Short-term movement patterns of the Pacific sleeper shark off California

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FULL RESEARCH ARTICLE

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Abstract

This study evaluated the movement patterns of four Pacific sleeper sharks (*Somniosus pacificus*) outfitted with satellite-based tags off the California coast, a region for which there is no reported tracking data. Pacific sleeper sharks (1.5–2.1 m) attained maximum individual depths ranging from 603–1,323 m, with an overall average depth of 424 ± 84 m. Depth distribution was relatively similar between day and night, remaining well below the thermocline throughout periods at liberty. A 180-cm individual tagged off central California exhibited a deeper but more consistent depth distribution throughout the day (μ = 528 ± 28 m) and night (μ = 545 ± 26 m), whereas a 221-cm shark tagged off southern California occurred deeper during the day (μ = 392 ± 43 m) than at night (μ = 352 ± 62 m) with continuous vertical oscillations between 300 and 500 m. Ambient water temperatures at depth ranged from 3.3–11.0°C, with a collective average temperature of 7.3°C. Despite extensive and continuous vertical movements, horizontal displacement was minimal over the 30-d tracks (μ = 1.7 km/d). Although the data presented here are temporally and spatially limited, findings support previous reports of consistent vertical oscillations within other regions in the Pacific. Insights into the movements and habitat use of this vulnerable elasmobranch provides a better understanding of the species within a previously undocumented portion of its range.

Key words: depth distribution, elasmobranch, *Somniosus pacificius,* sleeper shark, vertical oscillations

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Introduction

The Pacific sleeper shark (*Somniosus pacificus*) is a large, deep-water elasmobranch that occurs in the North Pacific from Taiwan to the Chukchi Sea, and along the West Coast of the United States through Baja California, Mexico (Compagno 1984; Orlov 1999; Wang and Yang 2004). More recent accounts suggest a broader range for Pacific sleeper sharks, with records spanning from the Hawaiian Islands down to Palau and around the Solomon Islands (Drazen et al. 2015; Classens et al. 2023). Across its range, little information is available on the biology, ecology, or life history of this vulnerable species (Compagno 1984; Courtney and Sigler 2007; Rigby et al. 2021; Matta et al. 2024). Data on sleeper shark movements and depth distribution is limited at lower latitudes; however, it has been proposed that they rarely occur near the surface and occupy depths down to 2000 m (Compagno 1984; Classens et al. 2023).

Although not the target of any commercial fisheries operating in the eastern north Pacific (ENP), Pacific sleeper sharks are commonly caught as bycatch in demersal hook-and-line and trawl operations (Ebert et al. 1987; Courtney and Sigler 2007; Orlov 2017). Groundfish trawl fisheries operating in certain regions of the north Pacific have a particularly high bycatch potential, with periods when dozens of individuals may be captured incidentally during a single tow (Orlov 2017). Similarly, bottom-set longline fisheries routinely interact with Pacific sleeper sharks; however, bycatch mortality may be more negligible as larger individuals generally break free from longline gear targeting groundfish (Courtney and Sigler 2007; Orlov 2017; Fujiwara et al. 2021).

Although little movement data exists, the Pacific sleeper shark has been described as a slow-moving predator with a broad vertical range (Compagno 1984; Fujiwara et al. 2021). In one of the only published accounts of Pacific sleeper shark movements and habitat utilization, Hulbert et. al. (2006) found that sleeper sharks displayed extensive vertical movements throughout the water column within the Gulf of Alaska. Vertical movements included near-continuous cyclic oscillations and diel migrations, ranging from the surface to depths exceeding 700 m, with most time spent between 150 and 450 m (Hulbert et al. 2006). As proposed for other large predators, oscillatory movements have been attributed to ambush hunting or searching strategies (Skomal and Benz 2004; Hulbert et al. 2006; Nakamura et. al. 2011). Pacific sleeper shark diet studies further support an ambush predation strategy based on the varied stomach contents of active teleost species (i.e., black cod, salmon, albacore, Pacific halibut), invertebrates (i.e., squid and octopus), and marine mammals, either consumed alive or as carrion (Ebert et al. 1987; Orlov 1999; Taggart et al. 2005; Hulbert et al. 2006; Sigler et al. 2006; Horning and Mellish 2014; Orlov 2017; Fujiwara et al. 2021).

To date, there are few published studies on the movement patterns of this species and no previous data on its regional depth distribution or temperature profiles off the US West Coast (Phillips 1953; Gotshal et al. 1965; Ebert et al. 1987). For this reason, the present study opportunistically deployed electronic tags on Pacific sleeper sharks to better understand their movements and habitat use along California coastal shelf and slope waters.

Methods

We electronically tagged four Pacific sleeper sharks off the coast of California (**Table 1**) following appropriate animal handling guidelines developed for this tagging work. One individual was caught in December 2019 off the coast of San Diego, CA (33.1°N, 117.5ºW) using deep-set buoy gear (Sepulveda et al. 2015), and three individuals were caught in April–May 2022 south of Monterey, California (36.8°N, 122.0°W) using fixed demersal hook-and-line gear (Phillips 1953). We deployed all tags opportunistically on sleeper sharks that were caught during fishing operations directed towards other species.

