Examining the spatial ecology of Giant Sea Bass (*Stereolepis gigas*) in a southern California kelp forest in relation to existing spatial management measures using acoustic telemetry.

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Spatial ecology of the Giant Sea Bass, *Stereolepis gigas*, in a kelp forest is southern California as determined by acoustic telemetry

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Abstract

The fishery history of the Giant Sea Bass, *Stereolepis gigas* (Telostei: Polyprionidae), is closely linked to its spatial ecology. Overharvest is directly associated with formation of spatially distinct spawning aggregations during summer, while its subsequent recovery is hypothesized to be the result of spatially explicit gear restrictions. Understanding its spatial ecology is a key part of efforts to assess contemporary threats, such as commercial harvest and incidental catch. In this study, we used acoustic telemetry to characterize its space use in the La Jolla kelp forest using an acoustic array in two marine protected areas (MPAs) and in heavily trafficked recreational fishing grounds. Five of the seven fish we tagged remained in the La Jolla array for at least six months. Two fish were resident across multiple years, with one fish consistently detected for four years and the other fish detected in the broader network of regional acoustic receivers moving north approximately 8 km to Del Mar. Most tagged fish had home ranges and core use areas indicating they spend considerable time outside MPAs, particularly in areas with high recreational fishing. During spawning season, we detected fish less frequently in the La Jolla array and showed higher movement rates. While the current MPA network in La Jolla by no means offers complete protection to this fish, it does appear to support long-term persistence of some individuals in a region of exceptionally high recreational fishing pressure.

Introduction

The Giant Sea Bass, *Stereolepis gigas* (Teleostei: Polyprionidae) is one of the largest (about 2 m in length) bony fish in kelp forests of the southern coasts of California and the Baja California Peninsula (Hawk & Allen, 2014). Giant Sea Bass is a high-level predator that was once plentiful in coastal rocky reef habitats south of Point Conception, California (Dayton et al., 1998; Domeier, 2001; Erauskin-Extramiana et al., 2017; Blincow et al., 2022). Historically, it

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was a sought-after fishery species, commercially and recreationally, which contributed to its near population extirpation from southern California waters (Domeier, 2001; Baldwin & Keiser, 2008; Allen, 2017). One contributing factor of its decline is formation of spawning aggregations (Allen, 2017; Erauskin-Extramiana et al., 2017). This reproductive strategy confers the fish to be an easy target once fishers identify an aggregation because many fish seasonally gather in the same geographic area (Erauskin-Extramiana et al., 2017). At the height of its commercial and recreational importance in the US, fishers heavily targeted its spawning aggregations during summer (Allen, 2017). The Red List of Threatened Species, of the International Union for Conservation of Nature (IUCN), recognized the Giant Sea Bass as *Critically Endangered* by (Cornish, 2004).

Recent reports indicate its population began to recover in the US (Pondella & Allen, 2008; Allen & Andrews, 2012; House, Clark & Allen, 2016). In response to population declines in the early to mid-1900s, the state of California implemented regulations in 1981 that essentially closed all US Giant Sea Bass fisheries (FGC §8380, Title 14, CCR, §28.10). Currently, the government in California has prohibited all recreational take of Giant Sea Bass and commercial take in the state is limited to one incidentally caught fish per trip for gill net and trammel net fisheries (Domeier, 2001; Baldwin & Keiser, 2008). Reports of population recovery attribute the return to species-specific state fishing regulations, as well as the banning of the nearshore gill net fishery in 1994, which many believe reduced incidental landings (Pondella & Allen, 2008; Allen & Andrews, 2012; House, Clark & Allen, 2016; Guerra et al., 2018).

While reports of its recovery in US are encouraging, the fish still experiences removals through the Mexican fishery, allowable commercial catch in the US, and incidental catch by US recreational fisheries. Recreational fishing of Giant Sea Bass in Mexico is limited to landing one

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fish per day (Ramírez-Valdez et al., 2021); however, there are currently no regulations on commercial Giant Sea Bass fisheries in the Mexican waters (Ramírez-Valdez et al., 2021). It is difficult to gather reliable data on the status of the Giant Sea Bass fishery in Mexico because much of the catch is artisanal, often reported based on coarse regional areas or in multi-specific groupings (Erauskin-Extramiana et al., 2017; Ramírez-Valdez et al., 2021). Fish production and consumptive value of Giant Sea Bass in Mexico is 19 times and 3.5 times greater than in the US, respectively (Ramírez-Valdez et al., 2021). If Giant Sea Bass travel between US and Mexican waters, the ongoing Mexican fisheries could be affecting its populations managed by US agencies.

Fishing in the US could also be mediating its continued recovery. From 2000 to 2020, commercial fishers in the US landed an average of 2.76 metric tons of Giant Sea Bass per year (calculated from Pacific Fisheries Information Network (PacFIN) Commercial Landed Catch Species Report; www.psmfc.org). While this is much less than the landings reported prior to implementation of fishing regulations in California, it is still a large number of fish when considering this species' history of overfishing. Recreationally, regulations limit Giant Sea Bass landings; however, a portion of individuals are caught incidentally and released. While recreational fishers are supposed to ensure the survival of incidentally caught Giant Sea Bass, it can be difficult to release fish of their size without any barotrauma, especially if captured from larger vessels with raised decks (Parker et al., 2006). If not handled properly, barotrauma can result in fatality of the fish (Parker et al., 2006; Jarvis & Lowe, 2008).

