

Progress Report: Evaluation of Fine Scale Movements of East Pacific Green Sea Turtles in San Diego Bay



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1.0 Introduction

1.1 Background

Bays and estuaries are some of the most dynamic marine environments, which nearshore animals utilize (Allen and Horn 2006). These highly variable habitats can have great physical and chemical changes over space and time as well as intense anthropogenic inputs (Emery and Stevenson 1957). Both top-down and bottom-up ecological controls drive a rich trophic environment, which can support a wide diversity of species. San Diego Bay (SDB) is the largest naturally occurring marine embayment between San Francisco and Scammon's Lagoon in central Baja California (Allen and Horn 2006). The bay is a long narrow crescent shaped body of water stretching to a length of 25 kilometers (km) with widths ranging between 1 to 3 kilometers (km) and depths between 1-18 meters (m) (DoN 2013).

Today, SDB is part of a highly urbanized ecosystem subject to anthropogenic watershed development and subsequent resource degradation and eutrophication. The bay is also home to the largest naval complex in the world and California's second largest incorporated city. Despite the anthropogenic influence on the bay, it serves as a crucial ecosystem for several sensitive marine species. The shallow water habitats of SDB support seagrass beds (*Zostera marina*) that provide vital spawning, nursery areas, and migration routes for nearshore marine fishes and invertebrates.

As a result of the highly productive seagrass habitat and relatively warm waters of the bay, a population of the federally threatened green sea turtle (*Chelonia mydas*) has taken up residence in SDB (Eguchi et al. 2010; Lemons et al. 2011). With studies dating back to the 1970s (Stinson 1984; McDonald et al. 1994), the turtles have historically aggregated in the southern portion of SDB and have consistently been associated with the warm water effluent of the South Bay Power Plant (SBPP; Figure 1; Eguchi et al. 2012; MacDonald et al. 2012). The SBPP began operating in 1960 and subsequently increased the water temperature in south SDB above ambient levels (Eguchi et al. 2012). Past monitoring efforts of green turtles in south SDB have been a result of a collaborative monitoring program headed by the National Marine Fisheries Service (NMFS) Marine Turtle Ecology and Assessment Program based at the Southwest Fisheries Science Center (SWFSC). Multi-year funding and in-kind support from the Navy (Commander, Navy Installations Command [CNIC] and Commander, U.S. Pacific Fleet), San Diego Unified Port District (SDUPD), and San Diego State University have allowed researchers to evaluate how turtles use south San Diego Bay.

In December of 2010, the SBPP was decommissioned and changes to turtle behaviors have already been documented most likely as a result of the decreasing water temperatures (Turner-Tomaszewicz & Seminoff 2012). Although south bay will most likely remain the preferred habitat for SDB green turtles, it is possible they may expand out of south bay and into other parts of SDB where there is increased boat traffic.

An increased presence of turtles outside of the southern portion of SDB may have potential implications for management of this species, as there is a higher likelihood of boat strike and potential interactions with Naval, commercial, and recreational activities. As an operational user of SDB and its nearshore waters, the Navy is required to manage its marine resources including this federally threatened green turtle population. With potential for overlap of Navy operating areas and turtle presence, it is important to determine how turtle movements are changing in the bay.

In an effort to evaluate how turtle behaviors may change as a result of the cessation of the warm water effluent, funding in Fiscal Year (FY) 2012 from the Navy (CNIC) provided for the deployment of satellite tags to detect small scale-movements of turtles in SDB. These post-closure data will serve as a comparison to previously collected pre-power plant closure satellite data (2007-2009), which were funded by SDUPD. Subsequent funding efforts in FY15 from Commander, U.S. Pacific Fleet and SDUPD allowed for the purchase of additional tags to continue to evaluate turtle movements.

To date, post-closure efforts have included satellite tag data beginning in 2011 and are still on-going. Within this report, those data from 2011 through 2014 are reported as the analyses were conducted in 2015. Preliminary satellite data from 2015 efforts are also included in this report.

1.2 Project and Report Objective

The objective of this project is to provide an update regarding the movements and home ranges of green turtles before and after the south SDB power plant was closed in December 2010.