Table 1. Satellite-based tag deployment and pop-up specifics for four Pacific sleeper sharks tagged off the coast of California between December 2019 and May 2022.

Shark #	Tag #	PTT #	Est. size (cm)	Date deploy	Date pop-up	Max Depth (m)	Deploy Lat, Long	Pop-up Lat, Lon	Displacement (km)
1	17P0214	172428	211	3 Dec 2019	4 Jan 2020	881	33.10, 117.45	32.74, 117.44	39.4
2	16P2175	171549	183	29 Apr 2022	30 May 2022	1,323	36.79, 121.95	36.62, 122.03	19.9
3	16P2332	171557	150	29 Apr 2022	30 May 2022	840	36.77, 121.97	36.73, 121.97	4.0
4	16P2343	171561	180	22 May 2022	22 Jun 2022	603	36.78, 122.02	37.48, 123.39	145.1

Prior to release, we measured captured sharks and outfitted them with Wildlife Computers satellite-based archival tags (sPATs) that were factory programmed using WC-proprietary software to automatically initiate 30-d deployments when submerged in seawater. Each tag was tethered to a plastic umbrella dart with an 11-cm section of 100-kg monofilament leader and embedded into the dorsal musculature using an extended tagging pole (Stokesbury et al. 2005; Campana et al. 2015; Aalbers et al. 2021). All tags contained depth sensors rated to 1,700 m with 0.5-m resolution and temperature sensors that ranged from –40° to 60° C at 0.05° C resolution and 0.1° C accuracy. Daily summaries generated from fast-sampled (1 s) data were transmitted to the Argos satellite network following release from the shark after 30-d deployment periods or if constant-depth conditions were met in the event of a mortality or shed tag. Transmitted records included minimum and maximum of depth, temperature, and light level, as well as 10-min resolution time-series data for the final five days of the deployment period. Second-generation sPATs also stored fine-scale (1-s resolution) depth, temperature, and light level records for download of archived data upon physical recovery. When possible, we used an Argos Goniometer signal direction finder to relocate and recover floating tags after release from the shark, which transmitted from the

surface at 60-s intervals (Sepulveda et al. 2010).

To evaluate vertical movements, we assigned each depth and temperature record a ‘day’ or ‘night’ value based on the time of sunrise and sunset from the United States Observatory database for San Diego and Monterey, California. We determined average depth and temperature (±SD) values for each individual shark and for the collective dataset. Vertical rate of movement (VROM) was calculated as the difference between consecutive depth values (Sepulveda et al. 2018). We calculated horizontal displacement as the straight-line distance between tagging and pop-up locations (Aalbers et al. 2021; **Fig. 1**). Since only recovered tags yielded archived data, all comparisons between individual sharks used transmitted datasets. Transmitted data included daily minimum and maximum depth and temperature values, as well as 10-min depth, temperature, and delta light level records for the final five days of each deployment. We evaluated time-series records from recovered tags independently to assess fine-scale rates of vertical movement as well as depth and temperature profiles. One-second resolution time-series data was directly downloaded for the entire 30-d deployment period of a sPAT that was physically recovered off southern California.

