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Ryan M. Freedman

California State University Long Beach, ryanfreedman2@gmail.com

Mario Espinoza

marioespinozamen@gmail.com

Kelley Voss

University of California Santa Cruz, kmvoss@ucsc.edu

Thomas Farrugia

University of Alaska Fairbanks, tjarrugia@alaska.edu

Christine R. Whitcraft

California State University Long Beach, Christine.Whitcraft@csulb.edu

See next page for additional authors

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Cover Page Footnote

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Authors

Ryan M. Freedman, Mario Espinoza, Kelley Voss, Thomas Farrugia, Christine R. Whitcraft, and Christopher Lowe

Does Estuary Restoration Design Alter the Fine Scale Movements of Gray Smoothhounds (*Mustelus californicus*) in Southern California?

Ryan Freedman,^{1,5*} Mario Espinoza,² Kelley M. Voss,³ Thomas Farrugia,⁴
Christine R. Whitcraft,¹ and Christopher G. Lowe¹

¹*Dept. of Biological Sciences, California State University Long Beach, 1250 Bellflower Blvd., CA 90840*

²*Centro de Investigación en Ciencias del Mar y Limnología & Escuela de Biología, Universidad de Costa Rica, 11501-2060 San José, Costa Rica*

³*University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA, 95064*

⁴*University of Alaska, Fairbanks, P.O. Box 757220, Fairbanks, AK 99775*

⁵*Channel Islands National Marine Sanctuary, University of California Santa Barbara, Ocean Science Education Building 514, MC 6155, Santa Barbara, CA 93106-6155*

Abstract.—Restored estuaries in southern California are limited in size and shape by fragmentation from human development, which can in turn restrict habitat use. Thus, it is important to assess how habitat design affects how fish use restored estuaries. Acoustic telemetry tracking from prior studies revealed that Gray Smoothhounds (*Mustelus californicus*) used primarily the eelgrass ecotone and warm interior waters in Bolsa Chica Full Tidal Basin (BCFTB), a 1.48 km² open-format marine dominated estuary. In this study, *M. californicus* utilized the Channel in Huntington Beach Wetlands Complex (HBWC), a smaller creek estuary. The Channel had more eelgrass than other available habitats but was also the coolest microhabitat, with temperatures below what *M. californicus* was found to select in BCFTB. Individuals may behaviorally thermoregulate by moving upstream, away from the HBWC Channel, during periods of incoming, cooler ocean water. *Mustelus californicus* translocated to different microhabitats within the HBWC selected the Channel habitat after the translocation regardless of where animals were released. Despite the large difference in available subtidal habitat between HBWC and BCFTB, no differences in patch size utilization distributions of *M. californicus* were observed. While individuals seem to shift between microhabitats based on temperature and eelgrass availability, the area size used by *M. californicus* appears to be the same within both sites despite the differences in overall size between sites. These results suggest that differences in microhabitat use may influence distribution patterns of *M. californicus* within each site, and therefore, shark abundance may vary with the restoration design (e.g. basin versus channel) and the size of the estuarine habitat. This information on habitat selection will be critical to planning future restorations on the Southern California coast.

Introduction

Restoration of lost or degraded estuarine habitat has become a strategy for recouping habitat loss and providing additional nursery habitat for fishes (Zedler and Langis 1991 Zedler 1996). Designs for restoration sites differ depending on the project's goals and are often limited by the space available for restoration. In turn, a number of environmental parameters that are

*Corresponding author: ryanfreedman2@gmail.com

influenced by restoration designs, including available subtidal habitat, tidal flow, vegetation cover, microhabitat (used here as a small scale environmental feature, such as an eelgrass bed or mudflat, within the larger estuary habitat) diversity, and average depth, vary greatly among sites, and can impact ecological function (Zedler 1996; Nicolas et al. 2010). Habitat size and availability has shown to shape the habitat use of fish in natural systems (Topping et al. 2005; Topping et al. 2006); thus, differences in microhabitat availability due to restoration design could also impact abundances of targeted commercial species (Fodrie and Mendoza 2006; Freedman et al. 2016).

