# Satellite Tracking and Dive Analysis of Green Turtles in San Diego Bay, California: 2023-2024, Progress Report


***Submitted to:***

*Naval Facilities Engineering Systems Command Southwest*
*San Diego, CA 92101, USA*

*Naval Information Warfare Center Pacific,*
*San Diego, CA 92152, USA*

***Prepared by:***

*Marine Turtle Research, Ecology, and Conservation Group*
*Earth, Ocean and Atmospheric Science*
*Florida State University*
*Tallahassee, FL 32304, USA*

**August 2024**

**Suggested Citation:**

Hope Lovich[1], Armando Santos[1], Mariana P.B. Fuentes[1], Megan Hanna[3], Brendan Saunders[4], Erica Pollard[4], and Jeffrey A. Seminoff[2]

[1] Marine Turtle Research, Ecology and Conservation Group,
Earth, Ocean and Atmospheric Science,
Florida State University, Tallahassee, Florida 32304 USA

[2] Marine Turtle Ecology & Assessment Program,
National Oceanic and Atmospheric Administration Southwest Fisheries Science Center,
La Jolla, California 92037 USA

[3]Naval Facilities Engineering Systems Command Southwest
United States Department of Defense
San Diego, California 92101 USA

[4]Naval Information Warfare Center Pacific
United States Department of Defense
San Diego, California 92152 USA

## 1.0 Introduction

San Diego Bay (SDB) has historically been an important known foraging ground for green turtles in southern California as it provides expansive eelgrass pastures in its southern ecoregion (Eguchi et al., 2020). Beginning in the mid-1970s, researchers conducted the first observations of this year-round population, identifying core areas of activity in SDB and providing initial population estimates (Stinson 1980). The population of foraging green turtles in SDB are from the East Pacific Distinct Population Segment (DPS) which is listed as threatened under the Endangered Species Act. This DPS is primarily found along the coasts of Mexico and the majority of the SDB population originates from nesting sites in the Michoacán region and Revillagigedo Islands. In 1990, in-water capture efforts, initiated by scientists from NOAA Southwest Fisheries Science Center, yielded information on the demographics of SDB turtles (e.g., Eguchi et al. 2010). Genetic information collected during these in-water capture efforts allowed scientists to track foraging green turtles in SDB back to specific rookeries in Michoacán and the Revillagigedo Islands (Dutton et al., 2019). These capture efforts also enabled researchers to equip turtles with satellite and/or ultrasonic transmitters to track their movements in SDB, as well as their long-distance migrations to nesting rookeries in Mexico (MacDonald et al. 2012, 2013; Dutton et al., 2019; Eguchi et al., 2020). These tracking efforts helped characterize the spatial distribution of green turtles in SDB, and depicted how temperature influences green turtle movements in SDB (Madrak et al., 2016, 2022). While horizontal spatial distribution of green turtles in SDB has been well studied, studies investigating green turtle dive patterns and vertical habitat utilization are lacking.

Knowledge of green turtle spatial use (both horizontal and vertical) can delineate which areas of SDB are most frequented by turtles and can highlight areas that may benefit from increased conservation, protection, and improved management strategies. Such information is particularly vital considering that growing anthropogenic use in SDB leads to a greater influence on SDB ecosystems and species. SDB, a site with high recreational and commercial activities, has seen numerous encounters of dead-stranded green turtles (NOAA, unpubl. data). In particular, the amount of time green turtles spends at, or near, the water's surface may have significant implications for mortality in areas with high vessel traffic. Historically, the majority of dead-stranded turtles found in SDB had external injuries consistent with boat strike mortality (Rodriguez, M., 2023).

Historically, the south Bay ecoregion (the core use area for green turtles), has remained relatively undeveloped. However, as of 2023, the south Bay ecoregion is undergoing significant coastal development to revitalize the Chula Vista Bayfront. As part of the Chula Vista Bayfront Revitalization Plan (Unified Port of San Diego Master Plan), multiple integrated high-rise apartment, shopping, and conference centers are scheduled for construction, with one development already near completion. In addition to an estimated 2,000 hotel rooms, these developments will host a myriad of human activities that will likely contribute to increased recreational activity (e.g. snorkeling, boating, water skiing, kite boarding, etc). Considering the large-scale changes that the southern portion of SDB is experiencing, it is essential to generate baseline information on where turtles may be most susceptible to the threats of vessel strikes or other human interaction. This information is crucial for developing conservation management plans and strategies to protect this threatened species.

The objective of this study is to use fine-scale, depth-enabled satellite telemetry to study green turtle movements and dive activity in SDB. In addition to determining home range and core areas of activity, the use of depth-enabled transmitters allows for evaluation of several dive parameters such as dive duration, time-at-depth and time-at-temperature over daily, monthly, and seasonal periods. Collecting these data will allow natural resource managers in SDB to identify green turtle vertical movements. This information can be used to develop conservation and management strategies to minimize human impacts, especially vessel strikes, to the SDB green turtle population.

## 2.0 Methods

2.1 Study Area

San Diego Bay (SDB) (32.6717 N, 117.1441 W) is located along the southern coast of California, six kilometers (km) north of the U.S.-Mexico border. SDB occupies approximately 25 km of coastline with semi-diurnal tides and depths ranging from 1 to 18 meters (m; Chadwick & Largier, 1999; Figure 1). San Diego Bay is an open-mouth bay that has direct access to the Pacific Ocean. The southern region of SDB, about 12 km from the bay mouth, is characterized by shallower waters (0.7 m to 4.0 m below the mean lower low water line [MLLW]), while the central and northern portions of SDB have greater depths ( >18 m) (U.S. Department of the Navy & Port of San Diego, 2013). Marine habitats in and around SDB include coastal marsh, intertidal and subtidal habitats, communities of mud and benthic invertebrates, and man-made habitats such as shoreline rip rap and marine floats (U.S. Department of the Navy & Port of San Diego, 2013). SDB also hosts two eelgrass species, *Zostera marina* and *Zostera pacifica,* with *Z. marina* being the most abundant throughout SDB and *Z. pacifica* only present at the mouth of SDB (Johnson et al., 2003; Merkel & Associates, 2022). While green turtles in SDB are part of the larger east Pacific DPS, green turtles in SDB also fall under the more spatially explicit east Pacific Regional Management Unit (RMU). RMU's were initially established to provide a management framework for conspecific assemblages that share regional boundaries and thus, similar environmental conditions (RMU, Wallace et al. 2023). This local green turtle population is found largely in the south SDB ecoregion, where turtles' activity and foraging ecology are closely tied to eelgrass meadows that provide food resources and habitat structure (Maurer et al., in review). Together, the various habitats in SDB support diverse assemblages of invertebrate and fish species, resident and migratory shorebirds and seabirds, and a year-round resident population of green turtles (Delgadillo-Hinojosa et al., 2008).

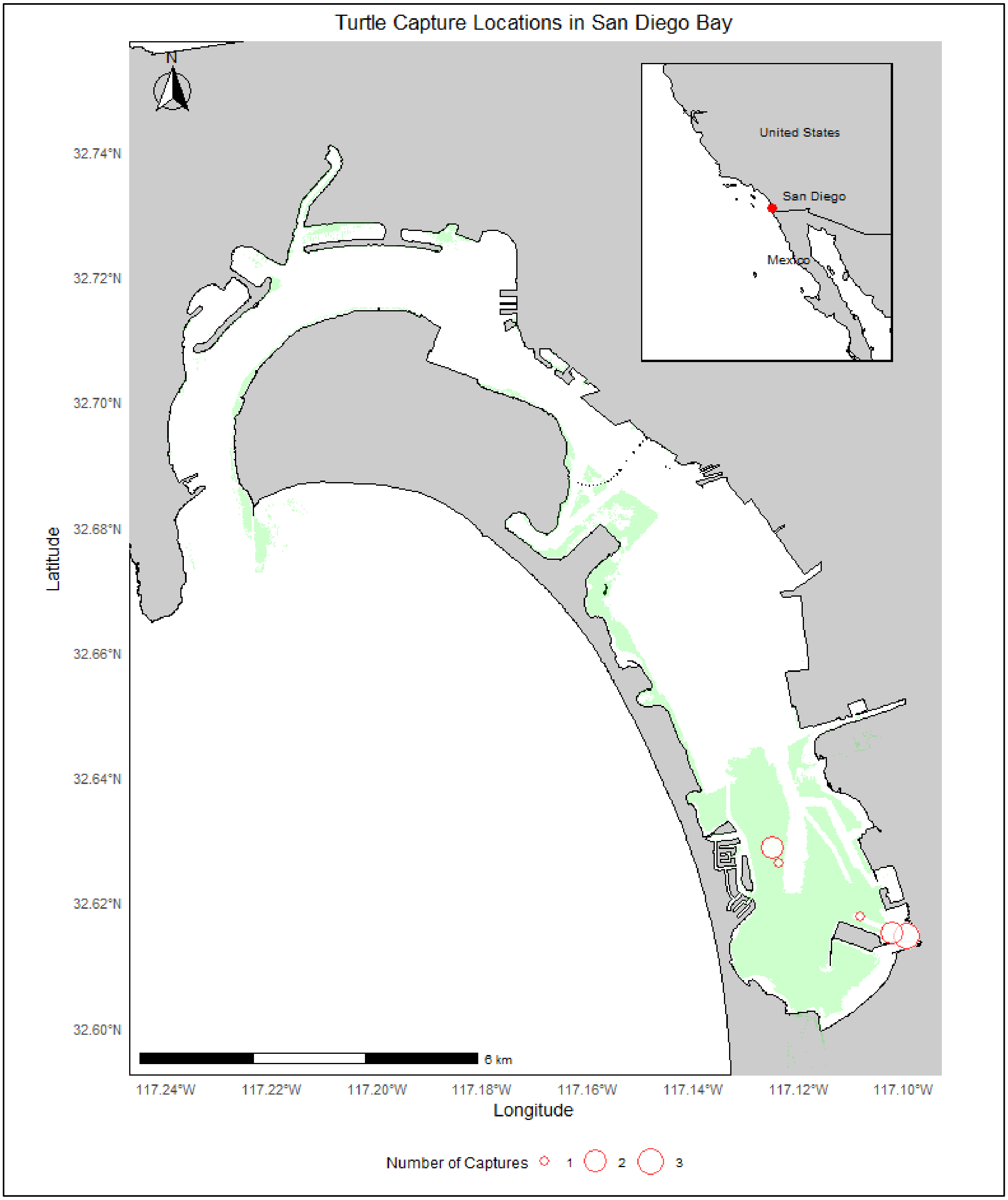


**Figure 1.** Map of San Diego Bay showing green turtle in-water capture locations (light red) and eelgrass distribution (light green).

## 2.2 Green Sea Turtle In-Water Capture and Release

Green turtles were captured (n=60) in 2023 as part of NOAA's long-term monitoring program in San Diego Bay (ongoing since 1990). Entanglement nets (50–100 m in length, 8-m depth, mesh size 40-centimeter [cm] knot to knot) were used to capture turtles. The nets were deployed throughout the southern portion of SDB in accordance with wind conditions, temperature, tidal height, current, and the number of turtle heads observed in a specific area. Net placement ranged from 100 m to 1.5 km from shore and at depths of 3-6 m. The nets were monitored every 30 minutes and soak time ranged from 1 to 3 h during diurnal tidal periods before nets were retrieved or relocated. Upon capture, green turtles were disentangled and transported to shore where they were kept under shaded protection during processing. Each individual turtle was tagged with a uniquely coded passive integrated transponder (PIT tag) and flipper tag (Inconel). Turtles were released within 2 hours of capture. Of the 60 captured, 15% (n=9) of green turtles were outfitted with Fastloc GPS-enabled Satellite Transmitters. Turtles were measured using curved carapace length (CCL; ± 0.1 cm) and straight carapace length (SCL; ± 0.1 cm), taken from the nuchal notch to the posterior-most edge of the marginal scutes using a flexible measuring tape and Forester's caliper, respectively. Body mass (± 0.5 kg) was determined using an electronic scale (Eckert et al., 1999).

## 2.3 Satellite Telemetry, Attachment and Programming

Argos-linked Fastloc™ GPS platform terminal transponders (hereafter, 'Fastloc transmitters') capable of recording several dive parameters and GPS locations were deployed on five turtles captured in June 2023 and four turtles captured in November 2023 (SPLASH 10, Wildlife Computers, models SPLASH-10-F-385A and 10-F-351A). Tags collected information on turtle dive behavior, including proportion of Time-At-Depth (TAD), Time-At-Temperature (TAT), and Dive Duration (DD). Fastloc transmitters were attached to each individual's carapace using modified methods described by Jones et al. (2011). Green turtles with large and undamaged carapaces were chosen to ensure the adhesive for the tags would hold properly and to provide a large space for the equipment to securely stay on the carapace. Briefly, we lightly sanded the carapace and rinsed with isopropyl alcohol to remove any residue, repeating this cycle until the shell was clean of algae and any flaking keratin. A base layer of carbon fiber was adhered to the turtle's carapace using 5-minute quick-set epoxy and carbon fiber cloth. Tags were attached to the top of the carapace within the second vertebral scute. The placement in this location minimizes drag and allows the highest point for the antenna to maximize frequency of antenna breaking the water's surface (Watson & Granger, 1998). Before deployment, the tags were painted with an antifouling paint to prevent the accumulation of algae (hinders GPS transmission) while the tag is present on the individual (Micron CSC, https://www.interlux.com/en/us/boat-paint/antifouling/micron-csc).

All data were transmitted through Argos Satellites. Dive duration data were binned in seconds (s) from 180s to 18,000s which were later converted to minutes (min) in bins from <3min to >300min (0-3, 3-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-180, 180-240, 240-300, >300min). Time-At-Depth (TAD) was binned from 2m to 30m (0-2, 2-5, 5-10, 10-15, 15-20, 20-25, 30m). As SDB's depth does not exceed 20m, we truncated the bins that exceeded that point. Furthermore, Fastloc transmitters are designed to sample depths from 0 – 1700 m, a rather large range, and have an accuracy of +/- 1 m. During preliminary analyses of TAD it was determined that green turtles in SDB frequently spend time in the first 2m of the water column and this provided challenges for transmitters to record shallow dives and surfacing events given the +/- 1m accuracy. For example, if a transmitter was set to have a 0m – 2m upper bin limit, a green turtle may be at 1m depth, but the transmitter could record either a surface value of 0 (-1m) or a 2m depth value (+1m). Thus, the "surface" depth was set to 2m, rather than 0m to 2m, in efforts to accurately capture shallow dives (<2m) and surfacing events occurring in the upper 2m of the water column. Furthermore, the transmitter's wet-dry sensor records when the tag is out of the water (a surfacing event), the sample interval for the wet/dry sensor was set to 1s to ensure that brief surfacing events were captured and recorded. Time-At-Temperature (TAT) was binned from 8°C to 32°C (8-10, 10-12, 12-14, 14-16, 16-18, 18-20, 20-22, 22-24, 24-26, 26-30, 30-32, 32°C). Temperatures beyond 32°C were not recorded. The data transmitted showed that SDB's temperature did not reach anything lower than 14°C. To ensure relevance of dive duration data, we filtered data to exclude dive durations exceeding 180 minutes based on several factors of SDB's habitat and the low probability that green turtles would frequently exceed dive durations of >180min.

2.4 Spatial Analysis

Fastloc-GPS data obtained from tags were complemented by Argos data to fill temporal gaps between transmission days where Fastloc-GPS data were unavailable. Logged positions were filtered to remove any anomalous points. This includes observations before tag deployment, points on land, those with missing Argos location quality class or those classified as A, B, and Z (i.e., did not have reported error estimates), and those with insufficient satellite numbers (GPS points with less than 8 satellite connections). The combined dataset including Fastloc-GPS and Argos had 11,276 locations from all nine turtles. The open water migration from one turtle (PTT ID 253468) was excluded from group SDB analyses. However, in between the pre- and post-migration, data from SDB were retained in group SDB analyses. Dive data for the 13 days of migration were also excluded from our group SDB analyses but were presented in the supplementary material. Dive duration data from the open water migration were excluded from SDB group analyses as migration and open ocean dive behavior can vary greatly from data seen at a foraging ground like SDB. Thus, to avoid bias in the group SDB analyses, pre- and post-migration dive data were not included in group SDB analyses. Since the raw turtle tracks are biased by location error, we derived the 'true' locations of each individual turtle using a Continuous-Time Correlated Random Walk (CRW) State Space Model (SSM) with an 8-h time interval using the aniMotum package (v1.0.7; Jonsen et al., 2023) in the R statistical software (v4.3.1; R Core Team, 2023). We selected the 8-hour time step interval since this dataset was expected to exhibit the least autocorrelation (Cullen et al., 2022).