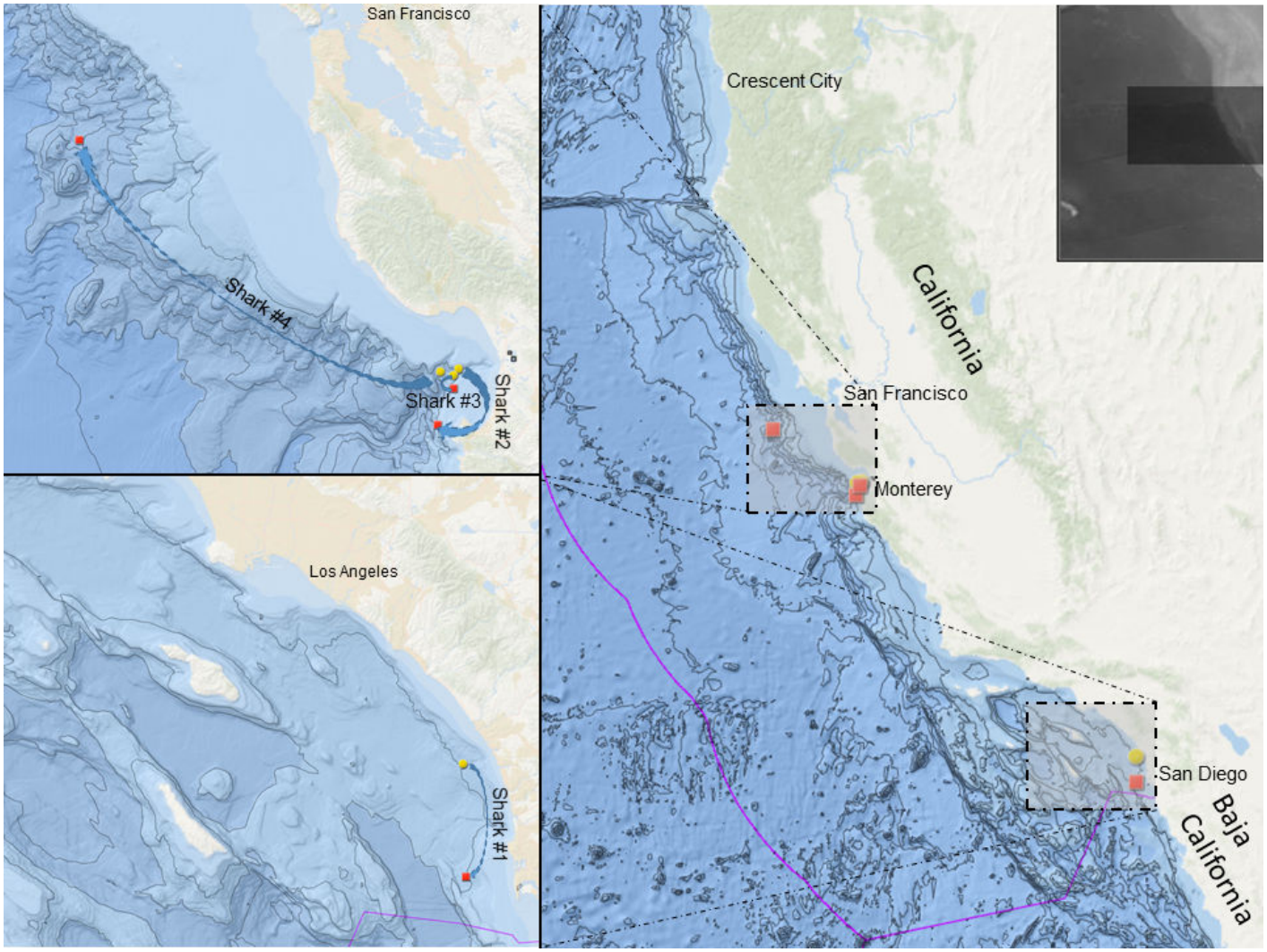

Figure 1. Satellite tag deployment positions (yellow dots) and 30-d pop-up locations (red squares) from four Pacific sleeper sharks (*Somniosus pacificus*) incidentally captured adjacent to the 500-m contour line (solid gray lines) along the coast of California.

Results

We collectively acquired 120 days of movement data from four Pacific sleeper sharks (1.5–2.1 m TL; Table 1). Horizontal displacement during tag deployments ranged from 3.9 to 145.1 km from the tagging site and the average horizontal displacement over a 30-d period at liberty was 52 ± 64 km. Individuals attained maximum depths ranging from 603 to 1,323 m (Table 1; Fig. 2), while minimum depths ranged from 106 to 219 m over the course of all tracks. The average depth recorded over the final 5-day period ranged from 383 ± 76 to 534 ± 28 m among the four tagged individuals, with a collective average depth of 424 ± 84 m. Although specific depth ranges varied between individual tracks, tagged sleeper sharks collectively spent more than 99% of the time at depths between 200 and 600 m (Fig. 3a–d), with a majority (>70%) of time spent from 300 to 500 m. Overall average depths during the day (μ = 435 ± 47 m) were slightly greater than night depths (μ = 414 ± 47 m); although, all individuals remained well below the thermocline throughout all tracks (>106 m). Across individuals, daily temperature at depth ranged from a minimum of 3.3°C (μ = 6.4°C) to a maximum of 11.0°C (μ = 8.1°C).

