Marine Environmental Research 120 (2016) 145–153

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Area use and movements of the white croaker (*Genyonemus lineatus*) in the Los Angeles and Long Beach Harbors

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ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form
24 June 2016
Accepted 5 August 2016
Available online 11 August 2016

Keywords:
Acoustic telemetry
White croaker
Fish movements
Habitat use

ABSTRACT

Understanding the movements of fish in relation to areas of contaminated and urbanized habitats is crucial to fisheries management and habitat remediation. In this study, the movements of white croaker in the Los Angeles and Long Beach Harbors were examined using both active and passive acoustic telemetry tracking. Daily area use for 20 fish actively tracked over multiple days averaged 94,720 ± 78,720 m^2 (±SD), with daily activity spaces shifting over periods of up to 1 month. Long-term dispersal (up to 7 months) of 93 passively tracked white croaker followed significantly non-random patterns, with 55 individuals (59.1%) making inter-regional Harbor movements. Inter-regional movements took an average of 4.7 ± 4.1 weeks to complete. Dispersal was significantly faster than what was predicted by an individual-based random walk model generated from short-term white croaker movements recorded during active tracking within the Harbor. Longer-term dispersal is likely the result of intentional movements between patches of favorable habitat rather than random daily shifts in activity spaces, indicating that white croaker deliberately utilize different areas within the Harbor and over the course of a year utilize much of the favorable Harbor habitat.

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1. Introduction

Understanding space use and movement patterns of marine fishes is critical for accurate stock assessment (Punt et al., 2000), fishery management (Forget et al., 2015; Villegas-Rios et al., 2015), and habitat remediation (Ahr et al., 2015; Freedman et al., 2015; Wolfe and Lowe, 2015). Historically, methods for assessing movements and behavior were limited by lack of appropriate technology and size constraints (Baggeroer, 1984; Kilfoyle and Baggeroer, 2000); however, advancements in technology have fostered dramatic improvements in both the collection and analysis of fish movement data, allowing researchers to develop a more intricate and complete understanding of the movements and behavior of marine fishes (Benhamou, 2011; Jacoby et al., 2012; Hussey et al., 2015; Walker et al., 2016). In addition, studies of fine-scale movements and habitat use have indicated that the extent of space use and dispersal probabilities can changes as individuals shift to using different habitats (Macpherson, 1998; McKinzie et al., 2014).

Understanding space use, movements and dispersal patterns of sentinel species is of particular importance, since these species are often used as a benchmark for similar species commonly harvested or impacted by environmental pollutants. The white croaker (*Genyonemus lineatus*) has historically been used as a sentinel species for contamination because of their high susceptibility and frequent exposure to environmental pollutants, and also due to their importance as a nearshore food fish for both humans and wildlife (LeBlanc and Bain, 1997; Phillips et al., 2001). The white croaker is a coastal sciaenid whose range extends from Baja California, Mexico in the south to Vancouver Island, Canada in the north, though it is rare north of the San Francisco Bay (central California, USA). Found commonly in bays and harbors, it is a benthic forager which feeds primarily on infaunal invertebrates (Ware, 1979; Love et al., 1984), which increases its exposure to sediment bound contaminants. The white croaker has historically been landed by recreational and subsistence anglers in southern California and is also commercially fished (Love et al., 1984).

Of particular concern is the white croaker population in the vicinity of the Palos Verdes Shelf (PV Shelf) and the adjacent Los Angeles and Long Beach Harbors (herein called "the Harbor") in southern California. White croaker in this region are known to contain high levels of dichlorodiphenyl trichloroethane (DDT) and polychlorinated biphenyls (PCBs) (Gossett et al., 1983; Puffer and

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http://dx.doi.org/10.1016/j.marenvres.2016.08.004
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Gossett, 1983; Malins et al., 1987), both of which are highly stable and lipophilic organochlorine compounds known to bioaccumulate as they are transferred up the food web from prey to predator (Blasius and Goodmanlowe, 2008). In addition to containing high levels of these contaminants, white croaker also exhibit extremely variable contaminant loads in their tissues; two fish sampled at the same time and location may contain contaminant loads differing by several orders of magnitude (Malins et al., 1987). Due to these high and variable levels of contaminants in white croaker from this region, the California Environmental Protection Agency (CalEPA) and the Office of Environmental Health Hazard Assessment (OEHHA) have issued a "no-consumption" advisory for white croaker caught in the region between Santa Monica Pier and Seal Beach Pier[1]. In order to examine the efficacy of these regulations and to address possible strategies for habitat remediation, it is necessary to understand the movements of the white croaker within this region.