Decline and subsequent rebound of its populations in are linked to a complex history of spatial resource use and spatial management. From fishers, actively targeting spawning aggregations (Allen, 2017; Erauskin-Extramiana et al., 2017), to the apparent positive response

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of US Giant Sea Bass populations to spatially explicit regulations limiting fishing gear types (Pondella & Allen, 2008; House, Clark & Allen, 2016), the space appears to be an important consideration for conservation. Acquiring a better understanding of how the fish uses space can help determine the effectiveness of current management strategies and better understand the risks posed by contemporary fishing. For example, spatial management initiatives such as the California Marine Protected Area network, while not explicitly directed at conserving Giant Sea Bass, might provide benefits by protecting important habitat or providing refuge from fisheries.

The ongoing recovery of this fish has allowed researchers to consider its spatial ecology. As part of a larger regional multi-species, mark-recapture study, Hanan and Curry (2012) recaptured two out of 14 tagged individuals, 245 and 1240 days post-tagging, one within 1 to 5 km and the other 5 to 20 km from the tagging locations. While only constituting data on two fish, Hanan and Curry (2012) found Giant Sea Bass showed some level of site fidelity. This finding is supported by more recent research tracking this fish on Santa Barbara Island, California where 12 acoustically tagged individuals were queried across regional acoustic telemetry databases, they were detected solely on receivers stationed around the island, sometimes leaving the array but returning during spawning season (Spector et al., 2022). Clevenstine and Lowe (2021) used external acoustic tagging to investigate its spawning aggregation site fidelity on Santa Catalina Island, California, and found tagged individuals resided at suspected spawning aggregation sites during the summer spawning season. About a third of the individuals tagged returned to the same spawning aggregation site in the subsequent year (Clevenstine & Lowe, 2021). However, they found that while some individuals remained on the island year-round, others traveled to other islands in the Channel Islands or the mainland coast of California (Burns et al., 2020; Clevenstine & Lowe, 2021). These excursions are a departure from the previous notion of Giant

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Sea Bass having limited home ranges (Cornish, 2004), and suggest that they can travel long distances.

In our study, we used acoustic tagging to characterize the spatial ecology of the Giant Sea Bass over a longer time scale than previously studied (> three years) focusing on their movement in the La Jolla kelp forest, which is one of the best areas for divers to observe adult and young-of-the-year Giant Sea Bass (Allen, Benseman & Couffer, 2019). The kelp forest overlaps with two separate no-take marine protected areas (MPAs) as well as one of the most intensely recreationally fished areas in the San Diego region (Parnell et al., 2010). Our objectives were to (1) determine whether tagged fish are resident to La Jolla, (2) characterize the seasonality of space use, and (3) investigate how the movement of fish relates to its spatial management and contemporary fishery-related threats.

Materials & Methods

Study Area

La Jolla kelp forest (~8.25 km^2) is the second largest kelp forest in California (Parnell et al., 2005, 2006), and its environment is marked by hard bottom, with channels of sand and cobble interspersed throughout. On the northern edge, La Jolla kelp forest is bounded by a submerged canyon with a sandy shelf, and on the western and southern edges is bounded by sandy bottom habitats (Parnell et al., 2006). In this area, there are two no-take marine reserves: Matlahuayl State Marine Reserve and South La Jolla State Marine Reserve. In addition, there are two conservation areas, San Diego-Scripps Coastal Marine Conservation Area and South La Jolla State Marine Conservation Area. These areas allow limited recreational and commercial fishing (Figure 1). The region between these reserves is an important fishing ground for commercial sea urchin and spiny lobster, for recreational anglers from private vessels with the San Diego

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Commercial Passenger Fishing Vessel fleet, which charters vessels with groups fishing (usually ~30-50 passengers) (Parnell et al., 2010). While our analysis focuses on the La Jolla region, we also shared our tag information with the network of researchers engaged in monitoring for acoustic tags in the broader region of southern California and Baja California, Mexico and report those results as well (Figure 1).

Acoustic Tagging

From August 2018 to October 2019, we tagged seven Giant Sea Bass in the La Jolla Kelp Forest (Figure 1) using Vemco V16-4H acoustic tags (randomized 30 to 120 s reporting interval and 1400 d battery life). Tags provide spatial and temporal presence information on individual fish. We monitored all tags from their date of release (Table 1) to 21 July 2022. We intended to have a larger fish sample size, but individuals were limited due to their rarity, and our decision to capture fish at <20m to reduce the negative impacts of barotrauma. Ultimately, we only captured 7 fish during 67 sampling days.

With the exception of one individual, we captured fish using hand lines with 9/0 or 10/0 circle hooks with Pacific Chub Mackerel (*Scomber japonicus*) as bait. We chummed the water using a combination of Shakin Bait (an Anchovy (*Engraulis mordax*) and Sardine (*Sardinops sagax*) based chum oil) and a frozen mixture of roughly chopped and/or blended Pacific Chub Mackerel, Pacific Jack Mackerel (*Trachurus symmetricus*), and/or Pacific Sardines. We captured fish at depths < 20 m and brought them to the surface at a moderate speed to minimize barotrauma while not exhausting the fish. To avoid barotrauma in fish, we reduced the time each fish spent at surface. The only fish not captured with hand lines was caught with gillnet during Hubbs Sea World Research Institute's (HSWRI) White Seabass (*Atractoscion nobilis*) survey by

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the California Department of Fish and Wildlife (CDFW; Permit: P1770011) and approved by the HSWRI Institutional Animal Care and Use Committee (IACUC) (Protocol APF #2016-09). After catch in the gill net, we assessed if was in good condition and transferred it to a holding tank before tagging.