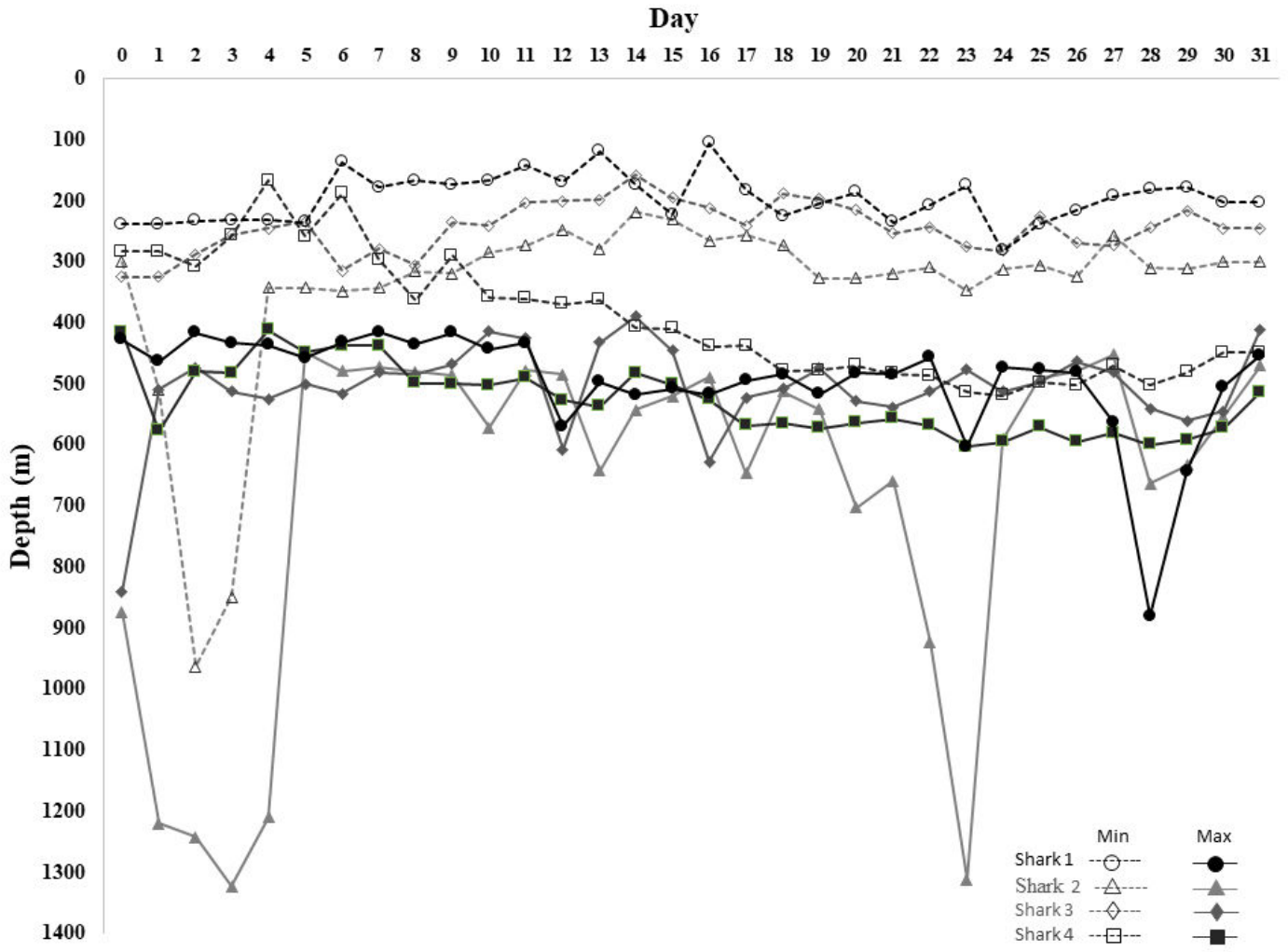

Figure 2. Daily min (dotted line) and max (solid line) depth values transmitted from four satellite-based tags programmed for 31-d deployments on Pacific sleeper sharks (150–211 cm FL) between December 2019 and June 2022 off the coast of California.