In a previous large-scale acoustic telemetry study of white croaker movements on the Palos Verdes Shelf (a federally recognized highly contaminated site, "U.S. EPA Superfund Site") by Wolfe and Lowe (2015), individuals were found to use an average of 0.36 ± 0.28 km^2 ($\pm$SD) over 1–147 days. Site fidelity also varied considerably, with 47 (56.6%) of the white croaker tagged being detected on the PV Shelf for 7 or fewer cumulative days, 14 (16.9%) being detected for > 60 cumulative days, and only six (7.2%) being detected for > 100 cumulative days, suggesting the majority of the fish tagged were highly transient while a smaller portion exhibited a moderate to high degree of residence. Furthermore, this study suggested that there may be considerable connectivity between white croaker populations on the PV Shelf and within the Los Angeles and Long Beach Harbors. Forty white croaker tagged on the PV Shelf (48.1%) were detected by acoustic receivers at the Harbor entrances, and 34 white croaker (41.0%) were confirmed to have entered the Harbor, though without receiver coverage inside of the Harbor it was not possible to determine what areas of the Harbor they may be utilizing nor to what extent. Ahr et al. (2015) studied habitat selection by white croaker in the Harbor and found that individuals select for lower sediment grain size, higher total organic carbon, and higher polychaete density, and select against areas of high dredging activity.

Because of the highly variable levels of contaminants found in white croaker sampled within the Harbor and the geographical proximity to the PV Shelf, understanding the degree of exchange between white croaker populations in the Harbor and on the PV Shelf is essential for development of habitat remediation strategies within the Harbor. Since the habitat within the Harbor differs considerably from the habitat on the Palos Verdes Shelf (e.g., depth, currents, ship and dredging activity), it is expected that white croaker may exhibit substantial differences in space use and movement behaviors between the two sites. Since the Harbor is also known to have areas of highly contaminated sediments (Andersen et al., 2001; LA RWQCB and EPA Region IX, 2010), it is important to understand how white croaker utilize the available habitat within it. Furthermore, there are several areas within the Harbor where recreational and subsistence fishing activity is concentrated, and despite posted warnings, white croaker are often caught and consumed. The aims of this study were to (1) quantify daily area use and characterize long-term dispersal of white croaker within the Harbor, (2) examine variability in movements exhibited by white croaker among different regions within the Harbor and over diel periods, and (3) determine the degree to which white croaker tagged within the Harbor move to the PV Shelf. These aims were achieved using two types of acoustic telemetry techniques, one designed to track short-term, fine-scale movements, and the other designed to track long-term, broad-scale movements.

[1] http://oehha.ca.gov/fish/so_cal/pdf_zip/SoCalFactsheet61809.pdf.

2. Methods

2.1. Study site

This study was conducted within the Los Angeles and Long Beach Harbors (Fig. 1), which are located on the coast of southern Los Angeles County, California, United States of America (33°43′45″ N, 118°15′43″ W), encompassing the Port of Los Angeles and the Port of Long Beach, which together form one of the largest commercial shipping ports in the world. The Harbor is sheltered from wave energy by the Los Angeles Federal Breakwater and varies greatly in depth, with many shallow water areas adjacent to deeper shipping channels. The Harbor is also subjected to several freshwater inputs, such as the Los Angeles River and the Dominguez Channel, which vary in seasonal flow based on inland weather conditions and anthropogenic input (Dwight et al., 2002). Along with freshwater, these inputs bring variable amounts of runoff including sewage, silt, and multiple pollutants (Dwight et al., 2002; Stein and Ackerman, 2007).

The habitat within the Harbor also varies by region, with the inner and outer regions of the Harbor differing in several characteristics including depth, sediment grain size, sediment total organic carbon, dredging activity, and prey abundance (Ahr et al., 2015). Because several of these factors are known to affect movement patterns of white croaker (Ahr et al., 2015), the study site was divided between the inner and outer Harbor regions. The Port of Los Angeles and the Port of Long Beach are not only separate commercial entities but also are largely divided by physical features that may serve as a barrier to fish movement; thus the study site was further divided along the commercial boundary that separates them, yielding a total of four regions. For the purposes of this study, these regions will be the Los Angeles Outer Harbor (LAOH), the Los Angeles Inner Harbor (LAIH), the Long Beach Inner Harbor (LBIH), and the Long Beach Outer Harbor (LBOH) (Fig. 1).

2.2. Capture and tagging

Between March 2011 and April 2013, a total of 119 white croaker were tagged and tracked using active and passive acoustic tracking techniques. Fish were captured within the Harbor using baited hook and line and following capture, the overall condition of the fish was assessed. All fish kept for tagging were placed in a bath of chilled seawater and Tricaine Methanesulfonate (MS-222, 100 mg/L) until stage four anesthesia was reached, usually taking approximately 3–5 min (Brown et al., 2010). The fish was then weighed, measured, and surgically implanted with an acoustic transmitter (Vemco V9-6L; 21 mm $\times$ 9 mm, 2.9 g in air, power output 145 dB). A 2 cm incision was made on the ventral surface through which the transmitter was inserted beneath the peritoneum. All transmitters were coated in a mixture of paraffin and beeswax (2.3:1) to reduce probability of immunorejection by the fish (Lowe et al., 2003). The incision was then closed with two interrupted sutures (chromic gut or PDS II), and the fish was allowed to recover in a bath of fresh seawater. Once normal swimming behavior and opercular motion resumed, the fish was released at the site of capture. The total tagging effort was divided as evenly as possible between the four designated regions of the Harbor. Five individuals each were tagged for active tracking in each of the four regions (LAOH, LAIH, LBIH, and LBOH). Twenty-five individuals each were tagged for passive tracking in the LAOH, LAIH, and LBOH regions, while only 24 individuals were tagged for passive tracking in the LBIH region due to

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