We positioned captured fish with hand lines at surface in vinyl sling mounted on the side of our vessel to restrict movement while in the water. For fish captured during the HSWRI survey (Tag 1), we kept it in a large oxygenated holding tank before and after tagging. While we preferred to keep fish submerged during tagging, we could not hold it steady at the surface in the holding tank or alongside the boat due to fish small size. We removed fish from the holding tank and placed it in a vinyl cradle on the deck of the vessel during surgical tagging. We covered the fish in a wet towel and used a seawater hose to maintain water flow over its gills for the short period spent outside of the holding tank (< 2 mins). We implanted acoustic tags in fish's gut cavity via incision off-center of the midline and posterior to the pelvic girdle following (Lowerre-Barbieri et al, (2014) and Blincow et al. (2020). We used sterile antibiotic infused, dissolvable cutting sutures (PDS II violet 27" CP-1) to close the incision. We measured fish for total length (cm), standard length (cm), and head length (cm), and took a small fin clip (1-2 cm) from the anal fin for later genetic and stable isotope analyses as part of separate studies that are not reported here. We secured an external Floy tag (BFIM-96) at the base of the dorsal fin as a visual identifier of surgically tagged fish. Later, we positioned the fish to recover in a dorsal side-up position alongside the vessel (or within the holding tank for the HSWRI fish) before release. If fish had swim bladders inflated, we released them at depth using a descending device (SeaQualizer). CDFW permitted our activities (Permit #S-192900002-19290-001), and the University of California, San Diego IACUC approved our tagging protocols (Protocol #S12116).

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Acoustic Receiver Arrays

We used a stationary receiver array, comprised 29 Vemco VR2W single channel passive autonomous data-loggers, deployed in the La Jolla kelp forest to track tagged fish movements. Each VR2W receiver logged date, time, and individual ID. Depth range of receivers was 11.27 to 24.69 m (19.81 m ± 3.04; Mean ± SD). In addition to the 29 receivers moored in the La Jolla Kelp Forest, we had two receivers moored to the north at Torrey Pines (VR2W) and Del Mar (VR2C) (Figure 1). The Torrey Pines receiver was deployed adjacent to a ~1 acre artificial reef habitat constructed by CDFW in 1975 of quarry rock and concrete dock floats at a depth of ~13m as part of their Nearshore Sportfish Habitat Enhancement Program (Lewis and McKee 1989). The Del Mar receiver was placed at 13 m depth on a multidisciplinary surface mooring deployed on the shelf break at 100 m just offshore from rocky reef, kelp forest habitat along the coast (Send and Nam 2012; Navarro et al. 2018). We verified detections by other regional acoustic receiver arrays ranging from Isla de Cedros, Baja California, Mexico to Santa Barbara, California, USA (Figure 1). These arrays were active throughout the study period.

We performed a detection range analysis on six of the 29 receivers in the La Jolla array (Blincow et al., 2020) (Figure 1). The six receivers chosen spanned a representative depth gradient for the array, ranging from 15.54 to 24.38 m (20.12 m ± 3.04). We performed drifts starting at the coordinates of a given receiver mooring while towing a Vemco-coded transmitter tag (~ 1 to 2 m depth). We simultaneously recorded all acoustic tag transmissions (pings) during the drift using a Vemco VR100 mobile receiver unit deployed off the vessel in close proximity to the tag and compared detections with those recorded on the moored VR2W receivers. Using the coordinates for each ping detection on the VR100, we calculated the distance of each ping from

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the VR2W receiver mooring. We compiled data for all receivers that detected the towed tag and analyzed them using a generalized linear mixed-effects model (glmm) with a logit link and a random slope effect of receiver to determine the detection probability of individual pings (binary response) and distance of the tag from the receiver (continuous covariate). With the exception of our movement rate analysis (described below), we assumed the detection range of all of our receivers to be the distance at which our model estimated we could detect tag pings with a 50% probability. We note that detection ranges can vary depending on environmental factors, such as diurnal noise patterns and current variability (Mathies et al., 2014; Huveneers et al., 2015); however, we chose to make the simplifying assumption of a relatively constant detection range over time for all our receivers.

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Data Analysis

Prior to analysis, we filtered data to remove detections on the same day as when we tagged the fish to avoid any behavior associated with recovery from tagging influencing our results (Farmer & Ault, 2011). To avoid spurious detections from code collisions, we removed any detections from the same tag on a single receiver across time intervals that were less than the minimum time it takes the tag to transmit a signal. We performed all analyses using R statistical software, version 4.1.1 (R Core Team, 2019). We implemented our models using a maximum likelihood approach with the 'lme4' package (Bates et al., 2015b) and estimated associated p values using the 'lmerTest' package, which uses the Satterthwaite approximation of degrees of freedom method (Kuznetsova, Brockhoff & Christensen, 2017). This method estimates the denominator degrees of freedom for F statistics or degrees of freedom for *t* statistics, depending on the model structure, to evaluate significance and produces more conservative p-value

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estimates with lower levels of Type 1 error rates when compared to other mixed-effect model p-value estimation methods, such as likelihood ratio tests (Luke, 2017).

We calculated the number of days each fish was at liberty by determining the number of days between the day after the release of fish and the end of the study (21 July 2022). We also calculated the number of days each fish was at liberty within the La Jolla array by determining the number of days between the first and last detection of the tag on La Jolla array receivers after data filtering. We calculated an array residency index, or the residency of each tagged fish within the La Jolla array, by dividing the number of days each fish detected within the array by the number of days at liberty within the array. We calculated residency index, or residency of each fish within the La Jolla array across the study, by dividing the number of days each fish was detected within the array by the total number of days at liberty across the study. One of our fish left the La Jolla array and was detected consistently at the Del Mar receiver for a period of months.