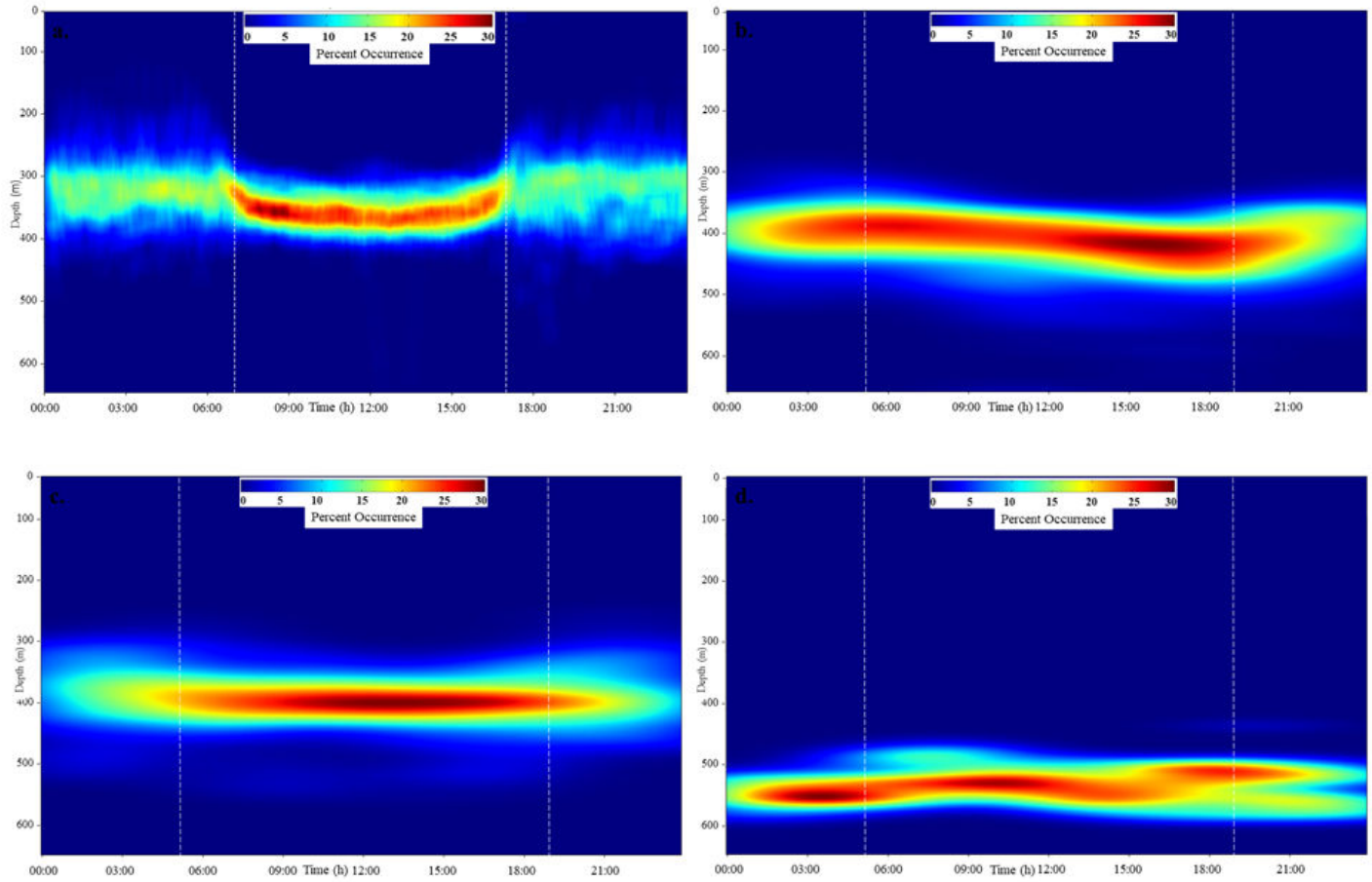

Figure 3. Depth probability plots summarized over a 24-h period with color representing percent occurrence values for a.) Shark#1 (211 cm FL; PTT 172428), b.) Shark #2 (183 cm FL; PTT 171549), c.) Shark #3 (150 cm FL; PTT 171557), and d.) Shark #4 (180 cm FL; PTT 171561) over the final five days of a 31-d track off the coast of California.

All individuals tracked in this study exhibited vertical fluctuations, with alternating ascents and descents throughout much of the day and night. Based on collective transmitted data sets (10-min resolution), vertical rates of movement were lower and less variable during the day than at night, with an overall average VROM of 2.7 ± 2.2 m/min. Day vertical rates of movement (DVROM) ranged from a low of 0.6 m/min (Shark #4) to a high of 3.1 m/min(Shark #1) and averaged 2.1 ± 2.0 m/min for all transmitted data. The collective night rate of movement (NVROM) averaged 3.2 ± 2.0 m/min and ranged from 0.6 m/min (Shark #4) to 6.6 m/min (Shark #1); however, transmitted datasets at 10-min resolution provided less precise VROM estimates than fine-scale data. Both DVROM and NVROM were consistently higher when calculated from downloaded data recovered from Shark #1.

Individual Shark Tracks

The first and largest sleeper shark (Shark #1; 211 cm FL) tagged in this study was caught off the coast of southern California on 3 December 2019 and provided the only detailed 1-s resolution dataset following recovery of the tag (Fig. 3a). Access to fine-scale data enabled more comprehensive analyses for accurately evaluating VROM and diurnal movement trends (Fig. 4). Based on the downloaded time series data from Tag #17P0214, day depths were deeper (μ = 392 ± 43 m) and less variable than night depths (μ = 352 ± 62 m), whereas NVROM were greater and more variable (8.1 ± 3.4 m/min) than DVROM (5.6 ± 2.4 m/min; Fig. 4). Vertical movements were consistent throughout the entire track, with nearly

continuous changes in depth across 97.4% of all records. Oscillatory movements were largely confined between 300-500m during the day and covered an increased range (~100–600 m) at night, with considerable changes in magnitude and period between day and night. For example, consecutive oscillations measured over a single 24-h period occurred on average every 15.2 ± 3.4 min during the day, with a mean vertical distance travelled of 79.5 ± 23 m across each ascent-descent cycle. At night, consecutive oscillations occurred over a mean cycle period (ascent + descent) of 45.1 ± 4.9 min and covered a much greater mean vertical distance of 470.8 ± 67.8 m (Fig. 4).