Kernel Density Estimates (KDE), used to determine home ranges, were calculated at 50% and 95% isopleth levels, using the 'amt' R package (Johannes Signer, 2019). Home ranges refer to the area where the turtles frequently travel to, and re-visit, within a given time period and are represented by the core (50%; high-use) and overall (95%; average-use) use areas. KDE identifies the spatial distribution of the turtles' locations and estimates the density. All KDE analyses were performed using R Statistical Software (v4.3.1; R Core Team 2023) with packages 'tidyverse' (v2.0.0; Wickham et al., 2019), 'ggplot2' (3.4.4;Hadley Wickham, 2016), 'lubridate' (v1.9.3; Garrett Grolemund & Hadley Wickham, 2011), 'amt' (v0.1.2.0; Johannes Signer, 2019), and 'sf''(v1.0.15; Pebesma, 2018).

2.5 Dive Data Analysis

Data were downloaded from the Wildlife Computers Data Portal. Descriptive analysis of Dive Duration, Time-At-Temperature, and Time-At-Depth were conducted for each individual turtle and summarized across all turtles. The data were analyzed for different temporal scales: daily (diel), monthly and seasonally. Tags were deployed during different time frames (June and November), resulting in varying durations and coverage across different months and seasons. This also provides a comprehensive analysis across different periods, as some months have more/less data than others. Temperature data were examined daily, monthly, and seasonally, both for individual turtles and summarized across all turtles. All analyses were performed using R Statistical Software (v4.3.1; R Core Team 2023) packages 'ggplot2' (3.4.4; Wickham 2016), 'dplyr' (1.1.3; Wickham et al., 2023), and 'tidyr' (1.3.1; Wickham 2023). Diel activity was examined to determine the proportion of time that turtles spent at different temperatures, depths, and dive durations during day-night periods. Day-night was determined based on sunrise and sunset data from Willy Weather (Willy Weather, 2024) (Table 1). Seasons were separated as the following: May to October as 'Summer' and December to April as 'Winter' (based off water temperature, rather than a typical calendar season).

**Table 1.** Hours considered for the day-night analysis were based on sunrise and sunset times for each month. The columns 'Sunrise' and 'Sunset' are shown in 24-hour format (PST). 'Diurnal Hours' indicates the total number of daytime hours and the 'Nocturnal Hours' represents the total number of nighttime hours.

| Month | Sunrise | Sunset | Diurnal Hours | Nocturnal Hours |
|---|---|---|---|---|
| January | 7 | 17 | 10 | 14 |
| February | 7 | 17 | 10 | 14 |
| March | 6 | 19 | 13 | 11 |
| April | 6 | 19 | 13 | 11 |
| May | 6 | 20 | 14 | 10 |
| June | 6 | 20 | 14 | 10 |
| July | 6 | 20 | 14 | 10 |
| August | 6 | 20 | 14 | 10 |
| September | 7 | 19 | 12 | 12 |
| October | 7 | 18 | 11 | 13 |
| November | 6 | 17 | 11 | 13 |
| December | 7 | 17 | 10 | 14 |

**3.0 Results**

3.1 Green Sea Turtle Study Animals

Straight carapace length of nine transmitter-equipped green turtles (Table 2) ranged from 52.5 to101.6 cm (mean = 72.9 cm, SD = 15.61 cm). Curved carapace length ranged from 56.9 to 109.0 cm (mean = 72.8 cm, SD = 15.8 cm). Body mass ranged from 21.0 to 131.0 kg (mean = 57.9 kg, SD = 35.9 kg). The number of transmission days ranged from 21.2 to 213.0 days (Table 2).

**Table 2.** Identification (ID) and PTT ID of green turtles equipped with Fastloc transmitters. Summary of body size (SCL = straight carapace length) (CCL = curved carapace length), body mass (kg), sex (U=unknown sex), first and last day of transmission and total tracking duration (days). Number of analyzed dive parameter measurements (dpm) transmitted via Argos for dive duration (DD), Time-At-Depth (TAD) and Time-At-Temperature (TAT).

| ID | PTT ID | SCL (cm) | CCL (cm) | Body Weight (kg) | Putative Sex | First Day of Transmission | Last Day of Transmission | Total Tracking Duration (Days) | DD dpm** | TAD dpm** | TAT dpm** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **GS1** | 244722 | 52.5 | 56.9 | 21 | U | 6/6/2023 | 8/3/2023 | 57 | 347 | 379 | 363 |
| **GS2** | 253468 | 56.5 | 59.9 | 26 | U | 11/30/2023 | 4/3/2024 | 116 | 540 | 536 | 384 |
| **GS3** | 244721 | 65.2 | 69.5 | 31 | U | 6/13/2023 | 7/19/2023 | 35 | NA* | NA* | 260 |
| **GS4** | 253467 | 65.4 | 69.3 | 42 | U | 11/30/2023 | 3/9/2024 | 99 | 245 | 260 | 260 |
| **GS5** | 244723 | 68.4 | 71.6 | 43 | M | 6/8/2023 | 6/30/2023 | 21 | 105 | 104 | 100 |
| **GS6** | 253469 | 76.4 | 80.1 | 61 | M | 11/30/2023 | 6/2/2024 | 184 | NA* | NA* | 2181 |
| **GS7** | 244729 | 83.6 | 90.1 | 75 | F | 6/1/2023 | 10/8/2023 | 128 | 1955 | 1929 | 1947 |
| **GS8** | 253470 | 86.3 | 93.0 | 91 | U | 11/30/2023 | 7/1/2024 | 213 | 3178 | 3181 | 3180 |
| **GS9** | 244730 | 101.6 | 109 | 131 | F | 6/8/2023 | 10/23/2023 | 136 | 1718 | 1701 | 1720 |

*Transmitter malfunction, depth data not transmitted
**data only from SDB

Turtle GS3 and GS6 did not give any information on dive parameters likely due to a malfunction in the tag's depth function. Also, note that turtle GS8 did not collect any data on dive duration during the month of July. Turtle GS2 departed San Diego Bay for 13 days, traveling about 125 km south to Baja, Mexico before returning to SDB. Coastal movements (outside SDB) for turtle GS2 were analyzed separately, insights to migration and dive patterns are detailed in the open water migration section of this report. Tag transmissions during these coastal movements showed deeper depth ranges and anomalous temperatures outside of SDB. These data were not included in the analysis with the other turtles that stayed within SDB, however this information is included in the supplemental material. Tags on turtles GS1, GS3 and GS5 were deployed and stopped transmission during the summer months. Tags on turtles GS7 and GS9 were deployed in the summer and stopped transmission during the fall. Tags on turtles GS2, GS4, GS6 and GS8 were deployed in the fall and stopped transmitting in the spring and summer months. For the purpose of analyses, all tag data aside from turtles GS3, GS6 and open water migration data from GS2, were used for depth and temperature analyses.

3.2 Home Range

We observed consistent use of the southern portion of SDB, near capture and release sites (Figure 2). For the KDE 95% criteria, home range sizes for SDB turtles ranged from 7.97 $km^2$ to 53.74 $km^2$, with a mean of 25.39 $km^2$ (SD = 18.21 $km^2$, SE = 6.07 $km^2$) (Table 3). The KDE 50% contour areas (core use areas) ranged from 0.86 $km^2$ to 12.73 $km^2$. At the 50% contour level, we found a mean of 5.07 $km^2$ (SD = 3.78 $km^2$, SE = 1.26 $km^2$). Turtle GS2 exhibited the largest 95% home range size of 53.74 $km^2$. Conversely, Turtle GS8 experienced small values for both 50% = 0.86 $km^2$ and 95% = 7.97 $km^2$, based on its transmission data. In addition, we included minimum convex polygons in our analysis to provide a more comprehensive understanding of the spatial areas utilized (see Supplementary Figure S7).

**Table 3.** Kernel Density Estimation (KDE) area of each individual turtle's home range ($km^2$), 50% KDE and 95% KDE.

| ID | PTT ID | 50% KDE ($km^2$) | 95% KDE ($km^2$) |
|---|---|---|---|
| GS1 | 244722 | 2.63 | 16.54 |
| GS2 | 253468 | 12.73 | 53.74 |
| GS3 | 244721 | 6.53 | 25.39 |
| GS4 | 253467 | 10.29 | 49.36 |
| GS5 | 244723 | 6.61 | 26.8 |
| GS6 | 253469 | 1.44 | 10.2 |
| GS7 | 244729 | 1.96 | 8.95 |
| GS8 | 253470 | 0.86 | 7.97 |
| GS9 | 244730 | 1.95 | 9.97 |


**Figure 2.** Kernel Density Estimation (KDE) distribution maps for each individual turtle (KDE50 is depicted in red and KDE95 is depicted in blue).

3.3. Open Water Migration

Turtle GS2 embarked on a migration from San Diego Bay (32.6717°N, 117.1441°W) to Baja California, Mexico (Figure 3). The turtle travelled a total distance of 214.3km (129.9km southbound and 111.4km northbound) from 8 December to 19 December 2023 (a total of 12 days).

Dive durations were analyzed across the migration (Figures 4, S8, and S9). During the day, the turtle spent extended periods of time diving at various durations, with notable proportions of dives in the <3-minute range (19.81%), 3–5-minute range (23.58%), and 5–10-minute range (27.36%; Table 4). At night the turtle spent majority of its time within three dive categories: <3min duration (24.63%), 3-5min duration (23.75%), and the 5–10min duration (29.03%). Across the entire migration, dives within the 5–10min duration (28.64%) were most common. The remaining dive durations were exhibited less frequently, with lower proportions for longer dives exceeding 10-20 minutes.

**Table 4.** Mean Dive Duration proportions of GS2 across both day and night through the month of December.

| Duration(min) | Total Proportion | Day Proportion | Night Proportion |
|---|---|---|---|
| <3 min | 23.49 | 19.81 | 24.63 |
| 3-5 min | 23.71 | 23.58 | 23.75 |
| 5-10 min | 28.64 | 27.36 | 29.03 |
| 10-20 min | 13.87 | 11.32 | 14.66 |
| 20-30 min | 3.80 | 6.60 | 2.93 |
| 30-40 min | 3.13 | 3.77 | 2.93 |
| 40-60 min | 1.79 | 2.83 | 1.47 |
| 60-80 min | 0.45 | 1.89 | 0.00 |
| 80-100 min | 0.22 | 0.00 | 0.29 |
| 100-120 min | 0.89 | 2.83 | 0.29 |

Time-at-depth was analyzed across the migration (Figure S10, S11, and S12). At night, the turtle occurred most frequently at 2m (59.93%), 5m (21.15%) and 10m (15.53%) depth bins (Table 5). During the day, the turtle frequented the upper-most 2m depth (67.20%). Interestingly, during the day, the turtle was tracked at the 15m depth (3.27%) more often than during the night (1.70%). Additionally, GS2 was least frequently reported at the 20m (1.42%), 25 m (1.19%), and 30m (0.04%) depths during migration. Across the entire migration period, the 2m depth (62.40%) was utilized the most frequently.

**Table 5.** Mean Time at Depth proportions of GS2 across day and night throughout the month of December.

| Depth (m) | Total Proportion | Day Proportion | Night Proportion |
|---|---|---|---|
| 2 m | 62.40 | 67.20 | 59.93 |
| 5 m | 17.90 | 13.75 | 21.15 |
| 10 m | 14.93 | 11.60 | 15.53 |
| 15 m | 2.13 | 3.27 | 1.70 |
| 20 m | 1.42 | 3.17 | 1.59 |
| 25 m | 1.19 | 0.87 | 0.11 |
| 30 m | 0.04 | 0.13 | 0.00 |

Time-at-temperature was observed during the migration (Figure S13, S14, and S15). The most frequent temperature that GS2 experienced was 18°C (96.34%; Table 6). The proportion of time spent at 18°C was nearly identical between day (95.93%) and night (96.56%).

**Table 6.** Mean Time at Temperature proportions of GS2 across day and night throughout the month of December.

| Temperature | Total Proportion | Day Proportion | Night Porportion |
|---|---|---|---|
| 14°C | 0.00 | 0.00 | 0.00 |
| 16°C | 3.65 | 4.07 | 3.44 |
| 18°C | 96.34 | 95.93 | 96.56 |
| 20°C | 0.00 | 0.00 | 0.01 |

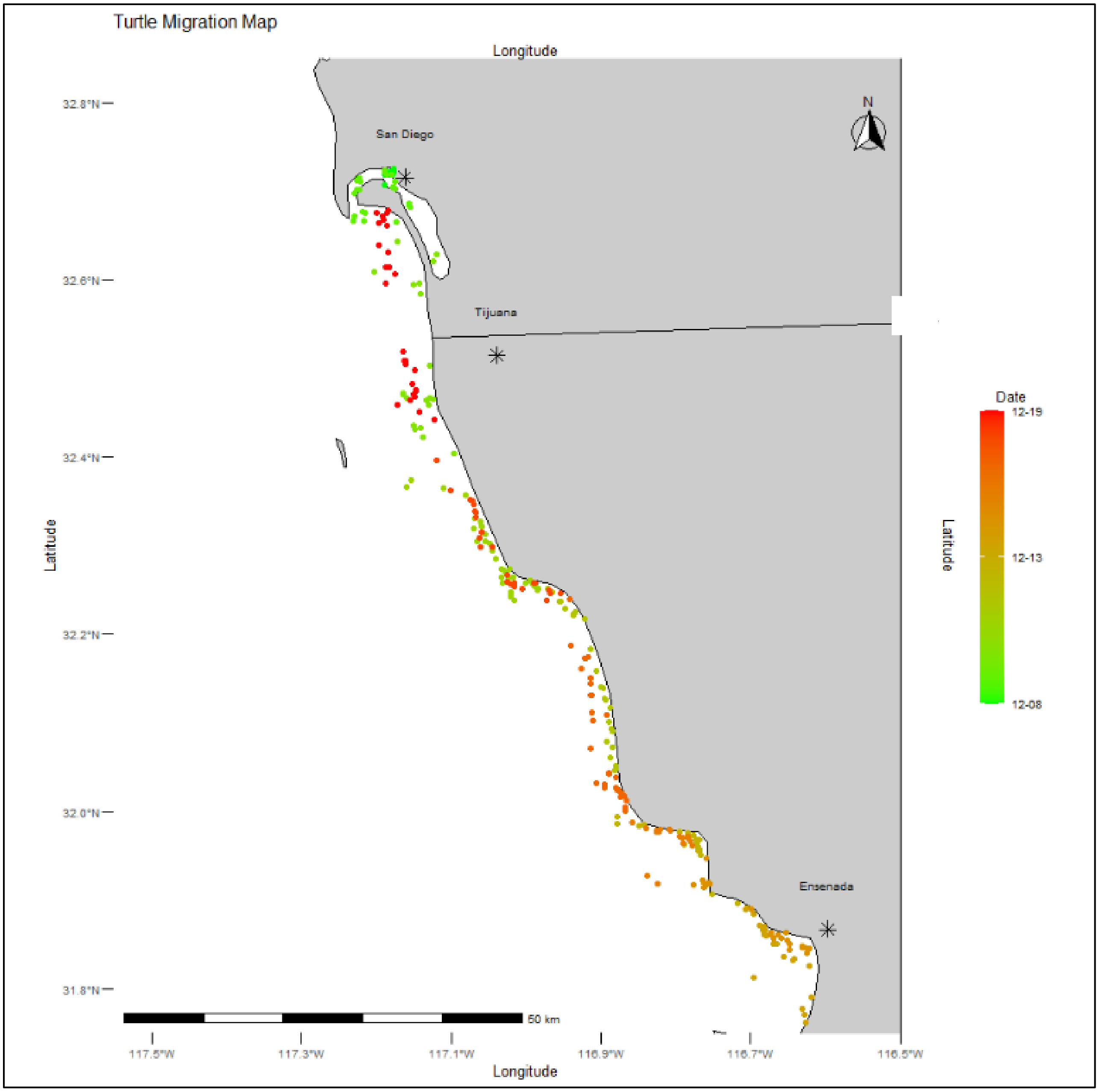


**Figure 3.** Map showing the roundtrip migration path of turtle GS2 (PTT ID 253468) over a 13-day period, displaying the raw locations (Argos and Fastloc-GPS) from SDB to Baja, California (and back to SDB). The map shows a color gradient to represent the dates of the turtle's locations, ranging from green (beginning of travel) to red (ending of travel).

