewed under transmitted light at 10X magnification with a SZ61 Olympus® dissection microscope.

Age analyses were performed using the cross-sections containing the primordial core by counting annuli along the dorsal axis from the primordial core to the otolith margin (Fig. 1). If annuli were not clear along any part of the otolith cross-section, they were viewed under reflected light because some annuli appeared more distinct under different light conditions. The width of the marginal increment was defined following a four-level, ordinal coding sys-