We summarized fish movements in La Jolla by calculating their activity spaces within the La Jolla array. First, we generated position estimates by calculating centers of activity (COAs), which are weighted average positions of each fish based on the number of detections present on each receiver across 30 min intervals (Simpfendorfer, Heupel & Hueter, 2002). We then used these COAs to calculate the 50 and 95% kernel utilization distributions (KUD) of each fish across spawning and non-spawning seasons in the La Jolla array using the 'adehabitatHR' package in R (Calenge 2006). We used the ad hoc method for determining the smoothing parameter for KUD calculations, which assumes the distribution is bivariate normal (Calenge 2006). We limited our KUD analyses to the La Jolla array due to our interest in investigating interactions between Giant Sea Bass resident to La Jolla with local spatial management. There

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was only one fish detected outside of the La Jolla array and it appeared to migrate from La Jolla to Del Mar receiver (fish spent nine months in La Jolla and traveled to Del Mar and never returned; Figure 2). If this fish had made regular excursions to Del Mar and back to La Jolla, we would have considered the full range of its movements in the KUD analysis. The 50% KUD is representative of the core use area of the fish, while the 95% KUD is representative of the home range of each fish within the La Jolla array. There was one instance in which the 95% KUD overlapped with land along the coast. In this case, we removed the land portion of the KUD. We used the resulting KUD estimates to calculate the area of overlap between La Jolla MPAs with core use areas and home ranges.

To investigate seasonal and diel differences in the activity of our fish in La Jolla, we calculated hourly movement rates, which we defined as the distance moved during one-hour intervals. We did this by estimating COAs as described above across 10-minute intervals. Since we are unable to measure movement rates when the fish are outside of the detection range of the array, we filtered for intervals consisting of six consecutive COAs. We summed the distance between COAs in the resulting hour intervals to generate hourly movement rates when fish were occupying the La Jolla array. The movement rate data were zero-inflated, so we analyzed them using two separate models. First, we converted the movement rates to a binary variable, with 0 being a zero movement rate and 1 being a non-zero movement rate. Using this information, we constructed a binomial glmm (logit link function) to calculate the probability of a positive movement rate given the explanatory variables of diel period (dawn, day, dusk, or night), lunar phase (waxing, full, waning, new), and month. Second, we filtered our data for only non-zero movement rates and used a linear mixed-effects model to determine the effect of the explanatory variables diel period, lunar phase, and month. In accordance with suggested best practices for

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mixed effects modeling that recommend fitting the most complex mixed effects structure allowed by your data (Bates et al., 2015a; Harrison et al., 2018), we first attempted to fit models with both random slope and intercept terms; however, we were unable to reach model convergence. As a result, both of our models included only a random intercept effect of individual, the most complex model structure allowed by our data. We calculated the associated pseudo-R^2 values (marginal and conditional) using the delta method via the 'MuMIn' package (Nakagawa, Johnson & Schielzeth, 2017; Barton, 2022).

Results

We tagged seven fish (126.14 cm TL ± 30.25; Mean ± SD, range 77 cm to 163 cm TL) (Table 1). Based on their sizes and available age-growth relationships for the species (Hawk and Allen 2014), all the fish we tagged were likely sexually mature; however, our smallest individual fell within the range of uncertainty regarding age at maturity for the species (Tag 1 estimated age: 9 years, species reported age at maturity: 7 to 13 years; Hawk and Allen 2014). The number of days each tagged fish was at liberty throughout the study ranged from 1000 to 1437 (1202.43 ± 169.68) (Table 1).

The number of days at liberty for each fish within the La Jolla array ranged from 0 to 1426 (435.29 ± 524.09) and the number of receivers each fish was detected at ranged from 0 to 25 (13.86 ± 9.99) (Table 1). The La Jolla array residency index ranged from 0 to 1 (0.64 ± 0.38) while study residency index ranged from 0 to 0.571 (0.20 ± 0.20) (Table 1). Two fish (Tag Numbers 5 and 6) left the La Jolla array within two days of being tagged and did not return (Table 1). We removed these fish from subsequent analyses.

VR2W receivers in the La Jolla array detected on average tag pings with a 50% probability at 218.3 m (Figure 3). Receivers in sandy areas on the edges of the kelp forest had a larger

Eliminado: Based on our range analysis, we found that the VR2W receivers in the La Jolla array on average detect tag pings with a 50% probability at 218.3 m (Figure 3). When investigating receiver effects, we found that receivers that were in sandy areas on the edges of the kelp forest,forest tended to have a larger detection radius than receivers within the kelp forest. The largest distance of 50% detection probability calculated for an individual receiver was 283 m and was associated with a receiver moored at 24.38 m depth in the open sandy area between the edge of the submarine canyon and kelp forest on the northwest edge of the array. The lowest was 180 m and was associated with a receiver moored at 17.07 m depth in the kelp. The presence of kelp (or lack thereof) appeared to outweigh other factors that could potentially influence detection ranges, including presence of currents or depth.¶

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detection radius than receivers within the kelp forest. The largest distance of 50% detection probability calculated for an individual receiver was 283 m and was associated with a receiver moored at 24.38 m depth in the open sandy area between the edge of the submarine canyon and kelp forest on the northwest edge of the array. The lowest was 180 m and was associated with a receiver moored at 17.07 m depth in the kelp. The presence of kelp (or lack thereof) appeared to outweigh other factors that could potentially influence detection ranges, including presence of currents or depth.