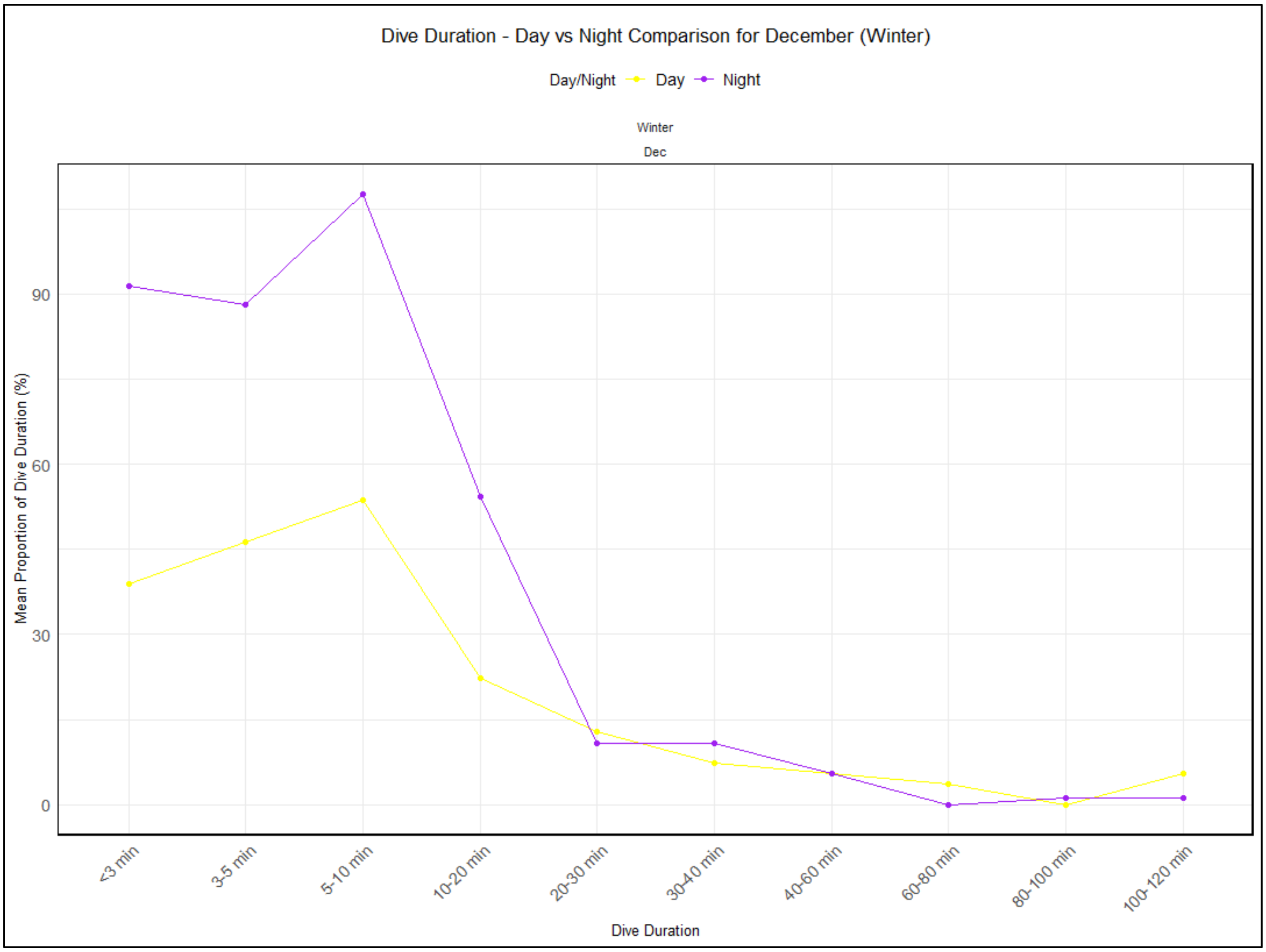


**Figure 4.** Mean dive duration during both day and night periods, across the migration of GS2 to Baja California. The horizontal axis represents the time of day, while the vertical axis illustrates the mean proportions of dive durations. Colored lines represent the dive duration.

3.4 San Diego Bay Dive Information

3.4.1 Dive Duration

The diel analysis revealed distinct variations in dive durations between day and night (Figure 5, Table 7 and 8). Overall, shorter dives (<3 minutes) were more common at night (27.10%) compared to during the day (20.09%), while longer dives between 30 to 100 minutes were also more frequent at night (1.21%) than during the day (0.40%). In terms of seasonal trends, the summer revealed that consistent and shorter dives were more common at night (27.10%) than during the day (20.09%) and longer dives (30-100 minutes) were also more common at night (1.21%; Table 7). Conversely, in the summer, 5 to 10 minute dives were most common during the day (27.77%). In the winter, daytime dives tended to be longer, ranging from 10 to 20 minutes (13.61%; Table 8). Furthermore, at night, dives during the winter showed a higher proportion of longer dives, particularly in the 40 to 60 minutes (9.68%) and 60 to 80 minutes (9.11%). Interestingly, the occurrence of very short dives (<3 minutes) was consistent across diel hours and both seasons, maintaining similar high proportions (~19%; Table 7 & 8).

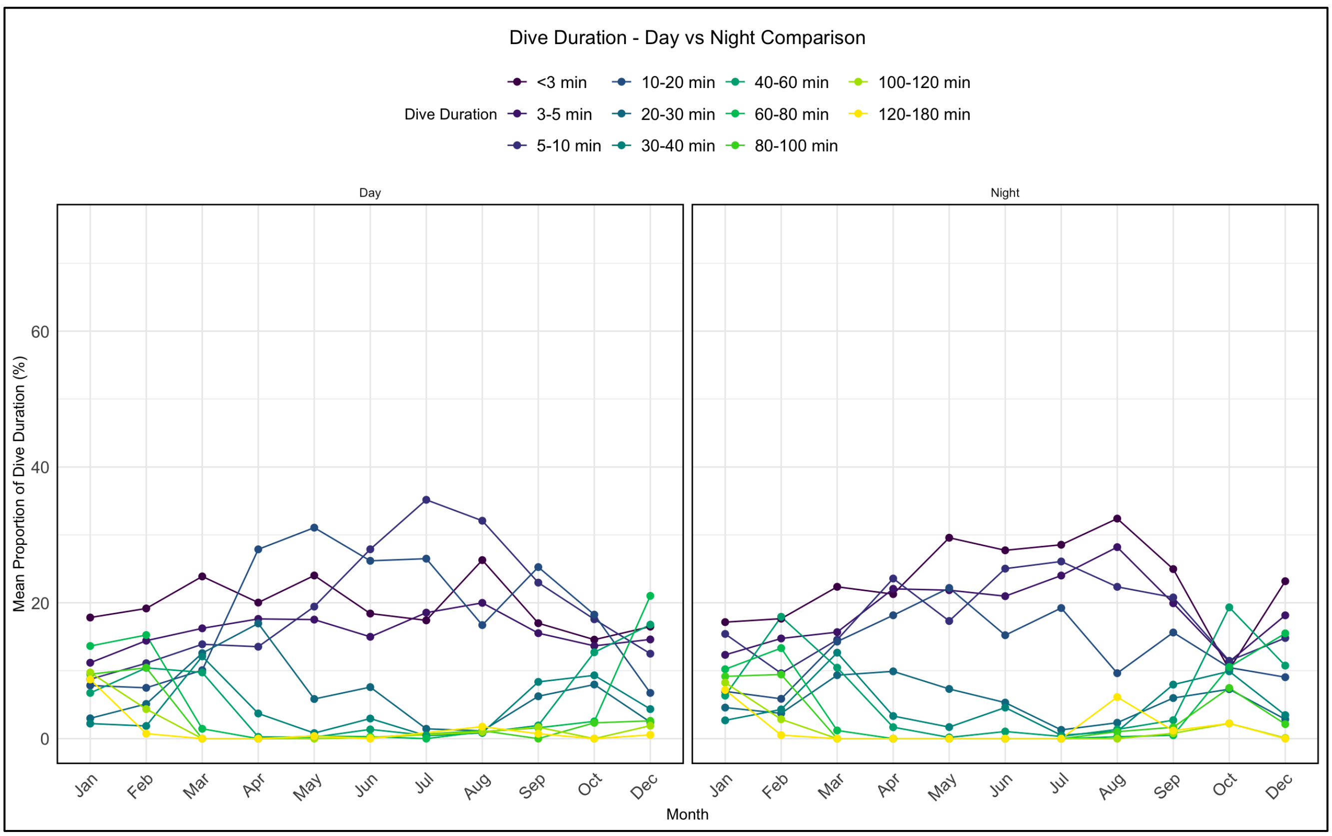


**Figure 5.** Mean dive durations across all turtles during diurnal hours (left plot: Day) and nocturnal hours (right plot: Night). Each plot corresponds to the overall dive duration patterns of the turtles across different months. The horizontal axis represents the months of the year, while the vertical axis represents the mean proportions of dive duration (%) for various duration intervals. These dive duration intervals are color coded in the legend from light yellow to purple.

**Table 7.** Mean Dive Duration proportions of tracks recorded in the summer months across both day and night.

| Dive Duration (minutes) | Mean Proportion of Dive Duration (Day) (%) | Mean Proportion of Dive Duration (Night) (%) |
|---|---|---|
| <3 | 20.09 | 27.10 |
| 3-5 | 17.05 | 21.92 |
| 5-10 | 27.77 | 21.77 |
| 10-20 | 24.85 | 15.58 |
| 20-30 | 4.68 | 4.74 |
| 30-40 | 2.84 | 4.07 |
| 40-60 | 1.39 | 2.52 |
| 60-80 | 0.74 | 1.04 |
| 80-100 | 0.40 | 1.21 |
| 100-120 | 0.44 | 0.40 |
| 120-180 | 0.42 | 0.95 |

**Table 8.** Mean Dive Duration proportions of tracks recorded in the winter months across both day and night.

| Dive Duration (minutes) | Mean Proportion of Dive Duration (Day) (%) | Mean Proportion of Dive Duration (Night) (%) |
|---|---|---|
| <3 | 19.78 | 20.68 |
| 3-5 | 15.41 | 16.77 |
| 5-10 | 12.48 | 15.44 |
| 10-20 | 13.61 | 10.56 |
| 20-30 | 9.33 | 5.62 |
| 30-40 | 5.42 | 5.02 |
| 40-60 | 8.44 | 9.68 |
| 60-80 | 8.84 | 9.11 |
| 80-100 | 3.20 | 3.95 |
| 100-120 | 2.19 | 1.98 |
| 120-180 | 1.24 | 1.34 |

Analysis of monthly dive duration patterns revealed seasonal variability (Figure 6, Table 9 and 10). During the summer, dives in the 5-to-10-minute category (31.97%) and the <3-minute category (28.86%) were the most frequent (Table 9). Shorter dives (<3 minutes) were most common during the month of August (28.86%) and least common in October (13.80%). Similarly, dives within the 5-to-10-minute category are highest during the month of July (31.97%) and are lowest in October (13.80%). Longer dives between 40 to 60 minutes increased in October (16.80%). During the winter, shorter dives (<3 minutes) were more consistent and were at peak in the month of February (23.19%; Table 10). Longer dives between 40 to 60 and 60 to 120 minutes were most frequent in December (8.80%) and January (14.83%). Winter months displayed a broader range of dive duration between

<3min to 180min. However, dive durations in the winter were more evenly distributed across the range of durations (Table 10), whereas during the summer shorter dive durations had a higher frequency of occurrence May through August (Table 9). Following August, the frequency of shorter dive durations decreased and the frequency of longer dive durations increased from August through October (Figure 6).

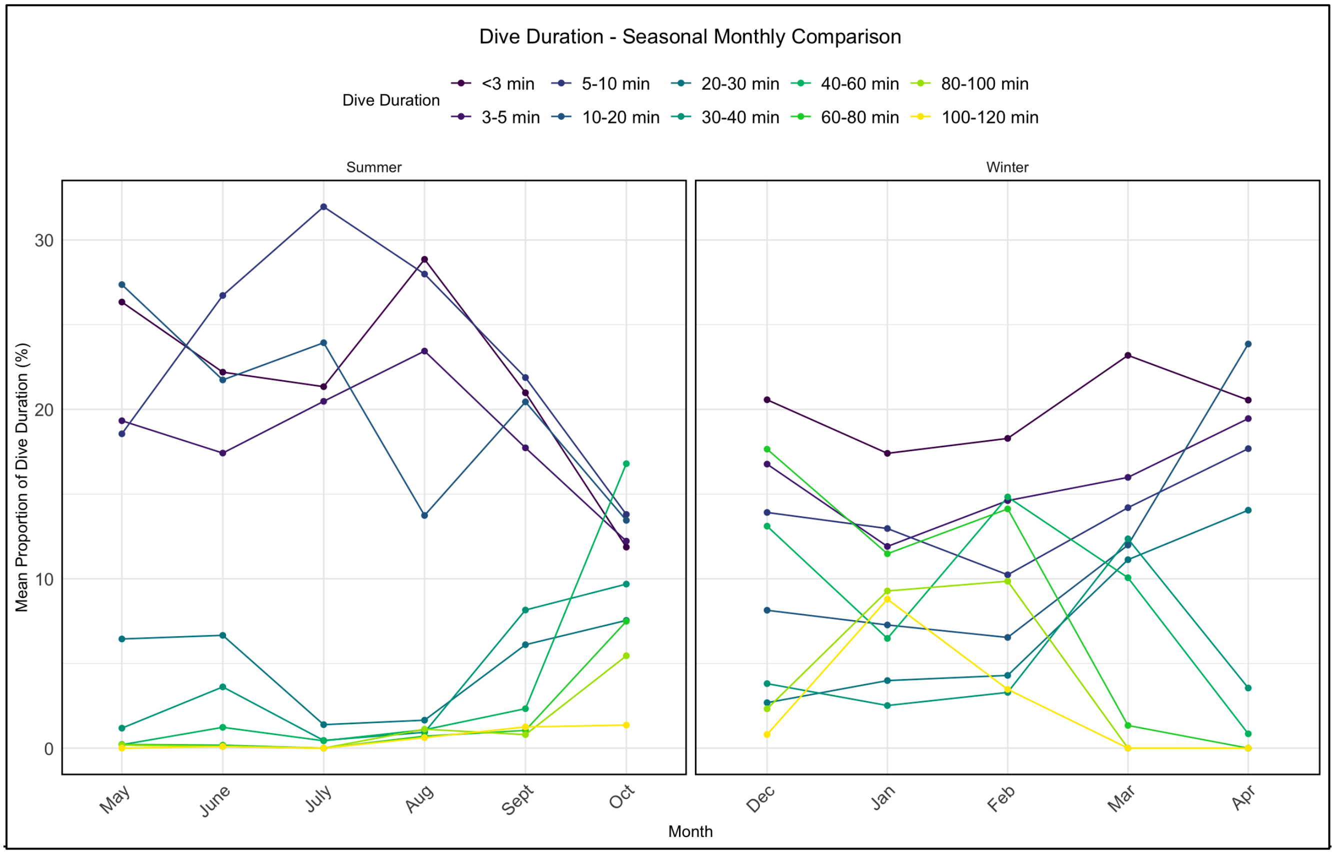


**Figure 6.** Monthly mean dive durations across all turtles. The left plot corresponds to the summer season months (May to October), while the right plot represents the winter season (December to April). The horizontal axis represents the months per season, while the vertical axis represents the mean proportion of dive duration (%) for various duration intervals. These dive duration intervals are color coded in the legend from light yellow to purple.