This progress report presents turtle movements from before and after the SBPP was decommissioned. As tagging efforts are still underway, this report is intended to provide an annual summary of work and should not be used for any trend analyses. However, the general differences observed in this report can be used to inform natural resource managers about preliminary turtle movements in San Diego Bay. The reported post-closure data collection efforts took place through collaboration between biologists at the SWFSC, Space and Naval Warfare Systems Center, Pacific (SSC PAC) Environmental Readiness Division Team, and Naval Facilities Engineering Command, Southwest (NAVFAC SW).

2.0 Methods

2.1 Location

The Southern California Bight (SCB), an area of the eastern Pacific Ocean, that follows the California coastline from Point Conception (Santa Barbara County, California) to Cabo Colnett (south of Ensenada, Mexico), has subtropical waters flowing nearshore with cooler subarctic waters flowing offshore creating a unique convergence pattern that forms a biological transition zone, which allows for an abundance of marine species to thrive within this area. San Diego Bay is the largest embayment within the SCB and represents one of the most northern foraging grounds of the East Pacific green sea turtles. The southern portion of the bay is the location where turtle captures and releases occurred during this effort (Figure 1).

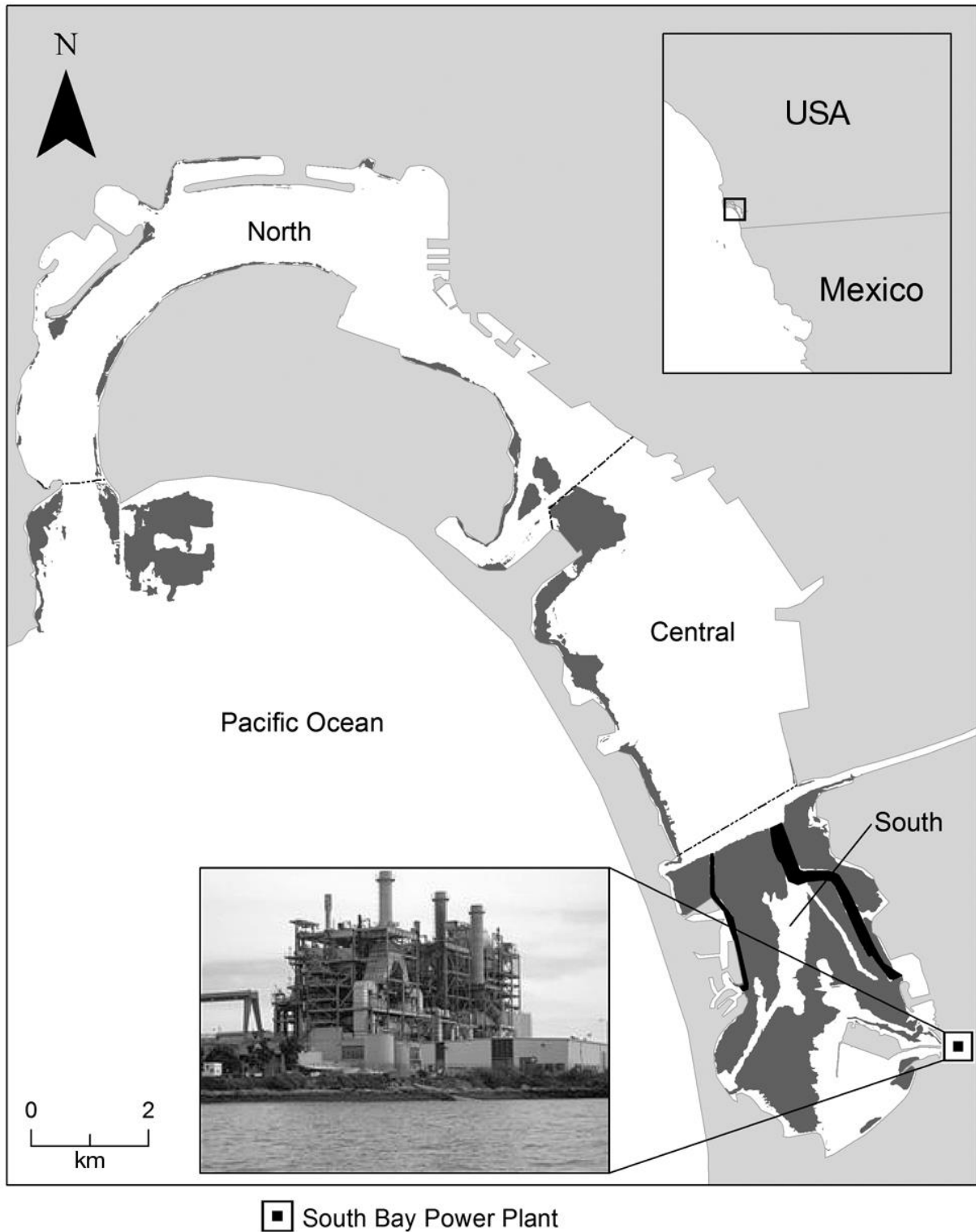


Figure 1: Overview of study area in San Diego Bay from MacDonald et al. 2012; Dark gray shading indicates eelgrass distribution, and black shading indicates boat channels on the eastern and western shores of south San Diego Bay.

2.2 Post-Power Plant Closure Satellite Tagging Field Collections

Turtles were captured via entanglement nets (50-100 m length x 8 m depth, mesh size = 40 cm stretched) as approved by U.S. National Marine Fisheries Service Permit #1591, and the adjoining NOAA Institutional Animal Use and Care Protocols. Nets were set in various locations near the old SBPP site during May 2011, June 2013, and the spring and summer months of 2014. The 2015 tagging efforts began in May 2015, however, no turtles were captured until August 2015. Individual turtles captured were brought to shore where morphometric data were collected including: sex (if possible), straight carapace length and width, curved carapace length and width, shell depth, and weight (Photo 1). Turtles are checked for flipper tags and passive integrated transponder tags to determine if the turtle had been previously