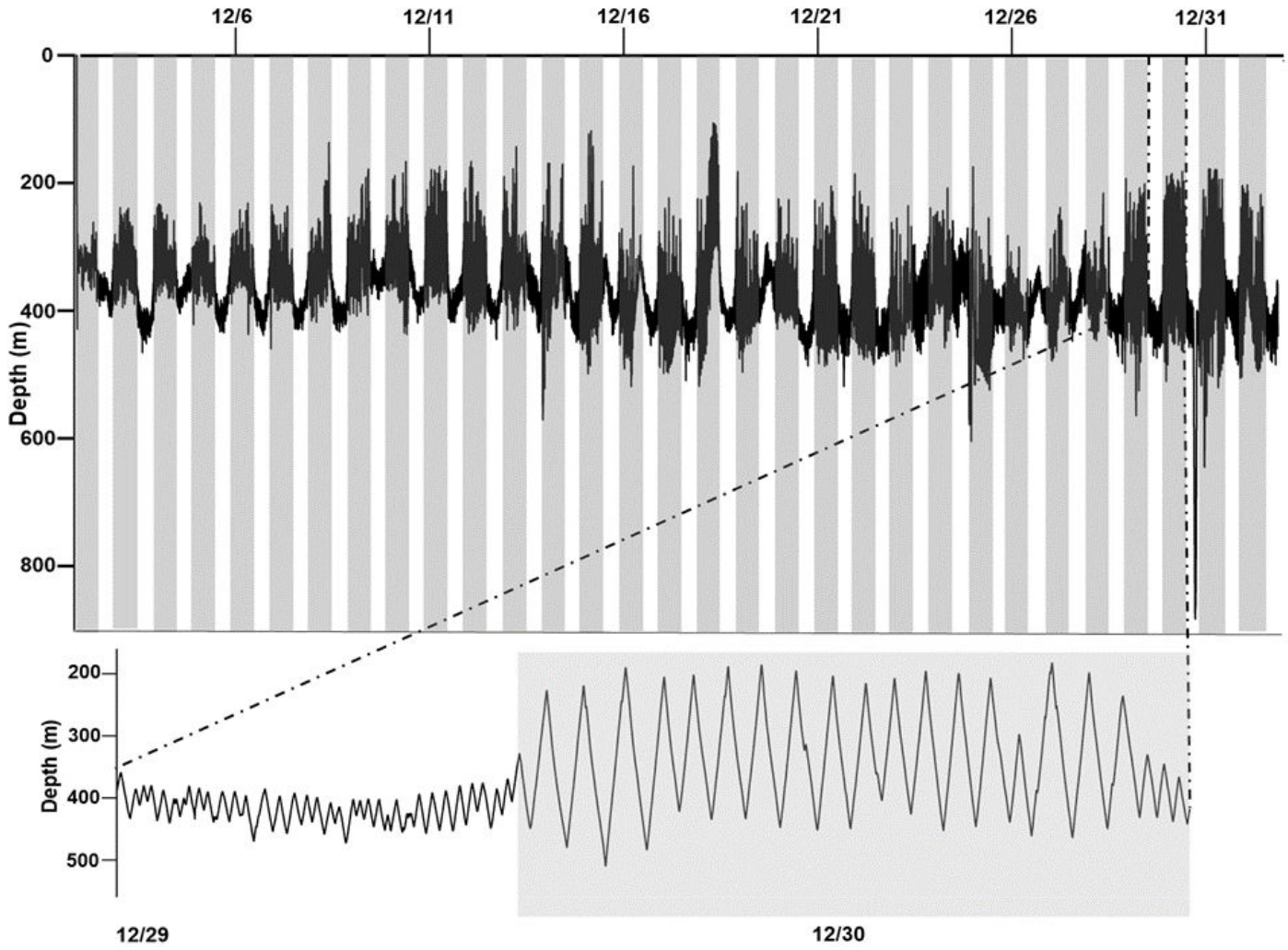

Figure 4. Fine-scale depth profile for a 211-cm Pacific sleeper shark from 4 December 1999 to 4 January 2020 with a magnified 24-h time series to exhibit the continuous vertical oscillations that were consistently shallower and more variable during the nighttime (shaded blocks).
Sharks #2 and #3 were both tagged on 29 April 2021 off Carmel Bay, California and exhibited relatively similar movement patterns (Fig. 3b,c), with average depths of 396 ± 48 m and 384 ± 49 m, respectively. Day depths were approximately 20 m greater on average than night depths for both individuals. Both sharks spent approximately 95% of the time between 300 and 500 m over the final five days of tracks. Shark #2 exhibited deeper dives than any of the other tagged sharks, with a maximum depth of 1,323 m and the lowest recorded temperature at depth of 3.3°C.

Shark #4 was also tagged off Carmel Bay, California on 22 May 2021, with a comparable depth distribution to other tagged sharks during the initial portion of the track (Fig. 2). However, based on

transmitted time-series data from the final five days of the track, Shark #4 displayed a markedly deeper profile (mean depth = 534 ± 28 m; Fig. 3d) than the other tagged sharks as it moved offshore where the tag popped up 145 km northwest of Monterey Bay. Shark #4 also exhibited reduced vertical oscillations during the final five days of the track, with 90% of this period spent between 500 and 600 m.