**Table 9.** Mean Dive Duration proportions of tracks recorded in the summer months.

| Dive Duration (minutes) | May (%) | Jun (%) | Jul (%) | Aug (%) | Sept (%) | Oct (%) |
|---|---|---|---|---|---|---|
| <3 | 26.34 | 22.20 | 21.34 | 28.86 | 20.98 | 11.87 |
| 3-5 | 19.33 | 17.42 | 20.48 | 23.45 | 17.73 | 12.22 |
| 5-10 | 18.56 | 26.73 | 31.97 | 27.99 | 21.88 | 13.80 |
| 10-20 | 27.37 | 21.74 | 23.94 | 13.74 | 20.44 | 13.45 |
| 20-30 | 6.45 | 6.66 | 1.39 | 1.65 | 6.11 | 7.54 |
| 30-40 | 1.18 | 3.62 | 0.46 | 0.94 | 8.16 | 9.69 |
| 40-60 | 0.20 | 1.23 | 0.43 | 1.09 | 2.33 | 16.80 |
| 60-80 | 0.22 | 0.18 | 0.00 | 0.71 | 1.05 | 7.49 |
| 80-100 | 0.18 | 0.10 | 0.00 | 1.12 | 0.80 | 5.45 |
| 100-120 | 0.00 | 0.10 | 0.00 | 0.62 | 1.25 | 1.36 |
| 120-180 | 0.22 | 0.00 | 0.00 | 3.36 | 0.94 | 1.36 |

**Table 10.** Mean Dive Duration proportions of tracks recorded in the winter months

| Dive Duration (minutes) | Dec (%) | Jan (%) | Feb (%) | Mar (%) | Apr (%) |
|---|---|---|---|---|---|
| <3 | 20.57 | 17.41 | 18.29 | 23.19 | 20.55 |
| 3-5 | 16.77 | 11.91 | 14.61 | 15.99 | 19.46 |
| 5-10 | 13.92 | 12.97 | 10.23 | 14.20 | 17.68 |
| 10-20 | 8.14 | 7.27 | 6.54 | 11.99 | 23.86 |
| 20-30 | 2.68 | 3.99 | 4.30 | 11.13 | 14.05 |
| 30-40 | 3.81 | 2.52 | 3.29 | 12.36 | 3.55 |
| 40-60 | 13.11 | 6.48 | 14.83 | 10.06 | 0.85 |
| 60-80 | 17.65 | 11.48 | 14.13 | 1.34 | 0.00 |
| 80-100 | 2.32 | 9.28 | 9.86 | 0.00 | 0.00 |
| 100-120 | 0.81 | 8.80 | 3.47 | 0.00 | 0.00 |
| 120-180 | 0.22 | 7.74 | 0.61 | 0.00 | 0.00 |

Based on preliminary analyses, there appears to be no clear trend or pattern in dive duration behavior among individual turtles. Dive durations seem to vary according to individual preferences. However, continued data collection and further statistical analyses are needed in the future to reveal statistically significant differences, trends, and patterns in dive duration behavior for the population of green turtles in SDB. All individual turtle dive duration graphs (day/night and monthly) are shown in the supplementary section (Figure S1 & S2).

3.4.2. Time-At-Depth

Diel analysis of time at depth revealed notable dive patterns during the day and night across seasons (Figure 7). During the summer, turtles spent a majority of time at depths between 0 and 2 meters during both day (80.11%) and night (81.21%; Table 10). The 2-to-5-meter depths were the second most frequented depths in the summer during both day (20.96%) and night (15.81%). All other depths deeper than 5m were not notable as turtles rarely dove deeper than 5m (9.36%.) Similarly, during the winter, the 0-to-2-meter depths were also the most frequented depths during both day (75.85%) and night (78.37%; Table 11). Additionally, during the winter, the 2-to-5-meter depths were also the second most frequented depths during both day (36.50%) and night (15.81%). In the winter, depths deeper than 5m were not notable as turtles rarely dove deeper than 5m (5.92%).

Seasonal and monthly analysis revealed notable trends across the time at depth (Figure 8). During the summer, individuals spent the majority of time in the 0-to-2-meter depths, while gradually increasing to deeper depths as the season progressed (Table 12, 13). The 0-to-2-meter depth had the highest proportion of time spent in May (91.05%), although proportion of time spent in this depth category decreased significantly through October (56.65%). Time spent within the 2 to 5 meters depth increased from May (15.57%) to July (21.07%), then decreased in August (19.08%). Time spent in the 2-to-5-meter depth category increased again in September when it reached the maximum amount of time spent in this depth category (23.03%). During the winter, individuals, similarly to summer, spent majority of time in the 0-to-2-meter depths, but also spent a large amount of time spent in the 2-to-5-meter depths. The 0-to-2-meter depth category had the highest proportion of time spent in April (88.16%) which was a notable increase from January (69.10%). During winter, the 2-to-5-meter depth category showed a high frequency of use in January (47.68%) and February (48.10%) and declined in use as the season progressed. Following this decline towards the end of winter, frequency of use shifted towards the 0-to-2-meter depth category for the summer as mentioned above. Overall, a trend appears demonstrating that turtles tend to use the shallower depth categories (0 to 2 meters) more frequently in the summer than in the winter. While, in the winter it appears that both shallow (0 to 2 meter) and moderately shallow (2 to 5 meter) depths are frequented by turtles.

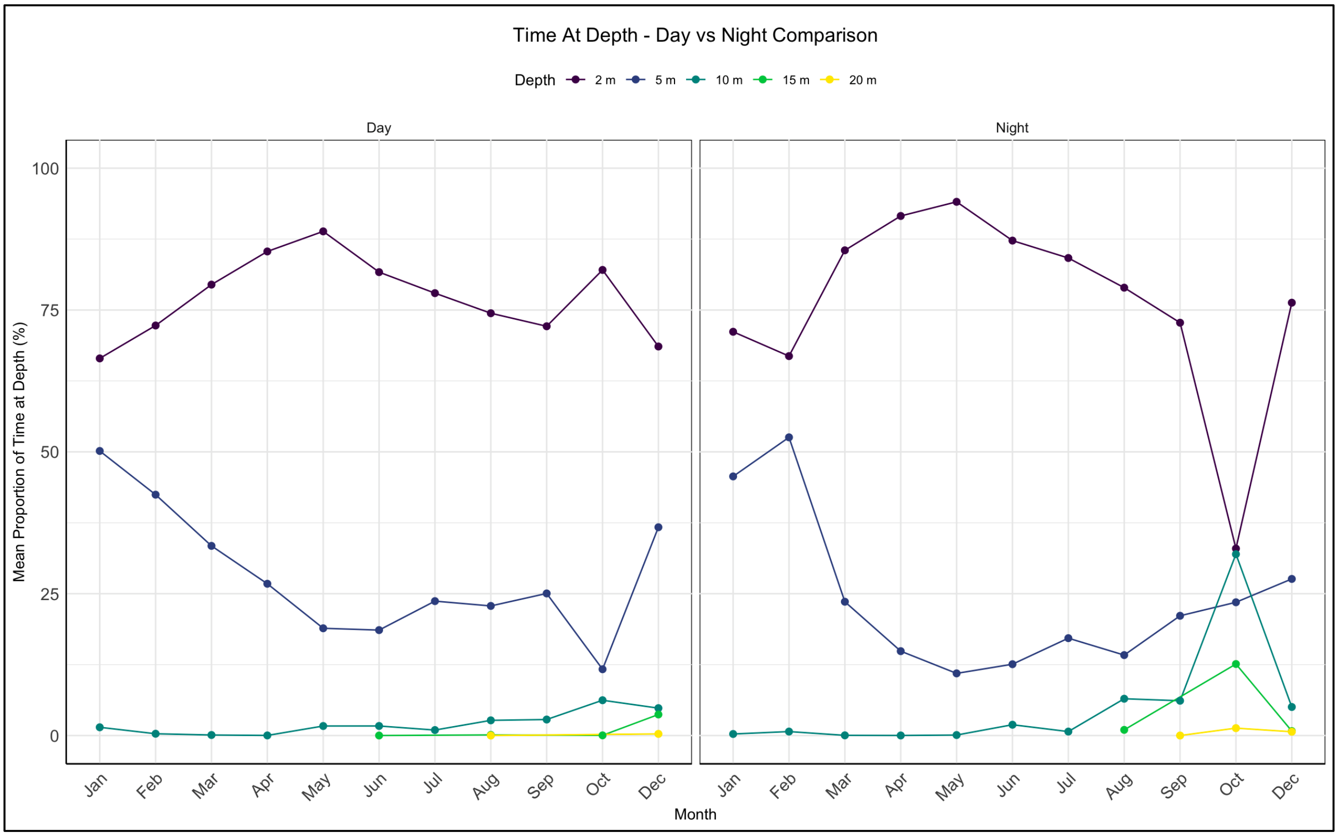


**Figure 7.** Mean proportions of time spent at certain depths across all turtles during diurnal hours (left plot: Day) and nocturnal hours (right plot: Night). Each plot corresponds to the overall time at depth patterns of the turtles across different months. The horizontal axis represents the months of the year, while the vertical axis represents the mean proportions of TAD (%) for various depths. These TAD depths are color coded in the legend from light yellow to purple.

**Table 10.** Mean Time at Depth proportions of tracks recorded in the summer months across day and night.

| Time At Depth (meters) | Mean Proportion of Dive Duration (Day) (%) | Mean Proportion of Dive Duration (Night) (%) |
|---|---|---|
| 0-2 | 80.11 | 81.21 |
| 2-5 | 20.96 | 15.81 |
| 5-10 | 2.06 | 5.03 |
| 10-15 | 0.03 | 2.20 |
| 15-20 | 0.00 | 0.22 |

**Table 11.** Mean Time at Depth proportions of tracks recorded in the winter months across day and night.

| Time At Depth (meters) | Mean Proportion of Dive Duration (Day) (%) | Mean Proportion of Dive Duration (Night) (%) |
|---|---|---|
| 0-2 | 75.85 | 78.37 |
| 2-5 | 36.50 | 31.92 |
| 5-10 | 1.42 | 1.82 |
| 10-15 | 1.75 | 0.43 |
| 15-20 | 0.14 | 0.36 |

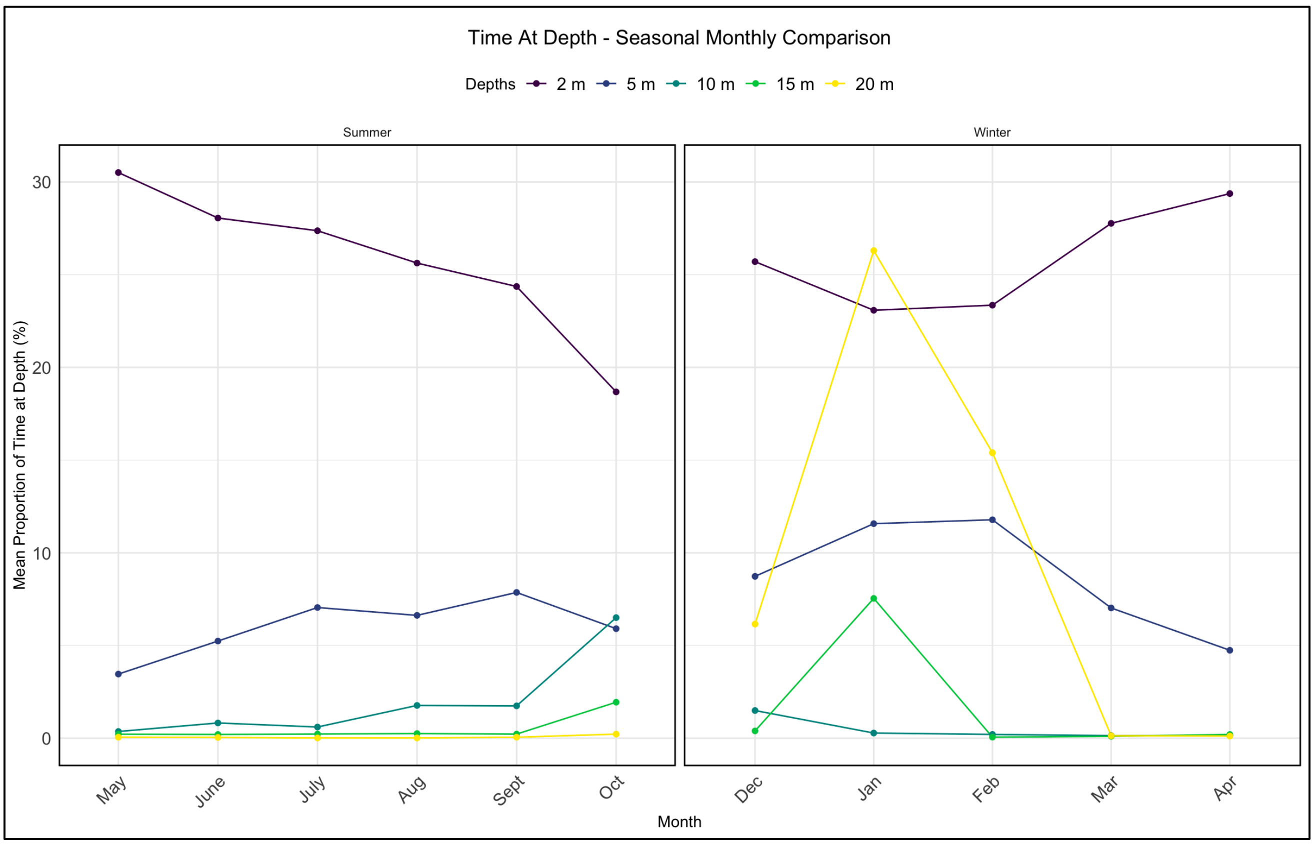


**Figure 8.** Monthly Mean proportions of time spent at certain depths across all turtles. The left plot corresponds to the summer season months (May to October), while the right plot represents the winter season (December to April). The horizontal axis represents the months per season, while the vertical axis represents the mean proportion of TAD (%) for various depths. These depths are color coded in the legend from light yellow to purple.

**Table 12.** Mean Time at Depth proportions of tracks recorded in the summer months.

| Time At Depth (meters) | May (%) | Jun (%) | Jul (%) | Aug (%) | Sept (%) | Oct (%) |
|---|---|---|---|---|---|---|
| 0-2 | 91.05 | 84.08 | 80.47 | 76.39 | 72.45 | 56.65 |
| 2-5 | 15.57 | 16.02 | 21.07 | 19.08 | 23.03 | 17.79 |
| 5-10 | 1.01 | 1.78 | 0.86 | 4.33 | 4.51 | 19.55 |
| 10-15 | 0.00 | 0.00 | 0.00 | 0.49 | 0.00 | 6.32 |
| 15-20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.65 |

**Table 13.** Mean Time at Depth proportions of tracks recorded in the winter months.

| Time At Depth (meters) | Dec (%) | Jan (%) | Feb (%) | Mar (%) | Apr (%) |
|---|---|---|---|---|---|
| 0-2 | 73.30 | 69.10 | 69.20 | 82.14 | 88.16 |
| 2-5 | 31.12 | 47.68 | 48.10 | 29.08 | 21.27 |
| 5-10 | 4.95 | 0.80 | 0.53 | 0.07 | 0.02 |
| 10-15 | 1.98 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15-20 | 0.51 | 0.00 | 0.00 | 0.00 | 0.00 |

3.4.3 Time-At-Temperature

Diel analysis of time at temperature revealed distinct patterns in time spent at various temperatures. These distinct patterns can be seen between day and night and across seasons (Table 14, 15). Generally, in the summer turtles experienced a range of temperatures from 18°C (0.01%.) to 32°C (0.01%). During summer month's turtles most frequently experienced 24°C temperatures across both day (36.55%) and night (32.29%; Table 14). The second most common temperature that turtles experienced was 26°C during both day (29.40%) and night (31.00%). Overall, during the summer, turtles primarily experienced temperatures between 22°C to 26°C. During the summer individuals experienced higher temperatures more frequently, with a peak in July (26°C: 54.88%) and August (26°C: 43.77%, 28°C: 51.03%). The high proportion of time that turtles spent between 22°C to 26°C in the summer months is likely a result of a higher consistent average water temperature in SDB during these summer months. Figure 9 demonstrates that average water temperatures in SDB are greater than 20°C from July through October. Green turtles may have experienced temperatures either below 20°C or higher than 26°C in the summer months as a result of moving north towards the mouth of the bay (towards cooler temperatures) or moving into shallower areas of the water column (towards warmer temperatures).