Two fish (Tag Numbers 1 and 3) remained within the La Jolla array consistently throughout their time at liberty, a period of 2.37 and 3.92 years respectively. Three fish (Tag Numbers 2, 4, and 7) left the array bounds after approximately nine, eight, and six months, respectively (Figure 4a). One of these three fish traveled to the Del Mar receiver (movement rate: ~0.45 m/s) and remained there consistently for approximately five months before leaving and returning again to Del Mar (Figure 2). The consistency of the detections was such that we initially considered that this was an incidence of mortality or tag expulsion near the receiver. After continued monitoring the variability in detections indicating departure from and return to the area led us to believe the fish was alive and just consistently occupying the area near the Del Mar receiver. Our fish were not detected at any other receivers from the broader southern California and Baja California, Mexico regional arrays.

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We found that KUDs varied across fish, but that the area between the two MPAs was the most highly used area overall (Figure 4). During non-spawning season, the 95% KUDs for tagged fish had, on average, 32% overlap with local MPAs, while during spawning season this overlap grew slightly to 36%, with a larger proportion attributed to space use within the Matlahuayl State Marine Reserve (Figure 4). The core use areas (50% KUD) of all fish averaged

9% overlap with MPAs in non-spawning season and grew to 20% overlap during spawning season; this latter finding was predominantly driven by the fish with Tag Number 7 (Figure 4).

Based on our movement rate analysis, fish had a lower probability of non-zero movement rates during summer months, particularly June through September (Table 2, Figure 5b); however, given a positive movement rate, the predicted movement rates were highest in the months of May through July (Table 3, Figure 5e). These periods coincide with the recorded spawning months of Giant Sea Bass (May through October). We recorded fewer detections per hour as well (Figure 5a) and the probability of non-zero movement rates was highest during the day, though all diel periods had predicted probabilities of non-zero movement rates inclusive of confidence intervals that were greater than 35% (Table 2, Figure 5d). Given non-zero movement rates, the predicted movement rate was lowest during nighttime and higher across all other diel periods (Table 3, Figure 5f). The predicted movement rate did not differ between dawn, day, or dusk (Table 3, Figure 5f). We did not find a relationship between lunar phase with either the probability or rate of movement (Table 2-3). Both movement models had relatively low conditional R^2 values (binary movement: 0.141, non-zero movement: 0.051), suggesting that there is a large amount of variability in the data that is unaccounted for by the explanatory variables included in the models (Table 2-3).

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Discussion

Giant Sea Bass are an ecologically and culturally important species in southern California and Baja California, Mexico. Understanding their spatial ecology is a critical step in supporting their ongoing recovery. In particular, the lack of knowledge about the residency of individuals to certain areas, the seasonality of their movements, and their interaction with existing spatial management measures hinders our ability to understand the extent to which contemporary fishing activities are impacting populations within the lattice of spatial management.

We found Giant Sea Bass to be a long-term resident of the La Jolla kelp forest and showed the highest predicted movement rates during summer spawning months. We detected some fish more outside of the La Jolla array during this same time, which suggests a local spawning aggregation site exists outside the bounds of our array. While our study only recorded data based on five fish, it still offers valuable insights into the spatial ecology of this fish considering the time length we monitored individuals and the paucity of related scientific literature.

When fish were present in the La Jolla array, we detected them more often outside of the boundaries of local MPAs, in both spawning and non-spawning season, particularly in highly trafficked recreational fishing areas. While this could be an artifact of where we captured individuals (outside MPAs), it still indicates that Giant Sea Bass in La Jolla are at risk of the potential negative impacts of incidental recreational catch. This high site fidelity indicates that MPAs could be effective management tools for this species if positioned appropriately.

Our results suggest that fish in the La Jolla array occupied relatively small, well-defined areas. Fish did not frequently move enough across hour time periods to be detected on multiple receivers (as evidenced by the zero-inflation of our movement rate data). Even the fish that traveled to Del Mar, while being detected on multiple receivers spanning the full extent of the array during it's time in La Jolla, showed remarkably consistent detections (averaging over 60 detections per hour) at the Del Mar receiver for a period of five months. Furthermore, most of our tagged fish had the greatest detection rates on receivers near where they were captured. We conducted our tagging efforts outside of MPAs, thus most of our fish tended to be detected in areas outside of spatial protection. Somewhat counterintuitively, this trend of high site fidelity

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Eliminado: While our study only gathered data on 5 individuals, it still offers valuable insight into the spatial ecology of this species, especially considering the length of time individuals were monitored and the paucity of published literature on this species in general. In this study, we

Eliminado: We found that some Giant Sea Bass appear to be long term residents of the La Jolla kelp forest. This high site fidelity indicates that MPAs could be effective management tools for this species if positioned appropriately., though there was variability in the residency among individuals. We also found that fFish had the highest predicted movement rates during summer spawning months and tended to spend more timebe detected more outside of the La Jolla array during this same time period, suggesting that a local spawning aggregation site exists outside the bounds of our array.. When fish were present in the La Jolla array, they tended to spend most of their time be detected more often outside of the boundaries of local MPAs, in both spawning and non-spawning season, particularly in highly trafficked recreational fishing areas. While this could be an artifact of where we captured individuals (outside MPAs), it still indicates that Giant Sea Bass in La Jolla are at risk of the potential negative impacts of incidental recreational catch.¶

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across smaller scales suggests that spatial management such as MPAs could be an effective tool for sheltering some individuals from fishing activity if their range is within the MPA; though more study is warranted to confirm this notion given our small sample size.