Two restored estuary habitat designs commonly used in southern California are tidal creek estuaries and full tidal basins. Tidal creek estuaries have narrow channelized aquatic microhabitats with relatively large intertidal mudflats interwoven with vegetated marsh plains. Comparatively, full tidal basins have larger continuous tracts of sub-tidal marine microhabitats, typically unbroken by intertidal habitats. Differences in microhabitats like intertidal mudflats, eelgrass beds, and deep channels likely affect habitat use within larger habitat complexes (e.g. tidal creek estuaries and full tidal basins). Generally, full tidal basins are thought to maximize available fish habitat, but it is unknown how various restoration designs impact habitat use of fishes. For example, vegetation on intertidal mudflats has been demonstrated to increase fish growth rates (Irlandi and Crawford 1997), and many predatory fishes have been found to selectively feed along and in this type of microhabitat (Carlisle and Starr 2009; Espinoza et al. 2011), which may make creek estuaries better suited for some fishes. The size, shape, and diversity of available habitat spaces have been shown to affect habitat utilization and movements of marine and estuarine fish species (Topping et al. 2005; Topping et al. 2006), and may therefore alter movements of coastal elasmobranchs while they are utilizing estuaries (Freedman et al. 2016; Huepel and Simpfendorfer 2011; Carlisle and Starr 2009).

Many nearshore elasmobranch species from southern California are seasonal migrants, using primarily warmer and highly productive estuarine habitats relative to other cooler coastal habitats in the summer (Barry and Cailliet 1981; Knip et al. 2010; Espinoza et al. 2011; Farrugia et al. 2011; Jirik and Lowe 2012; Nosal et al. 2014). These summer conditions in the estuary can increase growth potential and survivorship, which leads juvenile elasmobranchs to seasonally select protective estuarine and bay habitat over exposed coastlines (Huepel and Hueter 2002; Espinoza et al. 2011; Farrugia et al. 2011; Huepel and Simpfendorfer 2011). Despite their important role as nursery habitats for a variety of elasmobranchs (Huepel et al. 2007; Espinoza et al. 2011; Farrugia et al. 2011; Freedman et al. 2015), coastal wetlands in California have experienced a 90% decrease since 1850, mostly due to urbanization of coastlines (Zedler and Langis 1991; Zedler 1996; Larson 2001).

Compounding on the lack of available estuary habitat in the region, quality is not consistent across all estuaries (Fodrie and Mendoza 2006; Freedman et al. 2016). Although capture methods are not comparable quantitatively due to effort and gear differences, qualitatively, Catch Per Unit Effort (CPUE) of Gray Smoothhound, *Mustelus californicus*, were much higher in a full tidal basin (approximately 0.013 sharks per m²; Espinoza et al. 2011) than in a tidal creek estuary (approximately 0.001 sharks per m²; C. Whitcraft unpub. data). Differences in shark abundance between sites could be driven by microhabitat diversity, prey availability, and/or available habitat space and size between the sites. Restoration designs have the potential to alter available microhabitat types and habitat coverage as in natural systems, which in turn may alter fishes' behavior and habitat selection in differently designed restored estuaries. Because maximizing habitat use of fishes in restored estuaries is a common goal of restoration, understanding how designs alter habitat use is critical for coastal managers (Zedler 1996).



Fig. 1. Study sites, with animal release locations/translocations in yellow and color-designated habitat divisions: (A) Bolsa Chica Full Tidal Basin, (B) study sites in relation to each other, (C) HBWC, and (D) the location of study sites along California.

To understand how habitat design could alter movements of a common coastal elasmobranch such as *M. californicus*, we collected movement data in a tidal creek estuary and compared it with sharks tracked by Espinoza et al. (2011) within a full tidal basin using a similar method. In addition, we performed a small-scale translocation experiment within the Huntington Beach Wetlands Complex (HBWC) to test the microhabitat site fidelity of *M. californicus*.