During the winter, turtles experienced water temperatures between 14°C (Day: 3.34%, Night: 1.87%) and 26°C (Day: 0.00%, Night: 0.31%), not experiencing any temperatures past 26°C. In contrast to summer, during the winter season turtles most frequently experienced 18°C temperatures during both the day (37.39%) and night (41.90%). The second most common temperature that turtles experienced was 20°C (Day: 28.54%, Night: 18.62%). During the winter, individuals experienced lower temperatures a majority of the time with a peak in December (18°C: 84.99%) and January (16°C: 47.72%, 18°C: 35.53%). Generally, turtles experienced higher variation across temperatures in the winter months, while temperature range remained more consistent in the summer. While average SDB water temperature during winter months (Nov to Apr) tend to be between 14 to 18°C, it is possible that green turtles moved towards areas of SDB that might have warmer than average water temperatures, such as south SDB and shallower slope areas within south SDB (inshore areas of south SDB).

Overall, individuals during the summer months experienced a higher temperature range from 22°C to 28°C, while individuals during the winter experienced lower a lower temperature range from 14°C to 20°C. Between both seasons, it appears that, when possible, turtles tended to move towards warmer waters during the summer and winter.

**Table 14.** Mean Time at Temperature proportions of tracks recorded in the summer months across day and night.

| Time At Temperature (°C) | Mean Proportion of Dive Duration (Day) (%) | Mean Proportion of Dive Duration (Night) (%) |
|---|---|---|
| 14 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 |
| 18 | 0.01 | 0.00 |
| 20 | 0.59 | 0.06 |
| 22 | 21.40 | 11.98 |
| 24 | 36.55 | 32.29 |
| 26 | 29.40 | 31.00 |
| 28 | 13.56 | 25.08 |
| 30 | 0.03 | 2.57 |
| 32 | 0.00 | 0.01 |

**Table 15.** Mean Time at Temperature proportions of tracks recorded in the winter months across day and night.

| Time At Temperature (°C) | Mean Proportion of Dive Duration (Day) (%) | Mean Proportion of Dive Duration (Night) (%) |
|---|---|---|
| 14 | 3.34 | 1.87 |
| 16 | 14.82 | 15.90 |
| 18 | 37.39 | 41.90 |
| 20 | 28.54 | 18.62 |
| 22 | 14.17 | 15.34 |
| 24 | 1.83 | 6.54 |
| 26 | 0.00 | 0.31 |
| 28 | 0.00 | 0.00 |
| 30 | 0.00 | 0.00 |

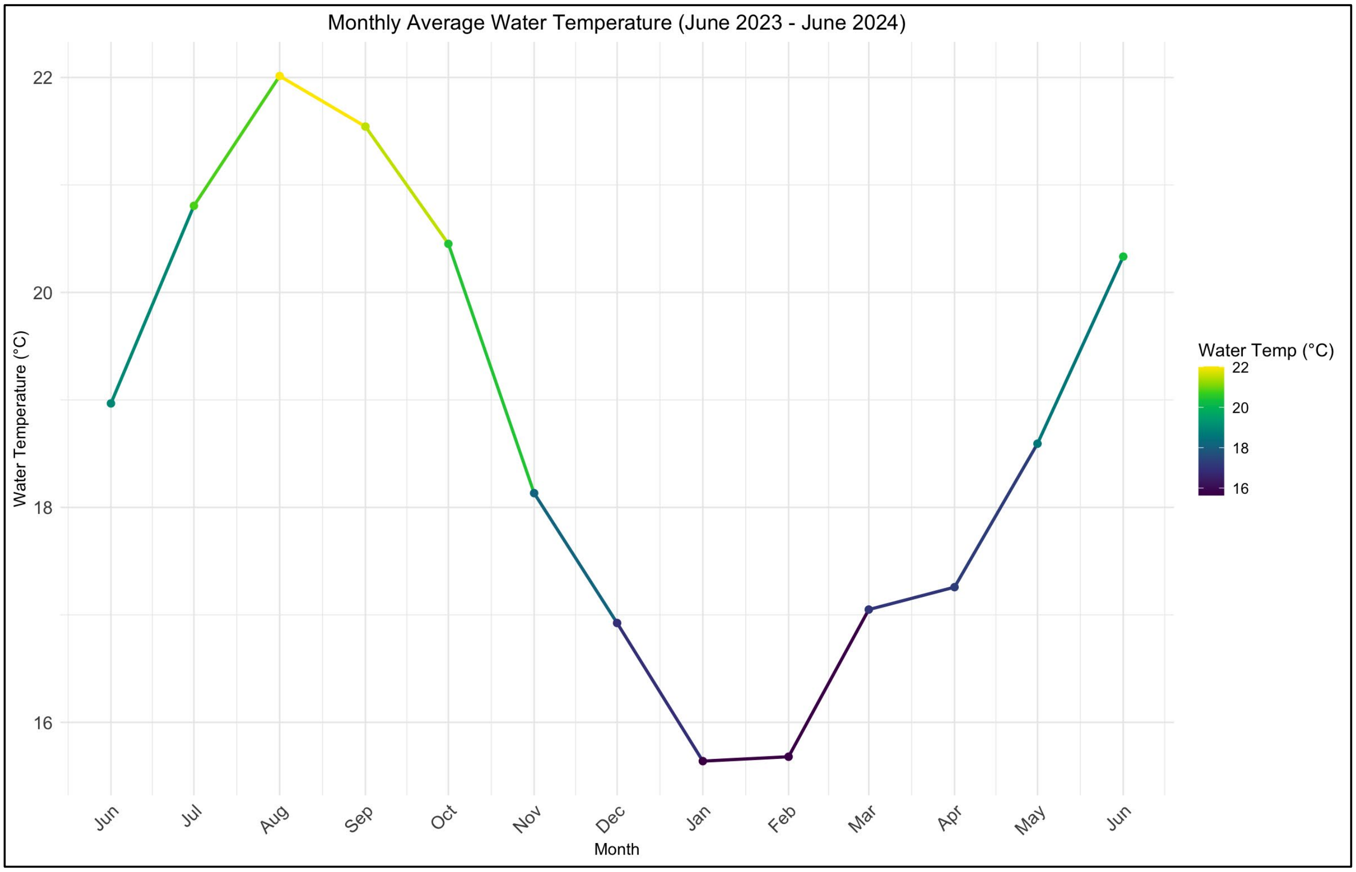


**Figure 9.** Monthly average water temperature in the bay from June 2023 to June 2024, based on NOAA buoy data. Each point represents the mean water temperature for the month, with warmer temperatures in late summer (August–September) and cooler temperatures in winter (February–March). The color scale indicates temperature variation.

### 4.0 Summary

Although green turtle diving activity in San Diego Bay has been explored in the past (Madrak et al., 2016, 2022), this is the first-ever study to examine green turtle dive behaviors throughout the diel cycle, and across various temporal scales (daily, monthly, seasonal). In this study, we combined Argos and Fastloc-GPS technologies to gather turtle diving behavior and location data. We collected dive data from the tagged green turtles to reveal distinct seasonal and diel behaviors through time spent at temperature and depth, and dive durations, despite limitations in both methods. Our turtle capture efforts were limited to one subsection of the southern region of the bay, where the demolished powerplant was previously located. A possible limitation is that these study animals may not be fully representative of the entire populations home range, although historic research in SDB indicates that the green turtle population primarily utilizes south SDB (Hart, K. et al. 2021).

A total of nine turtles were monitored with Fastloc GPS and depth enabled satellite transmitters, these transmitters provided novel data on green turtle dive patterns and habitat use within SDB. Analysis of dive duration indicated significant daily and seasonal patterns. The most frequent dive duration across all individuals was within less than 3min, while longer dives occurred more often throughout the daylight hours. Time individuals spent at specific depths was particullarly informative, indicating that turtles in SDB spend a majority of their time at the surface (indicated by dives <3 min), thus highlighting this popoulations vulnerability to anthropogenic activities and specifically vessel strikes. Across all individuals, turtles spent the majority of their time at the upper-most depth between 0 and 2 meters, with most dives within these depths occurring at night. Moderate depths between 2 and 5 meters were also highly utilized, especially during the winter season. This is important as turtles have high probabilities to vessel strike injuries due to the significant proportions of their time spent at shallower waters.

The results of this baseline analysis provide a better understanding of turtle hotspots and dive patterns across diel cycles and seasonally in SDB. This data along with those collected in future field efforts will be analyzed and comprehensive reports will be prepared. San Diego Bay has high vessel traffic year-round and data presented in this report are vital for informing conservation management in SDB and providing insight for future management strategies in SDB to avoid detrimental effects from vessel strikes to green turtles. This report provides data that on green turtle exposure and vulnerability in SDB and will aid natural resource managers in reducing the risk of injury or mortality in the green turtle population in SDB.

### 4.1 Recommendations

Given the results of this report and enhanced understanding of green turtle habitat use and dive patterns in San Diego Bay, recommendations for future direction of the study are:

- Expand and increase capture efforts in other subsections of the bay, such as the eastern areas within the Refuge which can potentially be used as an additional turtle capture site
- Assess the impact of human exposure such as vessel traffic, marinas, speed zones, and fishing presence on turtle behavior
- Increase the amount of deployed tags to give a better representation of behavioral patterns and movements
- Deploy turtle cameras to confirm specific behaviors such as foraging, resting, and transiting
- Identify and analyze dive patterns in alignment with Fastloc-GPS locations
- Identify and analyze dive duration simultaneously with depth of each dive to provide insights on specific green turtle activities during various dives
- Robust statistical analyses of green turtle behaviors amongst individuals to discern individual preferences

## 5.0 Acknowledgements

We gratefully acknowledge the NOAA Marine Turtle Ecology & Assessment Program (NOAA Southwest Fisheries Science Center), the Navy Marine Ecology Consortium (NMEC), and Naval Facilities Engineering Systems Command Southwest for logistical and funding support. Tracy Tempest provided invaluable assistance in preparation and undertaking of field capture efforts. This research was permitted under NOAA Research Permit No. 18238-03, and NOAA Institutional Animal Care and Use Committee Permit No. SWPI 2020-03.

## 6.0 References


Chadwick, D. B., & Largier, J. L. (1999). The influence of tidal range on the exchange between San Diego Bay and the ocean. Journal of Geophysical Research: Oceans, 104(C12), 29885–29899. https://doi.org/10.1029/1999jc900166

Cullen, J. A., Poli, C. L., Fletcher, R. J., & Valle, D. (2022). Identifying latent behavioural states in animal movement with M4, a nonparametric Bayesian method. Methods in Ecology and Evolution, 13(2), 432–446. https://doi.org/10.1111/2041-210X.13745

Dutton, P. H., LeRoux, R. A., LaCasella, E. L., Seminoff, J. A., Eguchi, T., & Dutton, D. L. (2019). Genetic analysis and satellite tracking reveal origin of the green turtles in San Diego Bay. Marine Biology, 166, 1-13.

Delgadillo-Hinojosa, F., Zirino, A., Holm-Hansen, O., Hernández-Ayón, J. M., Boyd, T. J., Chadwick, B., & Rivera-Duarte, I. (2008). Dissolved nutrient balance and net ecosystem metabolism in a Mediterranean - climate coastal lagoon: San Diego Bay. Estuarine, Coastal and Shelf Science, 76(3), 594–607. https://doi.org/10.1016/J.ECSS.2007.07.032

Eckert, K. L., Bjorndal, K. A., Abreu-Grobois, F. A., Donnelly, M., & Balazs, G. H. (1999). Research and Management Techniques for the Conservation of Sea Turtles Factors to Consider in the Tagging of Sea Turtles.

Eguchi T, Seminoff JA, LeRoux R, Dutton PH, Dutton DM (2010) Abundance and survival rates of green turtles in an urban environment: coexistence of humans and an endangered species. Mar Biol 157: 1869−1877.

Eguchi, T., Graham, S., Saunders, B., Bredvik, J., LeRoux, R., & Seminoff, J.A. (2020). Effects of power plant closure on green turtle spatial ecology. Endangered Species Research 41: 265–277.

Garrett Grolemund, & Hadley Wickham. (2011). Dates and times made easy with lubridate. Journal of Statistical Software, 40(3), 1-25.

Hadley Wickham. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. https://ggplot2.tidyverse.org

Hart, K. M., Guzy, J. C., & Smith, B. J. (2021). Drivers of realized satellite tracking duration in marine turtles. Movement Ecology, 9(1), 1. https://doi.org/10.1186/s40462-020-00237-3

Johnson, M. R., Williams, S. L., Lieberman, C. H., & Solbak, A. (2003). Changes in the abundance of the seagrasses Zostera marina L. (eelgrass) and Ruppia maritima L. (widgeongrass) in San Diego, California, following and El Niño Event. Estuaries, 26(1), 106–115. https://doi.org/10.1007/BF02691698

Jones, T.T., Bostrom, B., Carey, M., Imlach, B., Mikkelsen, J., Ostafichuk, P., Eckert, S.A., Opay, P., Swimmer, Y., Seminoff, J.A. and Jones, D.R. (2011). Determining transmitter drag and best-practice attachment procedures for sea turtle biotelemetry. NOAA Technical Memorandum. NOAA-NMFS-SWFSC-480

Jonsen, I. D., Grecian, W. J., Phillips, L., Carroll, G., McMahon, C., Harcourt, R. G., Hindell, M. A., & Patterson, T. A. (2023). aniMotum, an R package for animal movement data: Rapid quality control, behavioural estimation and simulation. Methods in Ecology and Evolution, 14(3), 806–816. https://doi.org/10.1111/2041-210X.14060

Lemons, G., Lewison, R., Komoroske, L., Gaos, A., Lai, C. T., Dutton, P., Eguchi, T., LeRoux, R., & Seminoff, J.A. (2011). Trophic ecology of green sea turtles in a highly urbanized bay: Insights from stable isotopes and mixing models. Journal of Experimental Marine Biology and Ecology, 405(1–2), 25–32. https://doi.org/10.1016/J.JEMBE.2011.05.012

MacDonald, B. D., Madrak, S. V., Lewison, R. L., Seminoff, J. A., & Eguchi, T. (2013). Fine scale diel movement of the east Pacific green turtle, Chelonia mydas, in a highly urbanized foraging environment. Journal of Experimental Marine Biology and Ecology, 443, 56–64. https://doi.org/10.1016/J.JEMBE.2013.02.033

MacDonald, B., Lewison, R., Madrak, S., Seminoff, J., & Eguchi, T. (2012). Home ranges of East Pacific green turtles Chelonia mydas in a highly urbanized temperate foraging ground. Marine Ecology Progress Series, 461, 211–221. https://doi.org/10.3354/meps09820

Madrak, S. V., Lewison, R. L., Seminoff, J. A., & Eguchi, T. (2016). Characterizing response of East Pacific green turtles to changing temperatures: using acoustic telemetry in a highly urbanized environment. Animal Biotelemetry, 4(1), 1-10.

Madrak, S. V., Lewison, R. L., Eguchi, T., Klimley, A. P., & Seminoff, J. A. (2022). Effects of ambient temperature on dive behavior of East Pacific green turtles before and after a power plant closure. Marine Ecology Progress Series, 683, 157-168.

Maurer, A.S., Eguchi, T., Lemons, G.E., LeRoux, R., LaCasella, E., Turner Tomaszewicz, C., Madrak, S., Chesney, B., & Seminoff. J.A. (In review). Resource selection by a megaomnivore in a marine foraging habitat. Ecology & Evolution.

Pebesma, E. (2018). Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal, 10(1), 439. https://doi.org/10.32614/RJ-2018-009

Rodriguez, M. (2023). Tides of Change: Analyzing Stranding and Sighting Data of Green Sea Turtles in the Southern California Region for Use in Conservation and Management. UC San Diego: Center for Marine Biodiversity and Conservation. Retrieved from https://escholarship.org/uc/item/45z7d6k7

Stinson, M. L. (1984). Biology of sea turtles in San Diego Bay, California, and in the northeastern Pacific Ocean (Doctoral dissertation, San Diego State University).578 pp.

U.S. Department of the Navy, N. F. E. C. S., & Port of San Diego. (2013). San Diego Bay Integrated Natural Resources Management Plan, Final September 2013.