Our finding of high site fidelity for most individuals agrees with previous studies on Giant Sea Bass and similar species (Eklund & Schull, 2001; Hanan & Curry, 2012; Clua et al., 2015; Spector et al., 2022). Goliath Grouper (*Epinephelus itajara*) and Giant Grouper (*Epinephelus lanceolatus*) also have shown site fidelity across years, in some cases with individuals being resighted in the same location up to four years after the initial record (Eklund & Schull, 2001; Giglio, Adelir-Alves & Bertoncini, 2014; Clua et al., 2015). In La Jolla, it is possible the large spatial extent of contiguous kelp forest habitat and the fish's ability to support an ample prey resource contribute to high site fidelity observed (Parnell et al., 2006; Udy et al., 2019). If site fidelity is driven by the availability of resources, it is possible it will lower as Giant Sea Bass populations continue to recover and intra-species competition for resources becomes more influential (Atwell, O'Neal & Ketterson, 2011; Dmitrieva et al., 2016).

We did not observe long-distance movements in our study, but it is possible these events occurred and went undetected given the sparse regional receiver coverage. Most fish disappeared from the La Jolla array prior to the end of tag battery life. This could be the result of either mortality outside of the receiver array or relocation to other areas. For the latter scenario, with the exception of the fish that went to Del Mar, we cannot say how far they could have traveled. Though we detected no fish on any of the regional receivers along the southern California coast, in the Channel Islands, or Baja California, Mexico, there is a chance fish that left the La Jolla array made long-distance excursions/relocations undetected. Previous studies have documented such long-distance movements in tagged fish (both generally, and in the case of Giant Sea Bass).

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For instance, one of the species' congeners in the Polyprionidae family, the Hāpuku (*Polyprionidae oxygeneios*), showed variable movement patterns during a multi-year mark-recapture study with some being recaptured close to 1400 km from their tagging location and others being recaptured at the same location as tagging (Beentjes & Francis, 1999). In another study, Giant Sea Bass tagged on Santa Catalina Island, California traveled long distances from the island following spawning season, traversing the San Pedro Channel to the mainland, or traveling to other islands in the area (Burns et al., 2020; Clevenstine & Lowe, 2021). Given these results from other studies, it is not out of the realm of possibility for individuals to travel from the San Diego region to areas where they are susceptible to either targeted or incidental commercial catch, such as Baja California, Mexico or outside of the 3-mile nearshore gill and trammel net ban. While we can't rule out such movements in our tagged fish, the relatively long residence of several individuals to La Jolla (3 of 7 fish detected in the region for ~2-4 years) suggests at least some Giant Sea Bass have strong site fidelity to a coastal region with intensive spatial fisheries restrictions.

We found that Giant Sea Bass tended to have a higher probability of movement during the day and that their movement patterns did not seem to be influence by lunar phase. Clevenstine and Lowe (2021) found something similar with this fish on Santa Catalina Island with longer distances traveled on average during the day and no effect of lunar phase on movement during spawning season. We agree in their assessment that a lack of influence of lunar phase could be the result of abundances being too low to support consistent aggregation behavior or alternatively the fish could be more akin to aggregation forming species that do not align their spawning with particular lunar phases, such as Gulf Grouper (*Mycteroperca jordani*) (Rowell et al. 2019, Clevenstine and Lowe 2021). We should note that our movement models indicated that

Movido hacia arriba[2]: Our finding of high site fidelity for most individuals agrees with the findings of previous studies on Giant Sea Bass and similar species (Eklund & Schull, 2001; Hanan & Curry, 2012; Clua et al., 2015; Spector et al., 2022). Studies on similar large predatory species, Goliath Grouper (*Epinephelus itajara*) and Giant Grouper (*Epinephelus lanceolatus*), also found site fidelity across years, in some cases with individuals being resighted in the same location up to four years after the initial record (Eklund & Schull, 2001; Giglio, Adelir-Alves & Bertoncini, 2014; Clua et al., 2015). In La Jolla, it is possible the large spatial extent of contiguous kelp forest habitat and its ability to support ample prey resources contribute to the high site fidelity we observed among tagged Giant Sea Bass (Parnell et al., 2006; Udy et al., 2019). If site fidelity is driven by the availability of resources, it is possible it will lower as Giant Sea Bass populations continue to recover and intra-species competition for resources becomes more influential (Atwell, O'Neal & Ketterson, 2011; Dmitrieva et al., 2016).

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Comentado [AAP10]: I urge to improve this idea our explanatory variables did not account for much of the variability in our data. We suspect they would have higher explanatory power if we had a more expansive receiver array and could better resolve the finer-scale movement patterns of our tagged fish. More research into the periodicity of Giant Sea Bass spawning behavior is warranted, especially as their populations continue to recover.

Spatial management tools would be most effective if they encompassed spawning aggregation sites in this fish. Previous studies showed that spatial protections of spawning aggregations help support recovery from overfishing (Nemeth, 2005; Chollett et al., 2020; Waterhouse et al., 2020). While the California MPAs were not implemented with Giant Sea Bass in mind, if MPA boundaries include spawning aggregation sites, then it would be a support for its population recovery by protecting fish during a critical stage of their life history (Chollett et al., 2020). Our results suggest that there is likely a spawning aggregation in La Jolla—we detected fish year-round and found seasonal differences in movement during the presumed spawning season.

Due to our small sample size and the array positioning, we cannot say whether a La Jolla aggregation is inside or outside the MPAs. However, fish were more active in the northwest corner of the array during the spawning season, which coincides with heavily trafficked fishing grounds. Previous characterizations of spawning aggregation sites of Giant Sea Bass and similar species occurring near promontories in areas with strong currents (Eklund & Schull, 2001; Clevenstine & Lowe, 2021) support the notion of an aggregation in this area. The La Jolla submarine canyon runs along the northwest corner of the La Jolla array and is home to steep sandstone cliffs and subsurface promontories that contribute to the generation of strong currents close the edge of the kelp forest (Parnell et al., 2005, 2006, 2010). Incidentally, these same

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Our results suggest the while present in the La Jolla array, individuals tended to occupy relatively small, well-defined areas. We found that, overall, tagged fish frequently did not move enough across hour time periods to be detected on multiple receivers (as evidenced by the zero-inflation of our movement rate data). Even the fish that traveled to Del Mar, while being detected on multiple receivers spanning the full extent of the array during it's time in La Jolla, showed remarkably consistent detections (averaging over 60 detections per hour) at the Del Mar receiver for a period of five months. Additionally, that fish was not detected at any of the other more coastal receivers just north of the Del M ... [13]

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currents are responsible for attracting pelagic migratory species that are highly sought after by recreational anglers (Parnell et al., 2010).