captured. After the attachment area on the carapace was lightly sanded to remove algae, a Global Positioning System (GPS) enabled satellite transmitter (Wildlife Computers SPLASH10-BF-296C, Octagon Backmount, SPLASH10-F-297A, SPLASH10-F-296A) was attached to the carapace with thin coats of fiberglass resin or epoxy resin (Photo 2). The tag was placed so that every time the turtle surfaces it can transmit a position via the Argos system. The tags deployed in 2015 included temperature sensors as well. Turtles were released into south bay waters near their capture location.



Photo 1: Measuring straight carapace length of turtle captured in San Diego Bay.



Photo 2: Fitting of satellite tag on carapace with epoxy resin.

2.3 Positional Data Processing

Post-closure tag data were received from the Argos system which included two sets of locational data, Argos and Fastloc GPS, along with the Location Class (LC) which is the positional accuracy of each recorded location. As reported by the Argos User's Manual (<http://www.argos-system.org>), errors associated with each defined LC can vary from less than 250 m (LC 3) to greater than 1500 m (LC 0). LCs are assigned if an estimate of error could not be obtained (LC A, B, Z). Data assigned with an LC of A, B, or Z were eliminated from the analyses for this progress report. To avoid autocorrelation errors, only positional fixes that were separated by four or more hours were utilized. Finally, data were plotted in ArcGIS 10.3 and visually filtered for points on land.

Pre-closure satellite data were obtained from researchers at the SWFSC and were processed in a similar fashion as described above to avoid autocorrelation and obvious erroneous land points. However, Fastloc GPS technology was not available during the period of time when these tags were deployed and thus did not receive the LC filtering.

2.4 Home Ranges

Turtle home ranges were estimated using kernel density methods with the `adehabitatHR` package in R using least squares cross validation (R 2015, Calnege 2006). Both 95% and 50% utilization distributions (UD) were calculated for two groups of tag data: the pooled turtle assemblage of pre-closure as well as the pooled post-closure tag dataset. These 50% and 95% utilization distributions, or home ranges, allow for a probabilistic representation of how turtles are using their space with

respect to time. Future analyses will calculate utilization distributions for individual turtles. Also, we will statistically examine the relationship between turtle home range sizes before and after power plant closure.