Watson, K., & Granger, R. (1998). Hydrodynamic effect of a satellite transmitter on a juvenile green turtle (Chelonia mydas). Journal of Experimental Biology, 201(17), 2497–2505. https://doi.org/10.1242/jeb.201.17.2497

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. Journal of Open Source Software, 4(43), 1686. https://doi.org/10.21105/joss.01686

## 5.0 Supplemental Material

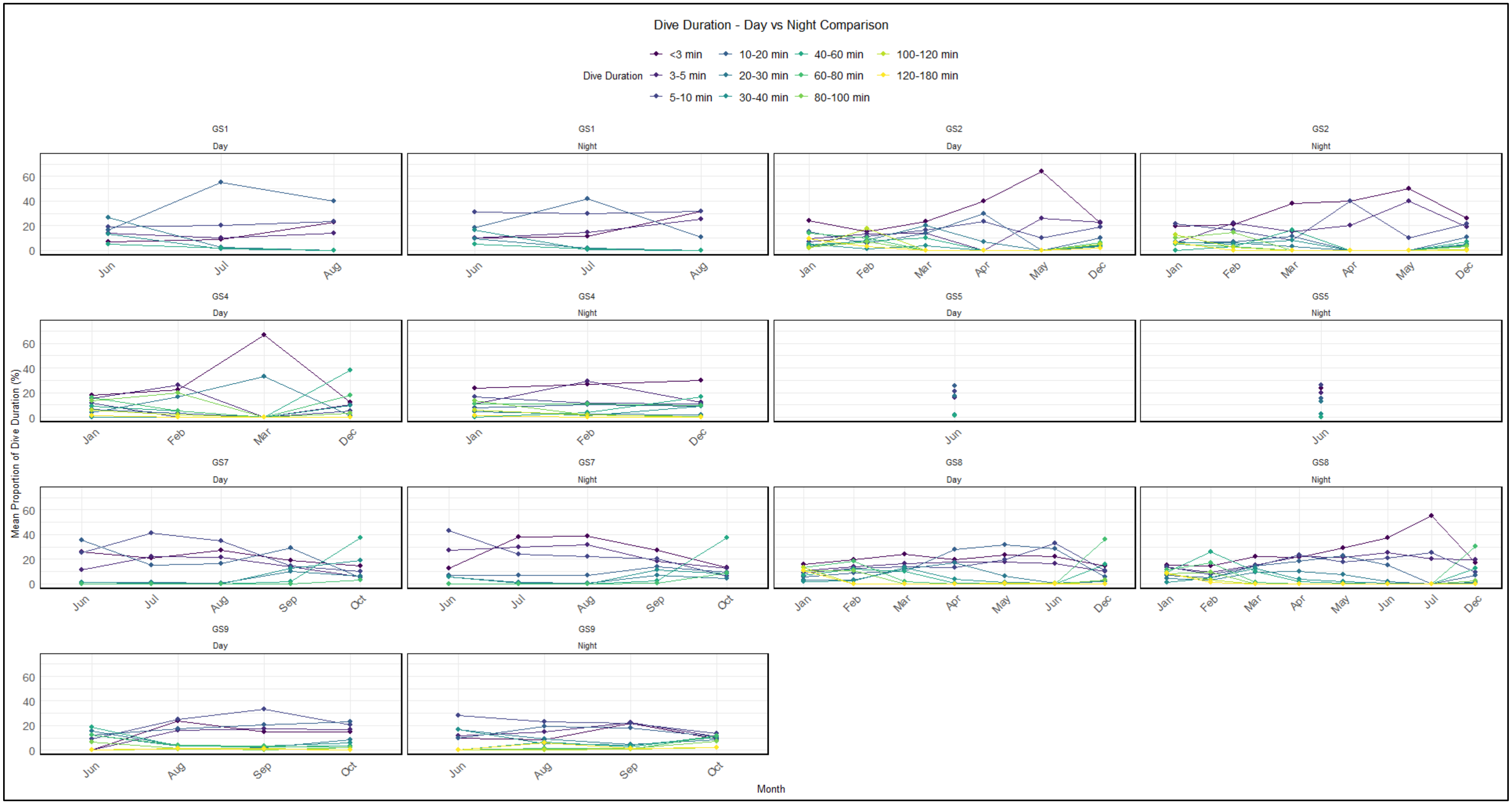


**Figure S1.** Mean dive durations across all turtles during diurnal hours (Day) and nocturnal hours (Night). Each individual plot corresponds to the overall dive duration patterns of each turtle across different months. The horizontal axis represents the months of the year, while the vertical axis represents the mean proportions of dive duration (%) for various duration intervals. These dive duration intervals are color coded in the legend from light yellow to purple.

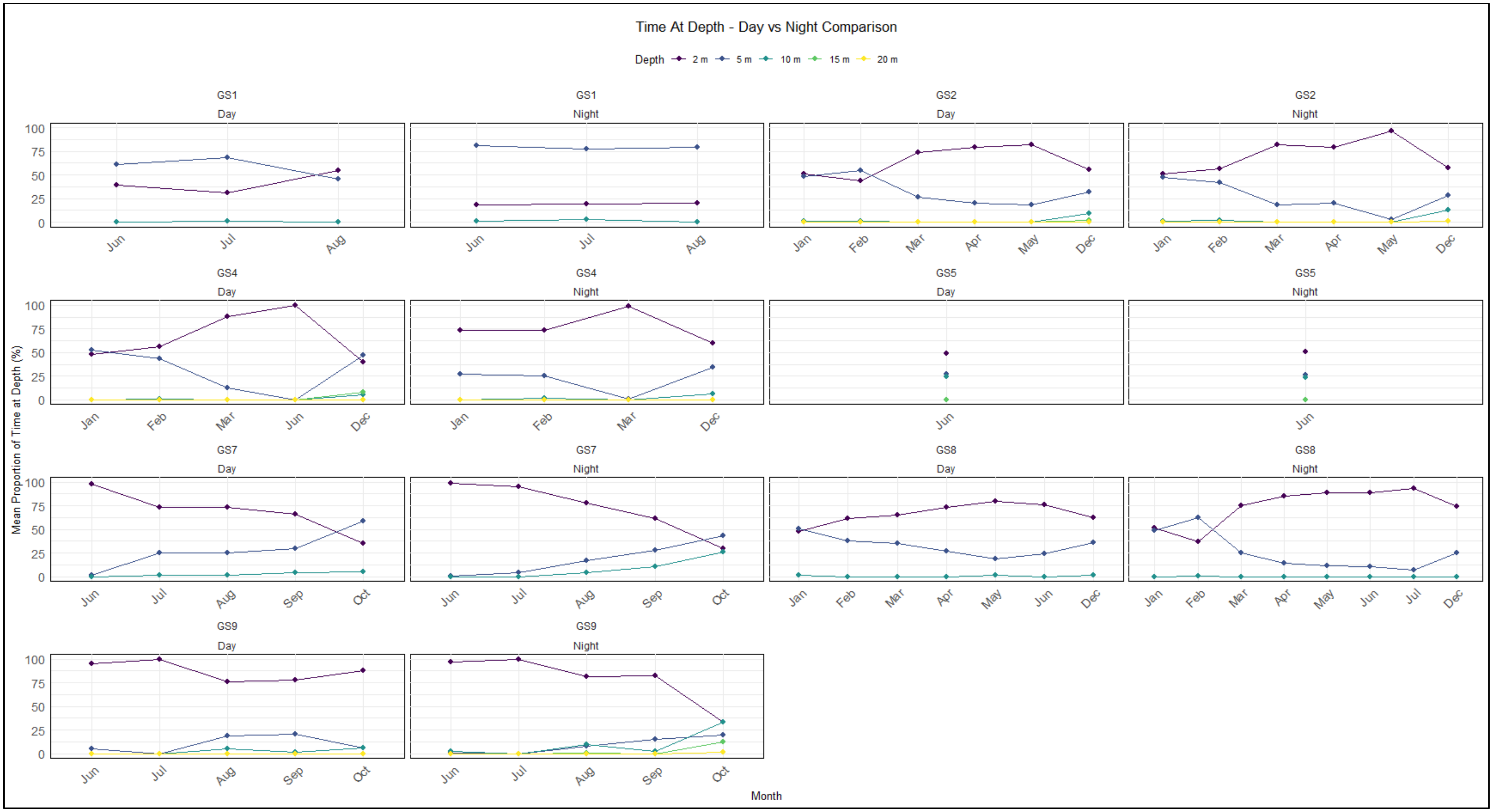


**Figure S2.** Mean proportions of time spent at certain depths across all turtles during diurnal hours (Day) and nocturnal hours (Night). Each individual plot corresponds to the overall time at depth patterns of each turtle across different months. The horizontal axis represents the months of the year, while the vertical axis represents the mean proportions of TAD (%) for various depths. These TAD depths are color coded in the legend from light yellow to purple.

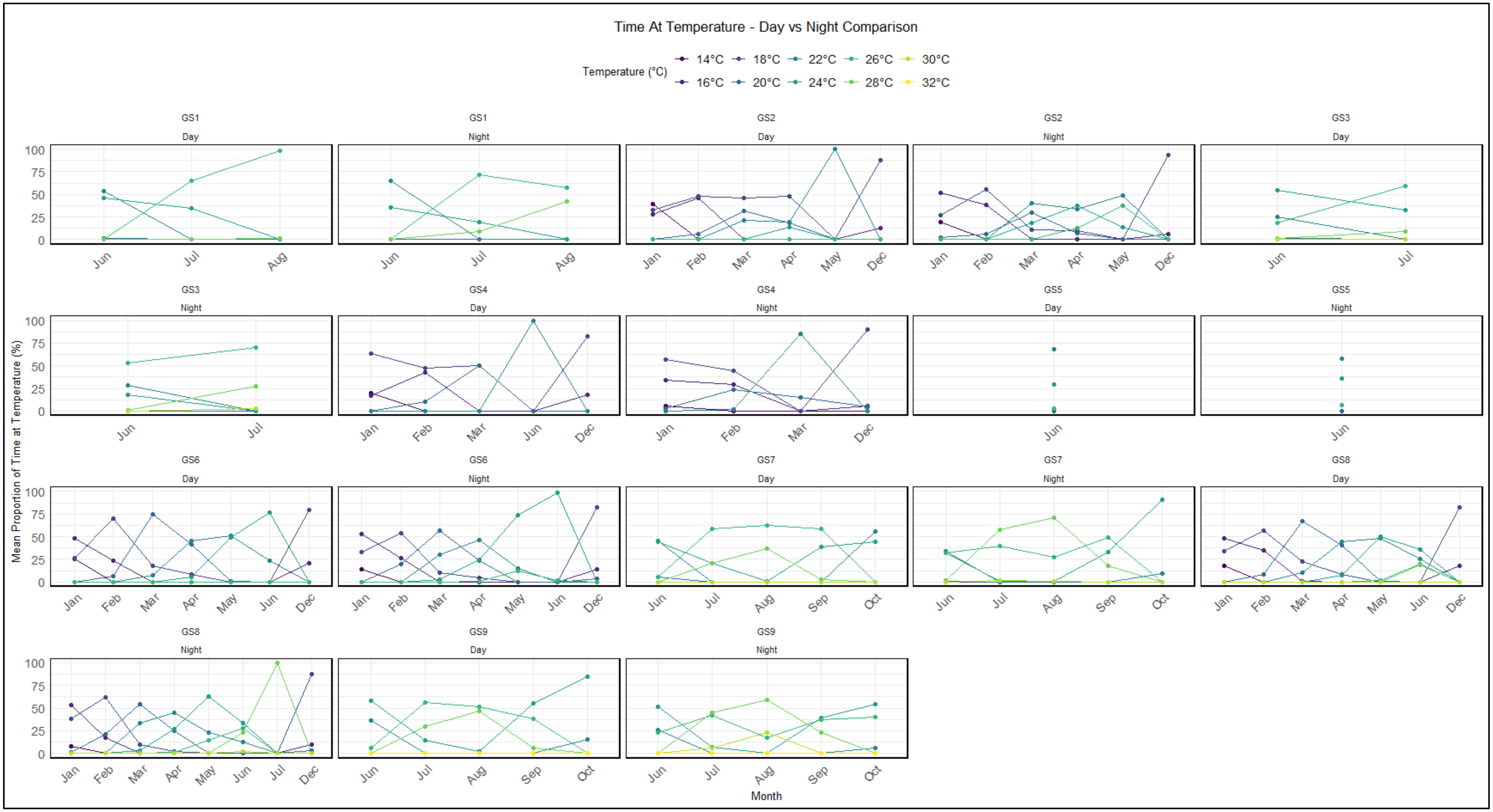


**Figure S3.** Mean proportions of time spent at certain temperatures across all turtles during diurnal hours (Day) and nocturnal hours (Night). Each individual plot corresponds to the overall time at temperature patterns of each turtle across different months. The horizontal axis represents the months of the year, while the vertical axis represents the mean proportions of TAT (%) for various temperatures. These TAT temperatures are color coded in the legend from light yellow to purple.

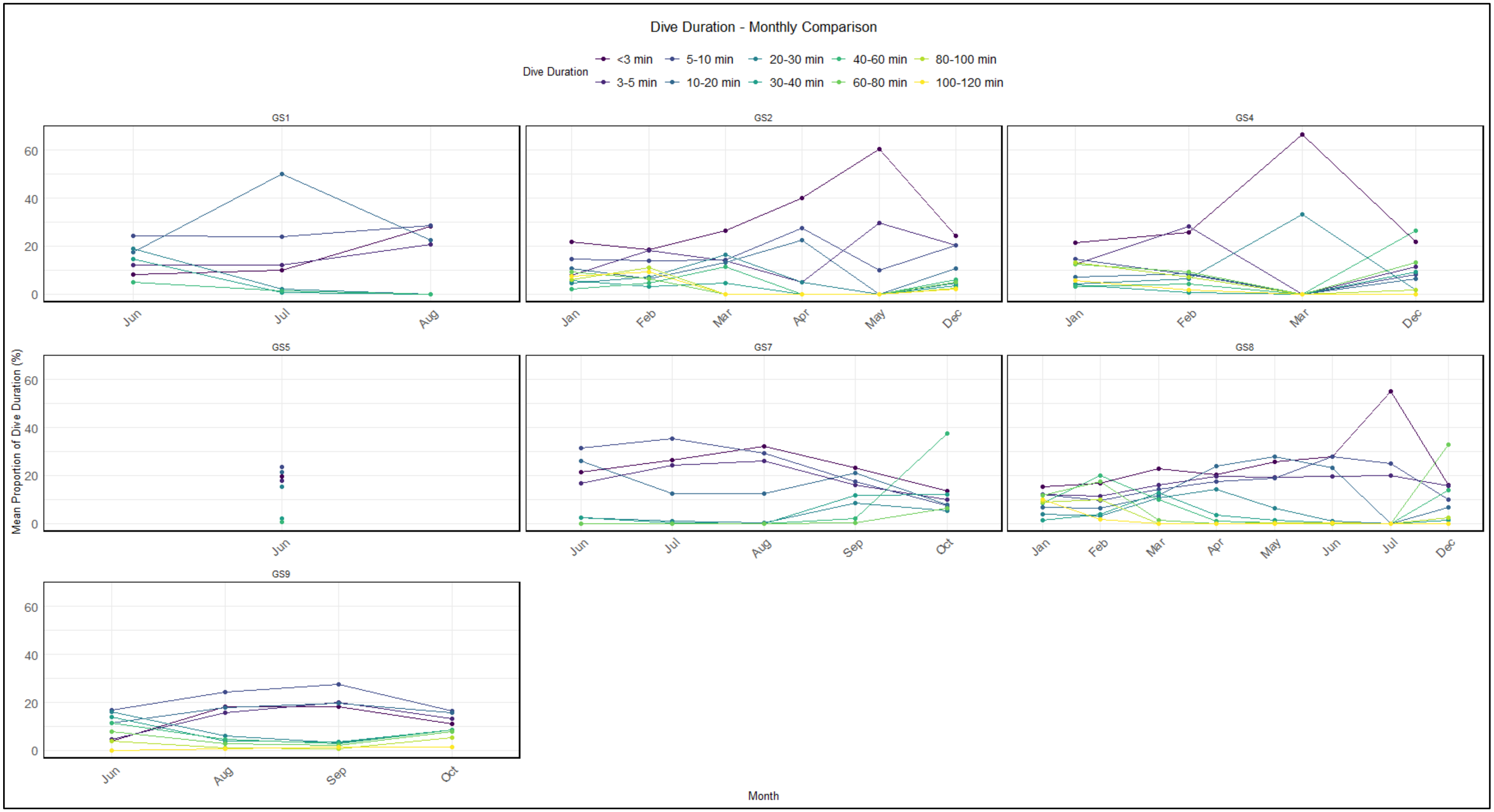


**Figure S4.** Monthly mean dive durations across all turtles. The left plot corresponds to the summer season months (May to October), while the right plot represents the winter season (December to April). The horizontal axis represents the months per season, while the vertical axis represents the mean proportion of dive duration (%) for various duration intervals. These dive duration intervals are color coded in the legend from light yellow to purple.