Materials and Methods

The Bolsa Chica Full Tidal Basin (BCFTB) and the Huntington Beach Wetlands Complex in Huntington Beach, CA are two restored estuaries in southern California situated approximately 10 km apart (Fig. 1). BCFTB is a 1.48 km² full tidal basin with a 4 m maximum depth that was opened to coastal waters in 2006. HBWC is a 0.77 km² tidal creek estuary composed of three distinct tidal creek marshes: a fully-draining creek system created in 1989 (Talbert Marsh), a 1.8 m deep fully-inundated creek opened to tidal flushing in 2009 (Brookhurst Marsh), and a small tidal basin with connecting marsh creeks that opened to tidal flushing in 2011 (Magnolia Marsh). All marshes are connected to each other and to the ocean via an armored flood control channel (hereafter “the Channel”). The HBWC marsh system and the BCFTB are composed primarily of mud and fine sediments, while the HBWC Channel is dominated by sand and shell hash. Eelgrass (*Zostera marina*) habitat, which can increase prey biomass (Kimmer et al. 1998; Leonard et al. 1998), was present but not evenly distributed in both the BCFTB and HBWC. In

the HBWC, eelgrass was most prominent in the Channel microhabitat, with only a few small patches of eelgrass in the marsh creeks at the time of the surveys and translocations. In BCFTB, eelgrass was mostly found in the deep center of the basin, closer to the ocean inlet, throughout the duration of the study.

Two Ruskin tide gauges (RBR Limited, Model TGR-2050P, 0-10 m working depth) were deployed for one-month intervals at six rotating locations in HBWC (Fig. 1) from 2009-2013 to record water level and temperature every 10 min. The rotation among stations meant that while two stations had a gauge for a one-month interval, the others were empty until the gauges were moved. Probes were placed within 10 cm of the bottom. “Front” stations were located at the interface between the Marshes and Channel, while stations interior of the Marsh were designated as “back.” Because Talbert fully drains at low tide, there was no Talbert “back” station. “Talbert Bridge” was placed under the Pacific Coast Highway bridge, approximately 300 m inland of the ocean inlet. Since *M. californicus* typically use estuaries during the summer months, daily mean summer temperature data (May to September) were calculated and compared among locations using Generalized Linear Mix Effect Model (GLMM), with “Date” as a random blocking factor.

To identify microhabitat use by *M. californicus*, the HBWC was divided into 6 major categories: Lower Channel (from Brookhurst Bridge to the ocean inlet), Middle Channel (From Brookhurst Bridge to Magnolia Bridge), Upper Channel (from Magnolia St. Bridge and beyond), Magnolia Marsh creek, Brookhurst Marsh creek, and Talbert Marsh creek (Fig. 1). These divisions were made based on expert judgment using estimated tidal flushing as assumed from distance from the mouth, and temperature (Freedman et al. 2016, Whitcraft unpub. data). BCFTB has no divisions, as the estuary was designed to maximize subtidal space once opened to tidal flushing in 2006. Ocean tidal height data were collected from the nearest NOAA tide station each minute (Los Angeles 9410660 NOS/CO-OPS) and used in analysis of movement data. Tidal height was used as a proxy for ocean temperature because temperature data was not available spatially throughout both estuaries, and tidal height would be available for both sites at their respective time periods. Data from monitoring programs in HBWC show a strong relationship between temperature and tidal height (Whitcraft unpub. data, Freedman et al. 2016).