We detected high levels of activity and evidence for a potential spawning aggregation in one of the most highly trafficked recreational fishing areas in San Diego (Parnell et al., 2010). While much of the local recreational fishing community is conscientious of regulations and efforts to support the recovery of Giant Sea Bass, fatalities do occur because of incidental catch. Barotrauma in fish can occur when there is rapid change in pressure, such as when it is brought to the surface quickly from a considerable depth, resulting in an overexpansion of gases in the body of the fish, especially in the swim bladder (Rummer & Bennett, 2005; Parker et al., 2006; Jarvis & Lowe, 2008). Giant Sea Bass are susceptible to barotrauma and, as large animals, can be difficult to handle properly.

One of the strongest indicators of post-release survival, following barotrauma in other species, is the ability to release the fish as quickly as possible (Jarvis & Lowe, 2008; Roach, Hall & Broadhurst, 2011). With a fish that regularly reaches over a meter in length and is often interacting with anglers on kayaks or larger chartered fishing vessels with raised decks (Parnell et al., 2010), reducing surface time is especially challenging. In the event a fish is released successfully, there is still a chance delayed mortality can occur if there is excessive damage to the swim bladder or other organs (Parker et al., 2006; Jarvis & Lowe, 2008). Furthermore, sublethal effects of catch and release fishing can also negatively impact individuals by decreasing their overall fitness (Cooke & Schramm, 2007; Campbell et al., 2010).

While incidental catch is of concern, the magnitude of negative effects is not so strong that it hindered the ongoing recovery of Giant Sea Bass in recent years. Our finding that individuals persisted in the La Jolla across multiple years suggests the existing spatial and fisheries

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Movido hacia arriba[1]: *. In particular, fish seemed to be most active in the northwest corner of the array, which coincides with heavily trafficked fishing grounds. Previous characterizations of spawning aggregation sites of Giant Sea Bass and similar species occurring near promontories in areas with strong currents (Eklund & Schull, 2001; Clevenstine & Lowe, 2021) support the notion of an aggregation in this area. The La Jolla submarine canyon runs along the northwest corner of the La Jolla array and is home to steep sandstone cliffs and subsurface promontories that contribute to the generation of strong currents close the edge of the kelp forest (Parnell et al., 2005, 2006, 2010). Incidentally, these same currents are responsible for attracting pelagic migratory species that are highly sought after by recreational anglers (Parnell et al., 2010).*

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Our results also indicate that the potential spawning aggregation site is likely outside of the local MPA boundaries. We found that fish were more often detected outside of MPAs than inside of them during summer spawning months, and that they had higher movement rates during this period

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While our sample size is small, our results provide insight into the susceptibility of Giant Sea Bass to their three major contemporary fishing-related threats: targeted commercial catch in Mexico, incidental commercial catch in the US, and incidental recreational catch. Regarding targeted commercial catch in Mexico, while we do not have evidence of fish tagged in the US crossing the border into Mexican waters, it is not out of the realm of possibility for individuals to travel from the San Diego region to Baja California given records of fish traveling long distances in other studies (Burns et ... [14]

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management measures afford protection in the La Jolla area. Management of the ongoing recovery throughout its range would benefit from further work quantifying the effects of incidental recreational catch. Fortunately, among people there is an understanding of best practices to mitigate the effects of incidental catch, chief among them quickly and efficiently releasing fish back to depth. Development of tools, such as larger versions of descending devices (e.g. SeaQualizers) often used with rockfish, can help support efforts to properly handle incidentally caught Giant Sea Bass.

Conclusions

We characterized residency and seasonality of Giant Sea Bass space use as determined by acoustic telemetry in one of the largest kelp forests in southern California, and identified how tagged individuals interact with local spatial management and fishing. While our sample size was small (five fish), we found valuable information for this Critically Endangered species. We found fish were resident to the La Jolla area for extended periods, with the longest consistent detection range lasting four years. We are unsure where the fish traveled after leaving the array, as we detected only one fish on receivers maintained in the broader southern California and Baja California region. Receiver coverage was sparse in many areas, especially in Mexican waters. We detected fish less frequently and displayed higher movement rates during spawning months. Based on the movement patterns, tagged fish are regularly interacting with a highly trafficked recreational fishing ground, including during spawning season. Nevertheless, existing spatial and fishery management measures appear to support long-term persistence of Giant Sea Bass in an area that is marked by high recreational fishing pressure. Future work would benefit from determining where Giant Sea Bass go when they exit the detection range of regional acoustic

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receiver arrays, and direct quantification of the impact of incidental take on the health of Giant Sea Bass populations in southern California waters.