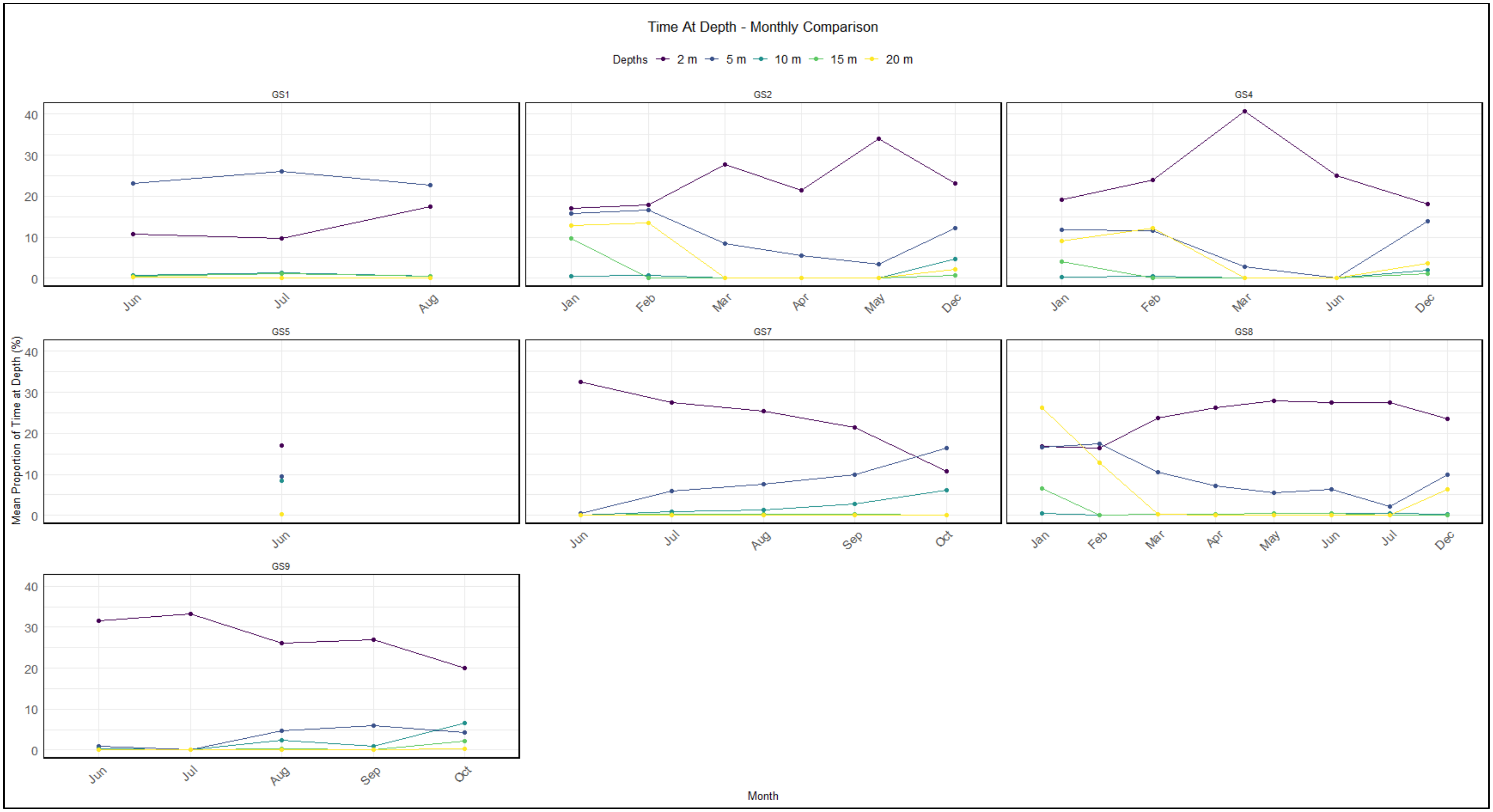


**Figure S5.** Monthly Mean proportions of time spent at certain depths across all turtles. Each turtle's individual plot corresponds to the summer (May to October) and winter season (December to April). The horizontal axis represents the months per season, while the vertical axis represents the mean proportion of TAD (%) for various depths. These depths are color coded in the legend from light yellow to purple.

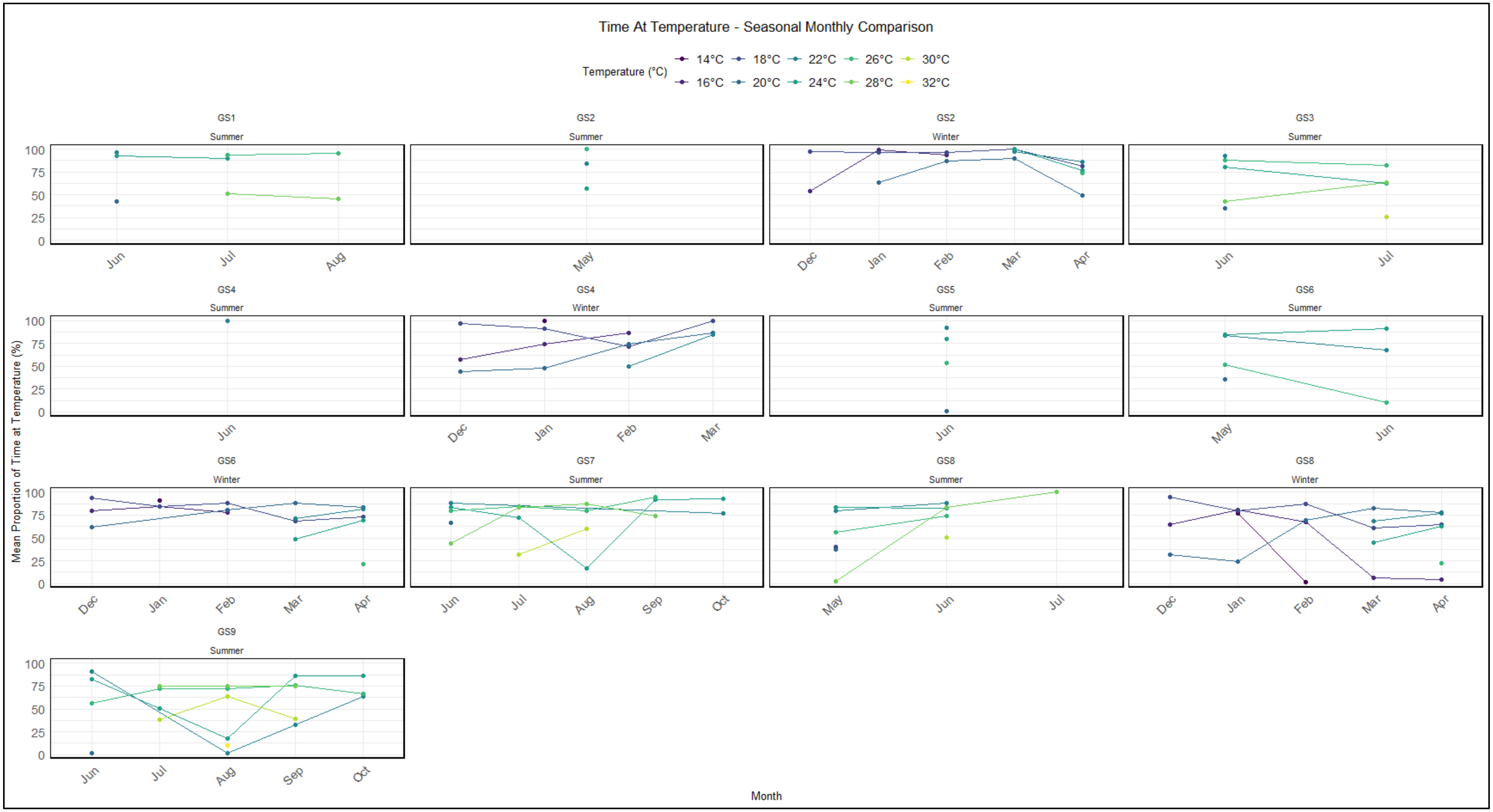


**Figure S6.** Monthly mean proportions of time spent at certain temperature across all turtles. Each turtle's individual plot corresponds to the summer (May to October) and winter season (December to April). The horizontal axis represents the months per season, while the vertical axis represents the mean proportion of TAT (%) for various temperatures. These temperatures are color coded in the legend from light yellow to purple.

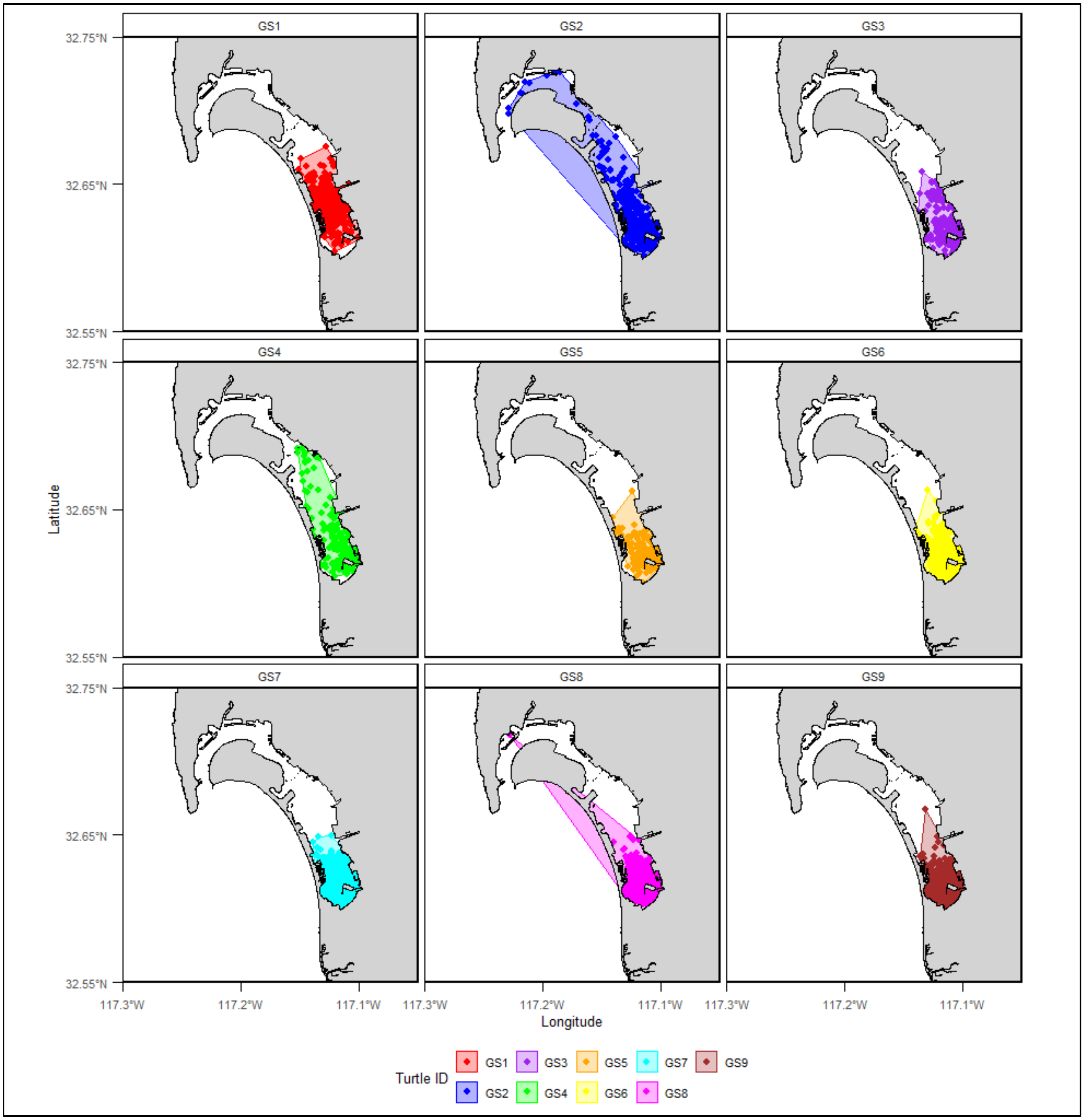


**Figure S7.** Minimum convex polygons (MCP) of turtles' home range locations during tag transmission in SDB.

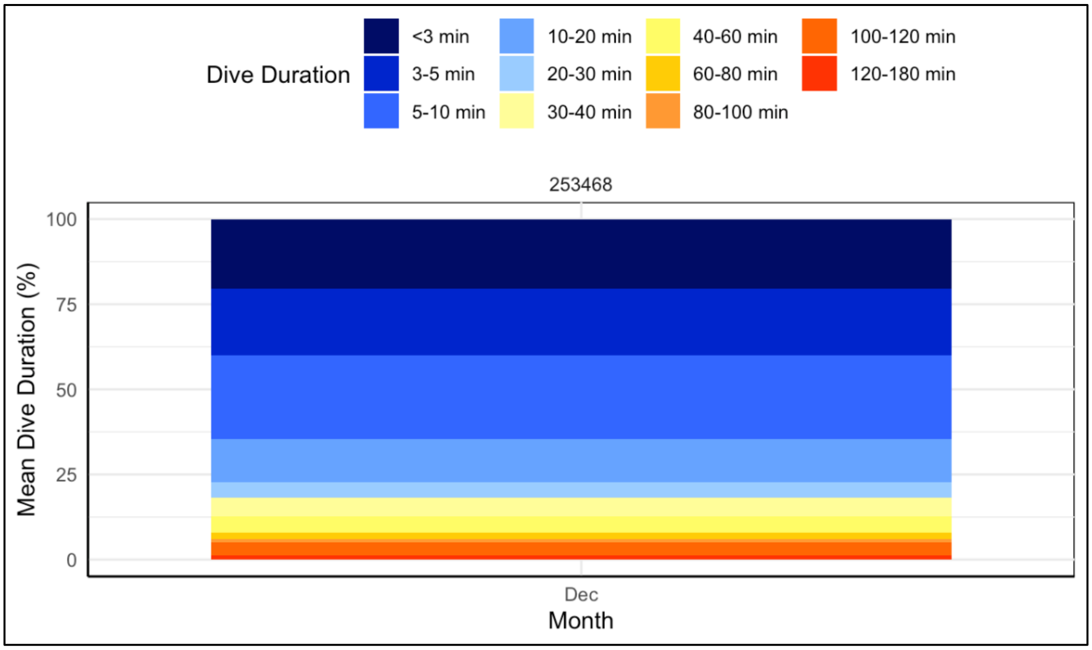


**Figure S8.** Mean proportions of dive duration during the month of December, across the migration of GS2 to Baja California. The horizontal axis represents the month, while the vertical axis illustrates the mean proportions of dive durations. Colored bars represent the dive duration.

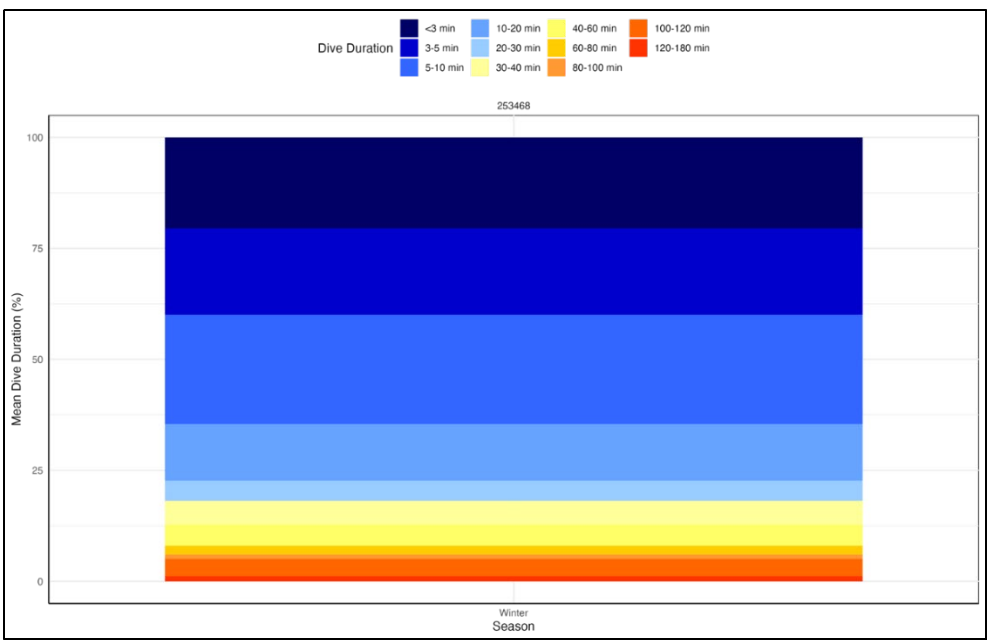


**Figure S9.** Mean proportions of dive duration during the winter season, across the migration of Turtle GS2 to Baja California. The horizontal axis represents the season, while the vertical axis illustrates the mean proportions of dive durations. Colored bars represent the dive duration.