Mustelus californicus were collected in both study sites using a 100 m long polyethylene long-line with 3 m long monofilament line (36 kg test) and a barbless circle hook (Mustad #4/0-5/0) baited with market squid. Once *M. californicus* were captured, total length was measured and individuals were held in coolers of fresh seawater until tagging. Individuals over 55 cm FL were inverted to induce tonic immobility before surgical implantation of coded acoustic transmitters. Shark sizes were comparable between BCFTB (average size = 68.47 cm TL, range = 60.2 cm – 101.4 cm TL) and HBWC (average size = 69.53 cm TL, range = 55.1 cm - 90 cm TL). Acoustic transmitters (VEMCO, V9-1L, 29 mm long, power output = 145–151 dB, battery life = 14 d, pulse interval = 2 s, frequency range = 63–84 kHz) were placed in the body cavity via a 1 cm incision along the ventral midline. The incision was closed with two sutures (Ethicon Chromic Gut 2–0) and then sharks were kept in seawater until they resumed normal swimming behavior. All animal handling and surgical procedures were approved by the CSULB IACUC (#254, 290).

In the BCFTB, coded acoustic transmitters (VEMCO V13-1L-R64k, 69 kHz, 40–80 s pulse interval, estimated battery life = 700 d) and 16 VR2W omni-directional underwater acoustic receivers in a VEMCO Position System array were used to assess the fine-scale movements of *M. californicus* (n = 22) in 2008 and 2009 (see Espinoza et al. 2011 for methods). The narrow width of the HBWC channels prevented an effective VPS system in that site, so we used an active acoustic tracking approach to collect similar fine-scale data.

Between June 2013 and October 2014, sharks were tracked in the HBWC following a translocation manipulation to test microhabitat associations determined by prior work in BCFTB. Sharks were captured in both the Channel ($n = 4$) and Magnolia Marsh Creek ($n = 4$) and translocated between Magnolia Marsh Creek and the Channel within HBWC (See Fig. 1 for translocation positions). Individuals were fitted with an acoustic transmitter (V9-1L, 29 mm long, power output = 145, battery life = 14 d, freq. pulse intervals = 2 s), translocated, and manually tracked continuously for 24 h from a vessel-based VR100 (VEMCO, Inc.) with a directional hydrophone immediately upon translocation. Three to four days after the initial 24 h track ended, *M. californicus* were located and tracked a second time for an additional continuous 24 h period. During these second tracks, sharks were assumed to have returned to their normal “pre-translocated” behavior.

Tracking geositions for sharks from both studies were loaded in R (R Development Core Team 2013) and randomly sub-sampled over 24 h periods to make the data comparable between methods. A Biased Random Bridge analysis from the ADEHabitatHR package (Calenge 2006) was used to generate 50% and 95% habitat space utilization distributions for fish location in each 24 h period. The core area was defined as the 50% extent of a shark spatial distribution in a 24 h period. Daily activity was defined as the 95% extent of the area used by a shark in a given day. To test whether space use size was different between sites, habitat utilization areas were compared between *M. californicus* in BCFTB and HBWC using a Mann-Whitney U-test. Because individuals in HBWC experienced translocation, we only used movements of fish from the second track that were assumed to represent normal behavior movements and unaffected by a translocation manipulation.

First-time passage analysis (FTP) was used to compare estimated foraging patch size between sites. In FTP, radii with the highest variances for the log of the passage time are assumed to be the estimated spatial scale at which an animal searches for resources, or the patch size. The radii of patch, as an estimate of patch use size, were compared between *M. californicus* tracked in BCFTB and those of individuals in HBWC using a Mann-Whitney U test.

Temperature was previously found to play a major role in *M. californicus* habitat selection (Espinoza et al. 2011). However, in the HBWC, tidal flushing can more drastically alter the water temperature and temperature fluctuations in comparison with BCFTB due to shallower depth and the narrow channelization of HBWC. General Additive Models (GAMs, R package ‘gam’) were used to test the effect of tide on habitat selection by sharks within HBWC and BCFTB. The distance of a shark to the estuary mouth was determined by the Euclidian distance to the ocean inlet, whereas tide was measured as tidal height. We used distance from ocean inlet because it is assumed that the amount of tidal flushing, and therefore the magnitude of influx of cooler water, in a habitat is inversely related to its distance from shore.