Discussion

This study provides insight into the movements and behaviors of the Pacific sleeper shark, a data-poor species that inhabits the shelf waters off the California coast. Although the data presented in this study are temporally and spatially limited, they provide the first recorded movements for this species off California and offer insight into Pacific sleeper shark habitat use and depth distribution in this region. Based on day and night depth trends, it is evident that Pacific sleeper sharks are capable of remaining within oxygen depleted waters at depths below 500 m and temperatures of less than 4°C for extended periods of time. The vertical movement patterns observed off California fall within the depth range previously reported for Pacific sleeper sharks off Alaska (Hulbert et al. 2006); however, considering the limited track durations it is likely that this study only captured a portion of the movement trends exhibited by Pacific sleeper sharks.

Although the three sleeper sharks tagged along the central California coast (Sharks 2–4) were similar in size, capture location and deployment period, Shark 4 moved further offshore and into deeper water (>2,000 m) where it remained at greater depths (range = 450–600 m) over the final five days of the track (Fig. 3d). However, based on min-max depth data throughout the 30-d deployment it was apparent that Shark 4 primarily occurred between 200 and 450 m for the majority of the track, which was comparable with the mean depth distribution of the other tagged individuals in the region (Fig. 2). Similarly, Pacific sleeper sharks tagged in the same general area off Alaska exhibited a wide range of vertical movements that varied over the course of tracks and between individuals (Hulbert et al. 2006). Hulbert et al. (2006) found that comparably sized sharks concurrently exhibited movements that ranged from 100 to 200 m for some individuals, while others spent more time in waters between 400 and 600 m. The depth distribution and movement trends recorded in this study were collectively deeper (mean depth = 424 m) and less variable than the wide range of vertical movements observed from 24 tagged individuals off Alaska, where sleeper sharks ranged from the surface to 724 m (mean depth = 184 m) and showed a considerably greater daily depth range. Longer tag deployments that cover multiple seasons would be needed to evaluate if the depth fluctuations observed in this study are part of a larger seasonal trend.

Sharks tagged in this study remained at depths below 106 m throughout all tracks and occurred between 300 and 600 m more than 95% of the time, which is consistent with literature suggesting that sleeper sharks transition to deeper waters and a more epi-benthic existence across the southern extent of their range (Compagno 1984; Orlov 1999). Although it was not practical to assess the percentage of time that sleeper sharks remained associated with the bottom in this study, movement data suggested that individuals likely remained within the water column throughout much of the track duration. For three of the tags that were deployed and popped up along the 500-m depth contour (Fig. 1: Sharks 1, 2, and 3), more than 97% of the transmitted depth data from the final five days of these tracks was above 500 m. Similarly, Shark 4 consistently remained above 600 m throughout the final five days of the track before the tag released at a position beyond the 2,000-m depth contour. In the northwest Atlantic, pelagic swimming activity was also demonstrated in the closely related Greenland shark, where maximum swimming depths ranged from 1,104 to 1,816 m over seafloor depths of at least 4,000 m where tags

popped up hundreds of kilometers offshore (Campana et al. 2015).

Further support of epi-benthic behavior was observed in the fine-scale time series data from Shark 1, which revealed prolonged periods of continuous vertical oscillations throughout much of the track (**Fig. 4**). Extended periods of vertical oscillations resulted in a high VROM (mean = 7.0 ± 3.3 m/min), and total vertical distance traversed (10.2 km/d), which approximated the VROM (range = 4–8 m/min) and daily vertical movement values (3.6–12.1 km/d) reported for sleeper sharks tagged within the Gulf of Alaska (Hulbert et al. 2006). Shark #1 moved approximately 315 km through the water column during the 31-d track, a distance nearly eight times greater than its overall horizontal displacement (39.4 km). Continuous vertical movements were more consistent and pronounced at night, when VROM averaged more than 8 m/min(0.14 m/sec), compared to an average VROM of 5.6 ± 2.4 m/min during the day, suggesting a diurnal component to observed movement trends. The peak VROM of 0.14 m/sec recorded during this study and by Hulbert et al. (2006) indicated that tagged sharks moved vertically in the water column at approximately 66% of the mean horizontal swimming rate (0.21 m/sec) reported for Pacific sleeper sharks (Fujiwara et al. 2021). The lack of fine-scale records for Sharks 2, 3 and 4 precluded accurate VROM estimates, thus it was not possible to determine the combined horizontal and vertical movement rate of these individuals.

The continuous vertical movements recorded in this study also suggest that Pacific sleeper sharks can exhibit a more active foraging strategy within the water column, particularly at night when their cryptic coloration and heightened oscillatory movements may enhance their effectiveness as an ambush predator (Fujiwara et al. 2021). Diurnal differences in the duration and variation of vertical oscillations suggest that sleeper sharks focused foraging activity within a narrower range of depths during daylight hours. The predominant daytime movements of Shark #1 largely cycled between depths of 300–500 m, which encompasses both the deep scattering layer (DSL) and the oxygen minimum zone (OMZ) off southern California. Consistent vertical oscillations may allow sleeper sharks to capitalize on the abundant prey resources within the DSL, while moving back and forth across the upper levels of the OMZ. Considering that stomach contents have been shown to consist of benthic and pelagic prey items as well as carrion (Compagno 1984; Orlov 1999; Sigler et al. 2006), sleeper sharks may vary their daily diving behavior based on spatial or temporal patterns of food availability, allowing them to effectively shift foraging strategies between pelagic and demersal habitats or capitalize on scavenging opportunities (Fujiwara et al. 2021).