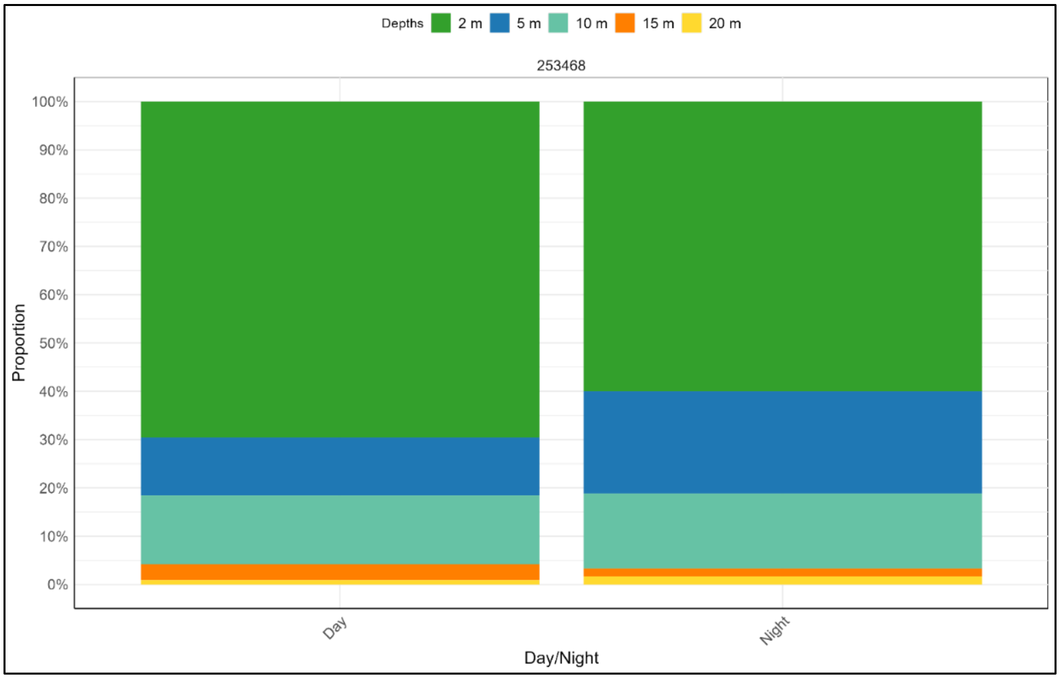


**Figure S10.** Mean proportion of time-at-depth between day and night, across the migration of GS2 to Baja California. The horizontal axis represents the time of day, while the vertical axis illustrates the mean proportion of time spent at various depths. Colored bars represent each depth.

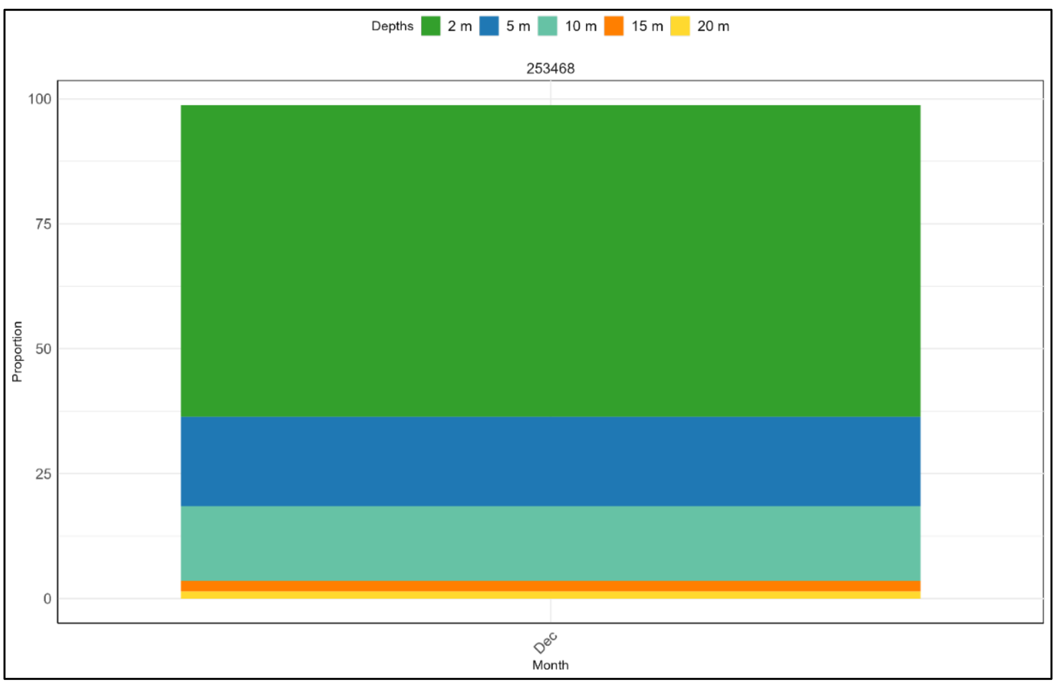


**Figure S11.** Mean proportion of time-at-depth during the month of December, across the migration of GS2 to Baja California. The horizontal axis represents the month, while the vertical axis illustrates the mean proportion of time spent at various depths. Colored bars represent each depth.

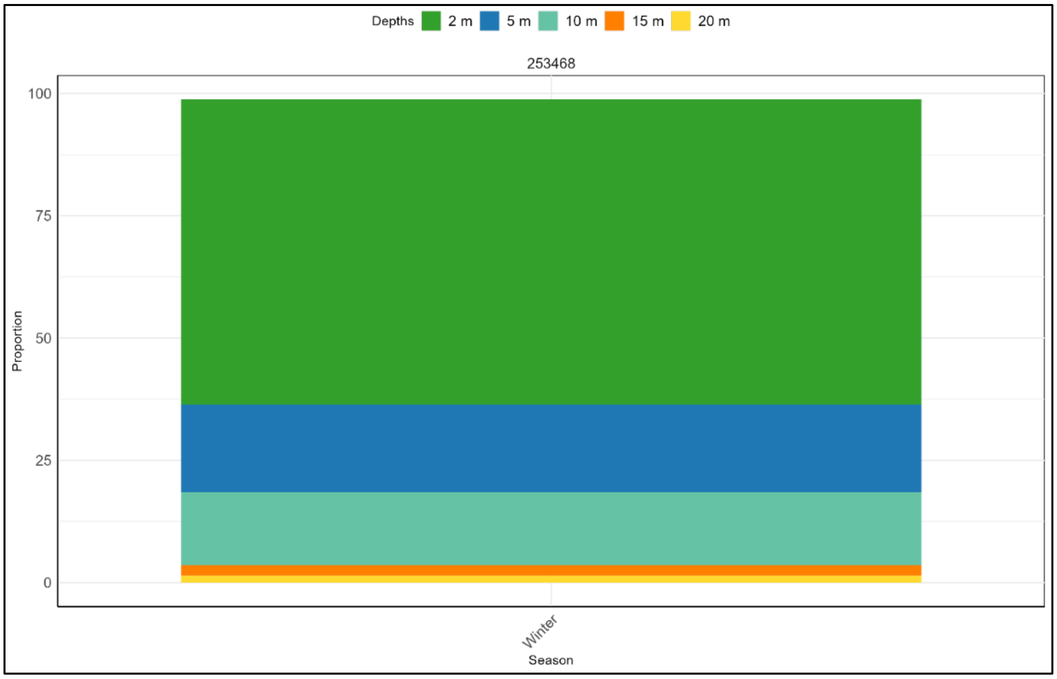


**Figure S12.** Mean proportion of time-at-depth during the winter season, across the migration of GS2 to Baja California. The horizontal axis represents the season, while the vertical axis illustrates the mean proportion of time spent at various depths. Colored bars represent each depth.

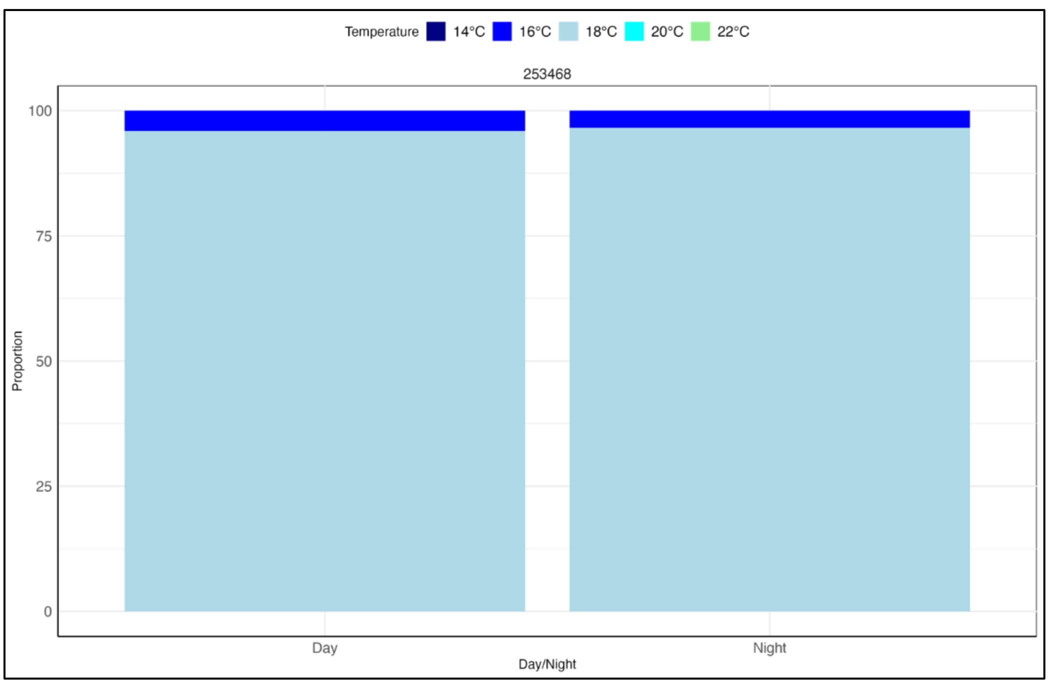


**Figure S13.** Mean proportion of time-at-temperature between day and night, across the migration of GS2 to Baja California. The horizontal axis represents time of day, while the vertical axis illustrates the mean proportion of time spent at various temperature ranges. Colored bars represent each temperature.

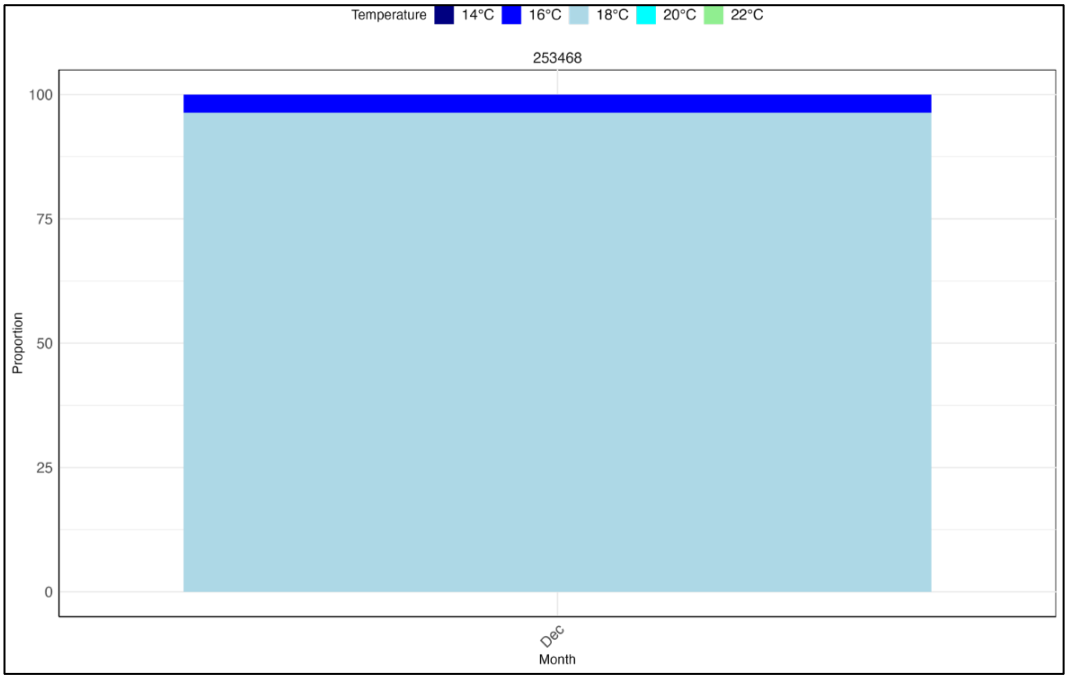


**Figure S14.** Mean proportion of time-at-temperature during the month of December, across the migration of GS2 to Baja California. The horizontal axis represents the month, while the vertical axis illustrates the mean proportion of time spent at various temperature ranges. Colored bars represent each temperature.

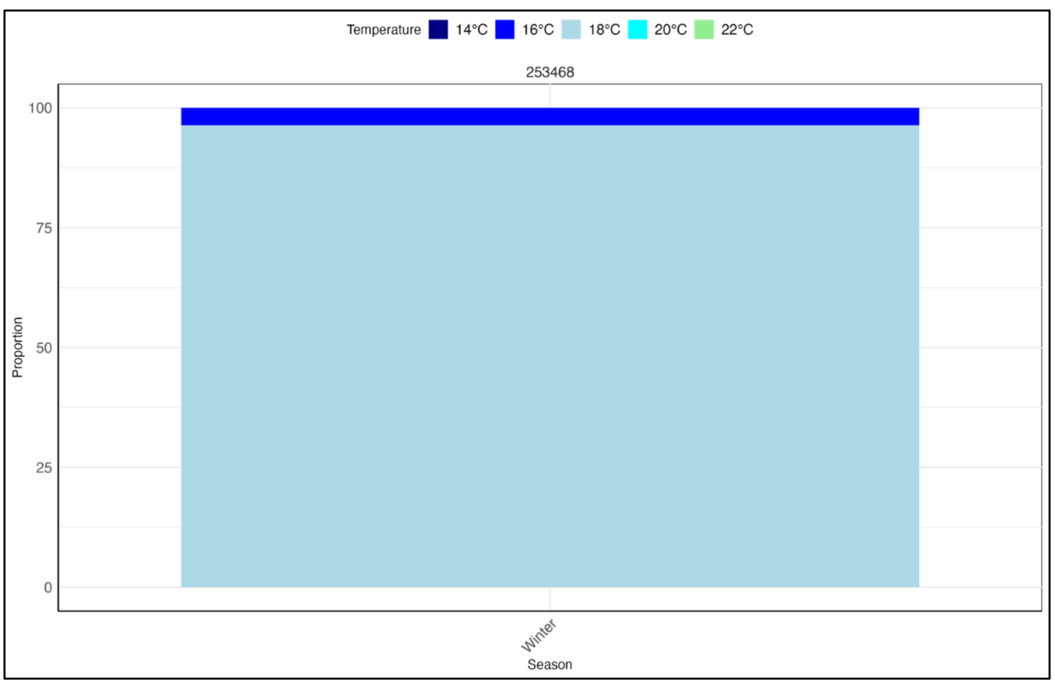


**Figure S15.** Mean proportion of time-at-temperature during the winter, across the migration of GS2 to Baja California. The horizontal axis represents the winter season, while the vertical axis illustrates the mean proportion of time spent at various temperature ranges. Colored bars represent each temperature.