Results

There was no difference in the amount of space used by sharks tracked in HBWC and BCFTB using both 95% and 50% utilization distributions from Biased Random Bridges (Table 1, $W = 64$, $p = 0.84$ for 95% utilization and $W = 76$, $p = 0.35$ for 50% utilization). In addition, patch use size from FTP was not significantly different between the HBWC and BCFTB (Mann-Whitney U, $W = 36$, $df = 2$, $p = 0.098$).

All *M. californicus* translocated to Magnolia Marsh Creeks from the Channel utilized the marsh for the full 24 h period after translocation, but were all found in the Channel two to three days following the translocation. During the second 24 h track in the Channel, *M. californicus* were typically found to remain in the Channel for the whole 24 h track. *Mustelus californicus*

Table 1. The 95% and 50% utilization distributions are in the table below. The sizes of both utilization distributions are similar in both sites, regardless of available subtidal habitat area.

Location	95% Utilization distribution in km ² (median, range)	50% Utilization distribution in km ² (median, range)
BCFTB	1.12, 0.22 – 11.12	0.19, 0.15 - 0.19
Channel	1.29, 0.12 - 7.71	0.12, 0.03 - 1.00

captured in Magnolia Marsh Creeks that were translocated to the Channel mostly used the Channel in the first 24 h after translocation, as well as two to three days after translocation. During the assumed return to normal behavior in the HBWC, *M. californicus* spent longer periods of time near the Lower Channel during both night and day time periods compared to any other available microhabitat in HBWC ($X^2 = 1569.35$, $df = 4$, $p < 0.001$ for day; $X^2 = 456.05$, $df = 4$, $p < 0.001$ for night). During high tides, *M. californicus* moved farther back into the HBWC Channel and marsh creeks. As tidal height went up, water temperatures would fall, especially in the Channel near the ocean inlet. Tidal height was significantly related to distance to estuary mouth in HBWC (Fig. 2, GAM, $df = 3$, $Npar = 5.27$, $Pr(F) = 0.0013$, $p = 0.001$). A similar relationship between tide and distance from mouth was also found in BCFTB (GAM, $df = 3$, $Npar = 19.42$, $Pr(F) = 1.81 \times 10^{-12}$, $p < 0.001$). While other parameters like water depth did change with high tide, many sharks traveled up into HBWC’s armored channel or back into the deeper channels in HWBC where depth would not change prey access.

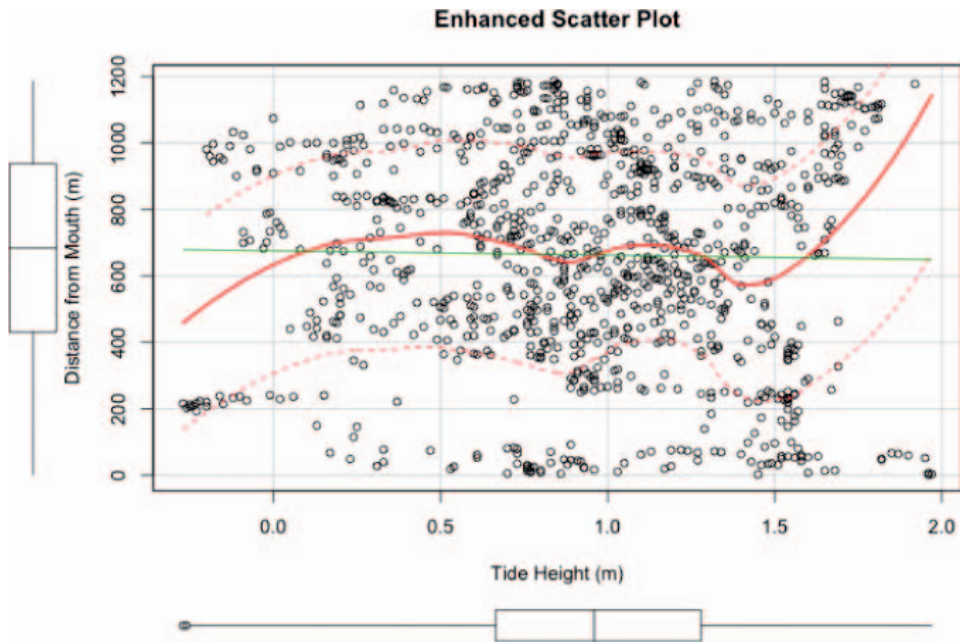


Fig. 2. Relationship between distance from the ocean inlet and tidal height. At the highest incoming tides, *M. californicus* retreat into the inner marshes and channel, likely using those habitats as thermal refuges. Dashed red lines show the confidence intervals, the red line shows the lowest line of best fit and the green line is the linear line of best fit. Box and whisker plots show the quartiles for each set of data.