Previous work related to the vertical movements of pelagic elasmobranchs have identified similar oscillatory movements suggestive of foraging behavior (Nakamura et al. 2011; Campana et al. 2015). The closely related Greenland shark (*Somniosus microcephalus*) has been shown to occupy depths well below the thermocline and remain largely pelagic over extended periods throughout the day and at night (Skomal and Benz 2004; Campana et al 2015). Greenland sharks have been shown to exhibit similar vertical fluctuations to those documented in this study, with seasonal variations in migratory or diving patterns that have been attributed to spatial or temporal changes in foraging activity (Skomal and Benz 2004; Watanabe et al. 2012; Edwards et al. 2022). A shallower type of “yo-yo” diving behavior was also observed in tagged tiger sharks and was hypothesized to serve as an effective strategy to search large 3-dimensional spaces for prey (Nakamura et al. 2011).

Movements Relative to Regional Fisheries

The Pacific sleeper shark depth distributions reported in this study suggest that there are only a few ongoing fisheries off California with which this species is likely to interact (Sweetnam et al. 2007). The most notable fisheries include demersal trap and longline operations for groundfish (i.e., sablefish [*Anoplopoma fimbria*]), which use baited gear set along the seafloor at depths between 200-600 m (Sasaki 1985; Ebert et al. 1987; McKnight and Leos 2008). Demersal longline fisheries have been reported to interact with Pacific sleeper sharks in other regions of the north Pacific (Courtney and Sigler 2007) and sleeper sharks are routinely observed with embedded hooks originating from the demersal fishery (Gotshall and Jow 1965; Orlov 2017). In this study, three of the sharks tagged were incidentally captured on demersal longline gear, two of which already had additional longline hooks embedded in their jaw. Sleeper sharks consume a variety of commercially valuable species and are considered a nuisance in bottom-set fisheries as they are often the source of considerable economic loss from catch depredation and gear damage (Orlov 2011; Orlov and Baitalyuk 2014; Orlov 2017). Pacific sleeper sharks have also been known to cause considerable setbacks to midwater and bottom-trawl operations when captured as bycatch (Orlov 2017). Sleeper sharks have been reported as bycatch in bottom trawl fisheries off California targeting halibut and deeper-water groundfish species (Phillips 1953; Gotshall and Jow 1965; Matthews et al. 2022) but are more commonly encountered by Alaskan and Russian trawlers (Orlov and Baitalyuk 2014).

Groundfish trawl fisheries account for the majority of sleeper shark bycatch in the north Pacific, with incidental catch rates totaling several thousand metric tons in the Gulf of Alaska from 2001–2007 (Courtney et al. 2016; Orlov 2017). Because Pacific sleeper sharks are a common component of trawl fishery bycatch in the north Pacific, the development of commercial markets for sleeper shark products has been explored (Orlov 2017). While the closely-related Greenland sharks are routinely harvested off Norway and Iceland for liver oil and food, the Pacific sleeper shark does not have an existing commercial market and there is concern that the meat may contain toxins (Orlov 2011). Although the fresh meat of Greenland shark is considered poisonous due to its extremely high urea and trimethylamine oxide concentrations (Orlov 2011), it is considered a delicacy in Iceland when served as *hákarl* following an extensive fermentation process to rid the meat of its toxins (Osimani et al. 2019).

The largest shark in the study (Shark #1) was captured on deep-set buoy gear, a new fishery off California that seasonally targets swordfish at depth during the day (Sepulveda et al. 2015). Although this fishery has the potential to interact with Pacific sleeper sharks, the initial >10 years of gear trials have resulted in minimal bycatch (Sepulveda et al. 2023), suggesting that there may be minimal spatial overlap between swordfish sets and Pacific sleeper shark habitat. Because the mean daytime depth distribution of the sleeper shark tracked off southern California (Shark #1) was deeper (392 m) than the standard deep-set buoy gear fishing depth (300 m), bycatch rates are not likely to be a concern within this region.

Due to the limited number of tagged individuals and short tag deployment durations, the movement patterns described in this work cannot be used to draw conclusions on longer term behaviors such as migration patterns or seasonal changes in depth distribution. Similarly, the presence of only a single dataset from the San Diego study site precludes comparisons of regional differences in vertical movements of sleeper sharks off the California coast. This study offers the first insights into the vertical distribution and habitat use of sleeper sharks within the southern portion of their range. Data from this

work support previous studies within the north Pacific and suggests that sleeper shark vertical movements may be more extensive and variable than previously thought. Given the slow growth and longevity of this elusive species, data on the movements and regional distribution off California can be helpful in assessing potential fishery impacts and offer considerations towards reducing future interactions.

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