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Acknowledgements

We acknowledge all the other regional acoustic telemetry research groups that queried their databases for our tag numbers, including Brian Sterling and Chris Lowe from the Lowe Lab at CSULB, Ryan Freedman and Pike Spector from the Channel Islands National Marine Sanctuary, and James Ketchum, Marc Aquino Baleytó, Mauricio Hoyos from Pelagios-Kakunjá A.C. in Baja California, Mexico. We thank the Hubbs Sea World Research Institute for allowing us to follow them during their surveys in case they caught a Giant Sea Bass. We would like to thank Phil Zerofski and Chugey Sepulveda for helping us develop our fishing and tagging protocols. We would also like to acknowledge the *many* volunteer anglers and divers who helped with the field work for this project, especially Rich Walsh, Ross Cooper, Zach Skelton, Erica Jarvis-Mason, Shane Finnerty, Mohammad Sedarat, and Youssef Doss.

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Página 19: [13] Eliminado **Kayla Blincow** **23/09/2023 05:04:00 p. m.**

We did not observe long-distance movements in our tagged fish, but it is possible they occurred and went undetected given sparse regional receiver coverage. Most fish disappeared from the La Jolla array prior to the end of tag life. Though none were detected on any of the regional receivers along the southern California coast, in the Channel Islands, or Baja California, Mexico, there is a chance that the tagged fish that left the La Jolla array made long-distance excursions/relocations that went undetected. Previous studies have documented such long distance movements in tagged fish (both generally, and in the case of Giant Sea Bass). For instance, one of the species' congeners in the Polyprionidae family, the Hāpuku (*Polyprionidae oxygeneios*), showed variable movement patterns during a multi-year mark-recapture study with some being recaptured close to 1400 km from their tagging location and others being recaptured at the same location as tagging (Beentjes & Francis, 1999). In another study, Giant Sea Bass tagged on Santa Catalina Island, California traveled long distances from the island following spawning season, traversing the San

Pedro Channel to the mainland or traveling to other islands in the area (Burns et al., 2020; Clevenstine & Lowe, 2021). While we can't rule out such movements in our tagged fish, the relatively long residence of several individuals to La Jolla (3 of 7 fish detected in the region for ~2-4 years) suggests at least some Giant Sea Bass have strong site fidelity to a coastal region with intensive spatial fisheries restrictions.

Our results suggest the while present in the La Jolla array, individuals tended to occupy relatively small, well-defined areas. We found that, overall, tagged fish frequently did not move enough across hour time periods to be detected on multiple receivers (as evidenced by the zero-inflation of our movement rate data). Even the fish that traveled to Del Mar, while being detected on multiple receivers spanning the full extent of the array during it's time in La Jolla, showed remarkably consistent detections (averaging over 60 detections per hour) at the Del Mar receiver for a period of five months. Additionally, that fish was not detected at any of the other more coastal receivers just north of the Del Mar receiver that are part of the larger southern California acoustic telemetry network. Furthermore, most of our tagged fish had the greatest detection rates on receivers near where they were captured. We conducted our tagging efforts outside of MPAs, thus most of our fish tended to occupy areas outside of spatial protection. Despite this trend, the high site fidelity across smaller scales suggests that spatial management such as MPAs could be an effective tool for sheltering some individuals from fishing activity if their range is within the MPA.

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While our sample size is small, our results provide insight into the susceptibility of Giant Sea Bass to their three major contemporary fishing-related threats: targeted commercial catch in Mexico, incidental commercial catch in the US, and incidental recreational catch. Regarding targeted commercial catch in Mexico, while we do not have evidence of fish tagged in the US crossing the border into Mexican waters, it is not out of the realm of possibility for individuals to travel from the San Diego region to Baja California given records of fish traveling long distances in other studies (Burns et al., 2020; Clevenstine & Lowe, 2021). However, based on our findings of generally high levels of regional and local site fidelity, these types of long-distance excursions are not necessarily the norm for Giant Sea Bass, and fish residing in US waters are likely to be well-protected [MOU1]despite the differences in management between the US and Mexico. Similarly, incidental catch by commercial fisheries in the US does not seem to be a strong threat, at least for Giant Sea Bass in La Jolla. We did not find any evidence that fish travel beyond the scope of the 3-mile nearshore gill and trammel net ban, and the records of long-distance movements from other studies indicate that when Giant Sea Bass do traverse beyond the scope of these spatial gear restrictions it is to transit relatively quickly to other coastal areas (Clevenstine & Lowe, 2021).

The greatest threat to Giant Sea Bass in La Jolla appears to be incidental catch by recreational fisheries. The area where tagged fish spent most of their time is one of the most highly trafficked recreational fishing areas in San Diego (Parnell et al., 2010). While much of the recreational fishing community in San Diego is conscientious of regulations and efforts to support the recovery of Giant Sea Bass, fatalities do occur because of incidental catch. Barotrauma can occur when there is rapid change in pressure, such as when a fish is brought to the surface quickly from depth, resulting in an overexpansion of gases in the body of the fish, especially in the swim bladder (Rummer & Bennett, 2005; Parker et al., 2006; Jarvis & Lowe, 2008). Giant Sea Bass are susceptible to barotrauma and, as large animals, can be difficult to handle properly. One of the strongest indicators of post-release survival following barotrauma in other species is the ability to release the fish as quickly as possible (Jarvis & Lowe, 2008; Roach, Hall & Broadhurst, 2011). With a species that regularly reaches over a meter in length and is often interacting with anglers on kayaks or larger chartered fishing vessels with raised decks (Parnell et al., 2010), reducing surface time is especially challenging. In the event a fish is released successfully, there is still a chance delayed mortality can occur if there is excessive damage to the swim bladder or other organs (Parker et al., 2006; Jarvis & Lowe, 2008). Furthermore, sublethal effects of catch and release fishing can also negatively impact individuals by decreasing their overall fitness (Cooke & Schramm, 2007; Campbell et al., 2010).

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Giant Sea Bass are a hardy fish that appear to handle stress well as evidenced by their apparent ability to recover from handling during this study. Furthermore, o