Discussion

Despite major differences in the amount of available subtidal habitat, individual *Mustelus californicus* used approximately the same amount of area at both sites. Individuals tracked in the HBWC exhibited no difference in 95% and 50% utilization distributions or patch use size compared to those tracked in the BCFTB. They likely limited their movement to similar-sized areas in both sites to regulate energy expenditure (Werner and Hall 1985; Sinervo 1997). Even though HBWC is much narrower, the smaller size does not seem to restrict space use. Its narrow shape does not force *M. californicus* to travel far between microhabitat patches, potentially because eelgrass habitat is relatively continuous along the Channel. While sample sizes were different between BCFTB ($n = 22$) and HBWC ($n = 8$) which may reduce the ability to detect differences, daily activity spaces were less 0.10 km^2 for both 50% and 95% utilization distributions. While the temporal offset of 5 years between the two studies complicates interpretation, the microhabitat amounts and abiotic parameters were collected at the same time within an estuary, allowing us to compare how *M. californicus* select microhabitats.

In addition to using similar habitat sizes, *M. californicus* in both HBWC and BCFTB appear to select areas with eelgrass ecotone, where the edges of eelgrass beds meet the bare soft substratum. Espinoza et al. (2011) found that sharks disproportionately used eelgrass ecotone more, despite its low availability in BCFTB. Sharks in HBWC were located for significantly longer periods in the Channel near the ocean inlet, which was also the habitat with the most eelgrass ecotone available. Eelgrass ecotone is thought to be an important foraging microhabitat for *M. californicus*, as these habitats typically are associated with increased prey density (Kimmer et al. 1998; Leonard et al. 1998; Espinoza et al. 2011; Freedman et al. 2016). The spatial distribution of eelgrass is likely an important driver of habitat selection for this species across all restored estuaries, and could explain why *M. californicus* tend to exhibit high site fidelity to estuaries with abundant eelgrass ecotone.

Temperature appears to be another important driver of *M. californicus* microhabitat selection in both sites; however, the responses to temperature appear to differ by location. We used tidal height as a proxy for water temperature; as incoming ocean water drops the ambient temperatures in the marsh, microhabitats nearest to the ocean inlet are the most affected. Tidal height related significantly to the distance of *M. californicus* individuals from the estuary mouth in both habitats. Espinoza et al. (2011) found that *M. californicus* had core centers of activity in the warmer interior waters of BCFTB ($21\text{-}23^\circ\text{C}$), but made forays away from core centers to forage in mudflat microhabitats during cooler high tidal stages. However, distance from estuary mouth does not appear to be related to foraging in HBWC, as individuals swim away from the ocean inlet in the Channel to microhabitats assumed to have high prey density, where armoring excludes tidal mudflats or restored wetland habitat. These forays away from areas of high prey density only occur during cool water periods, which suggests that animals are behaviorally thermoregulating and not foraging. *Mustelus californicus* could also be avoiding larger predators with incoming tide; however, *M. californicus* are often top predators in estuarine systems, as estuaries have shorter trophic structures and larger predators typically do not enter these systems (Able et al. 2004; Allen et al. 2006). Sharks could also use the tidal current as an energy subsidy (i.e. simply moving with the current); however, individuals would typically make movements both against and with current flow during high tide periods to maintain their position in marshes.

In HBWC, *M. californicus* spent the majority of their time in the Channel, the coolest microhabitat within HBWC, likely because high prey densities increase foraging efficiency. Thus, individuals are presented with a trade-off between higher prey density in colder microhabitats and the warmer temperatures that lead to faster growth rates in the back of HBWC's marsh creeks

(Hight and Lowe 2007; Espinoza et al. 2011). When incoming high tides flood the Channel with colder water, the temperatures may fall below *M. californicus*' temperature thresholds, and individuals will likely move into the warmer creek microhabitats as a thermal refuge. Other species of coastal elasmobranchs have shown similar movements between different temperatures to behaviorally thermoregulate (Hight and Lowe 2007; Farrugia et al. 2011). HBWC marsh creeks typically had temperatures closer to what *M. californicus* in BCFTB were found to preferentially use (21°C; Espinoza et al. 2011), while the HBWC Channel has an average temperature of 19°C (Freedman et al. 2016; Whitcraft unpub. data). Even though *M. californicus* seek refuge during times with the lowest temperatures, individuals in HBWC appear to generally tolerate colder temperatures than those in BCFTB to remain in areas with highest abundance of eelgrass ecotone. This suggests that prey densities in the Channel are what drive *M. californicus* to select this habitat over the warmer temperatures available in marsh creeks. The sharks may behaviorally modulate their metabolic rates by moving between foraging grounds and warm water microhabitats. Similar behavioral trade-offs between thermal advantages and food availability have been documented for fishes in laboratory (Wildhaber and Crowder 1990; Krause et al. 1998); and in the field (Garner et al. 1998; Hight & Lowe 2007; Jirik & Lowe 2012).

With these preferred microhabitat conditions in mind, we translocated *M. californicus* to test their site fidelity to channel-type microhabitat. *Mustelus californicus* translocated away from the Channel always returned after translocation, whereas those translocated to the Channel remained there. Translocated individuals consistently returning to the HBWC Channel suggesting that this is a preferred microhabitat for the species. Despite being closer to the thermal range of the preferred microhabitats in BCFTB, HBWC marsh creeks must lack one or more microhabitat conditions that *M. californicus* consider when establishing core activity spaces. The marsh creeks' lack of eelgrass may not support sufficient prey biomass or diversity (Rozas and Minello 1998). However, as eelgrass grows into marsh creeks and the restored habitat and associated communities mature, *M. californicus* may begin to use that microhabitat. Restoration managers have seeded or transplanted eelgrass in newly resorted estuaries to help create high quality microhabitat in their managed sites. In HBWC, eelgrass rapidly expanded shortly after transplantation and it appears to be important to habitat use of target species (Freedman et al. 2016). Future work should try to understand the role of habitat-associated community maturation on fish habitat selection so managers can account for how restored sites may fishes' habitat utilization will shift over time.

Conclusions

To our knowledge, this is the first study to compare the movements of a single fish species in two unique restored estuary designs. Despite the temporal differences between the tracking studies, it is still likely that tagged individuals were responding to available microhabitats in the same ways. Because *M. californicus* have similar habitat utilization areas, habitat size may not be an important factor in driving habitat selection for estuarine fishes after a minimum available subtidal area is met. However, the availability of subtidal warm microhabitats with high prey densities may drive the differences in *M. californicus* abundance seen between BCFTB and HBWC. Espinoza et al. (2011) reported much higher CPUEs than those reported in HBWC (Whitcraft, unpub. data). Large open format tidal basins like BCFTB that probably dampen the temperature change with tidal flux may be better suited to *M. californicus* compared to tidal creek estuaries where animals may have to leave core habitat areas with incoming tides. Additionally, the increased amount of available eelgrass and subtidal foraging area may be an important driver of habitat selection for restoration planners to consider when designing new

sites. To design more effective restored estuaries, resource managers must identify target species and create habitats best suited to their needs, as different restoration designs will affect which species benefit most from the planned design. Moving forward, regional managers should focus on creating a diversity of restored estuary designs in the network of estuaries along southern California that should be most effective at supporting a range of juvenile predatory fishes.

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