3.0 Preliminary Results

3.1 Pre- and Post-Power Plant Closure Home Ranges

Results are intended to provide an annual summary of work to date and should not be used for any trend analyses. Satellite data from eleven turtles were utilized in the post-closure dataset to compare against seven tags that were deployed before power plant closure (Table 1). The length of time a tag transmitted data was as short as 14 days with the longest transmission of 121 days. Additionally, the number of turtles tagged each year varied. Although the gender of all tagged turtles was not able to be collected, out of those 11 turtles that were sexed, most were females (82%, n = 9).

Table 1: Turtle and tag deployment information for turtles tagged before and after the power plant was decommissioned.

Tag ID	SCL cm	CCL cm	Sex	Date Deployed	Date of Last Used Transmission	Number of Transmitting Days
Pre-Power Plant Closure						
52675	-	-	Female	3/7/2007	6/18/2007	103
37616	70.0	-	-	5/23/2007	7/19/2007	57
37623	90.0	-	-	5/23/2007	7/15/2007	53
52674	-	-	Male	4/25/2008	5/11/2008	16
79786	101.0	110.0	Female	3/25/2009	5/17/2009	53
44366	-	-	Female	3/25/2009	6/4/2009	71
78500	100.4	104.0	Female	11/5/2009	1/4/2010	60
Post-Power Plant Closure						
44359	74.6	79.2	-	5/25/2011	9/23/2011	121
126065	100.5	107.0	Female	6/4/2013	9/9/2013	97
126066	51.9	54.0	-	6/12/2013	7/4/2013	22
126070	109.3	118.3	-	3/13/2014	5/30/2014	78
126069*	95.0	102.0	Female	5/13/2014	6/26/2014	44
126064	65.8	68.4	Juvenile	6/10/2014	7/14/2014	34
126067	102.6	108.3	Male	6/10/2014	7/16/2014	36
126071*	100.8	109.5	Female	6/26/2014	7/25/2014	30
126068	99	107.0	Female	7/1/2014	8/6/2014	36
126069*	75.4	80	Juvenile	7/24/2014	8/7/2014	14
126071*	107.2	115.1	Female	7/24/2014	8/7/2014	15

* = two tags were retrieved from turtles that were recaptured, those retrieved tags were redeployed on newly caught turtles; SCL = straight carapace length; CCL = curved carapace length; - = data not collected

The pre-power plant closure 95% home range estimate was 5.98 km² and 50% estimate was 1.03 km². The 95% and 50% home ranges estimates were larger for the post-closure dataset, 7.98 km² and 2.11 km², respectively (Table 2). In addition to the greater size of the 95% and 50% utilization estimates, the areas turtles most commonly used have changed. Turtles tagged before the closure, were most commonly found at the power plant effluent, on the south side of the jetty (Figure 2). A similar distribution was observed in a previous study of green turtles in San Diego Bay using acoustic telemetry from 2009-2011 (Figure 3; MacDonald et al. 2012). After the power plant closure, it appears the turtle home range has shifted to the other side of the jetty at the old power plant intake as well as more northerly areas in south San Diego Bay (Figure 4).

Table 2: Home range estimations (km²) for green turtles in pre- and post-power plant closure environments.

Time Period	95% UD	50% UD
Pre Closure	5.98	1.03
Post Closure	7.98	2.11

Changes in UD shapes of the current effort compared to those of the MacDonald et al. (2012) study could be due to differences in bandwidth values that are used in each respective kernel density analysis. MacDonald et al. (2012) used acoustic tracking techniques to collect position data. As a result of this method, they have fewer relocation data points for each tagged turtle than compared to satellite tags. In their analysis, the UDs are based on kernel density estimates that use a reference bandwidth. Reference bandwidths are commonly used in studies where there are duplicate locations for an animal, but can be known to over smooth a UD (Silverman 1986, Worton 1995). The current study had a greater number of locational data points than compared to MacDonald et al. (2012), which resulted in a multimodal distribution of the data. In this circumstance, least squares cross validation bandwidth methodology is better suited for kernel density estimates (Walter and Fischer 2014).

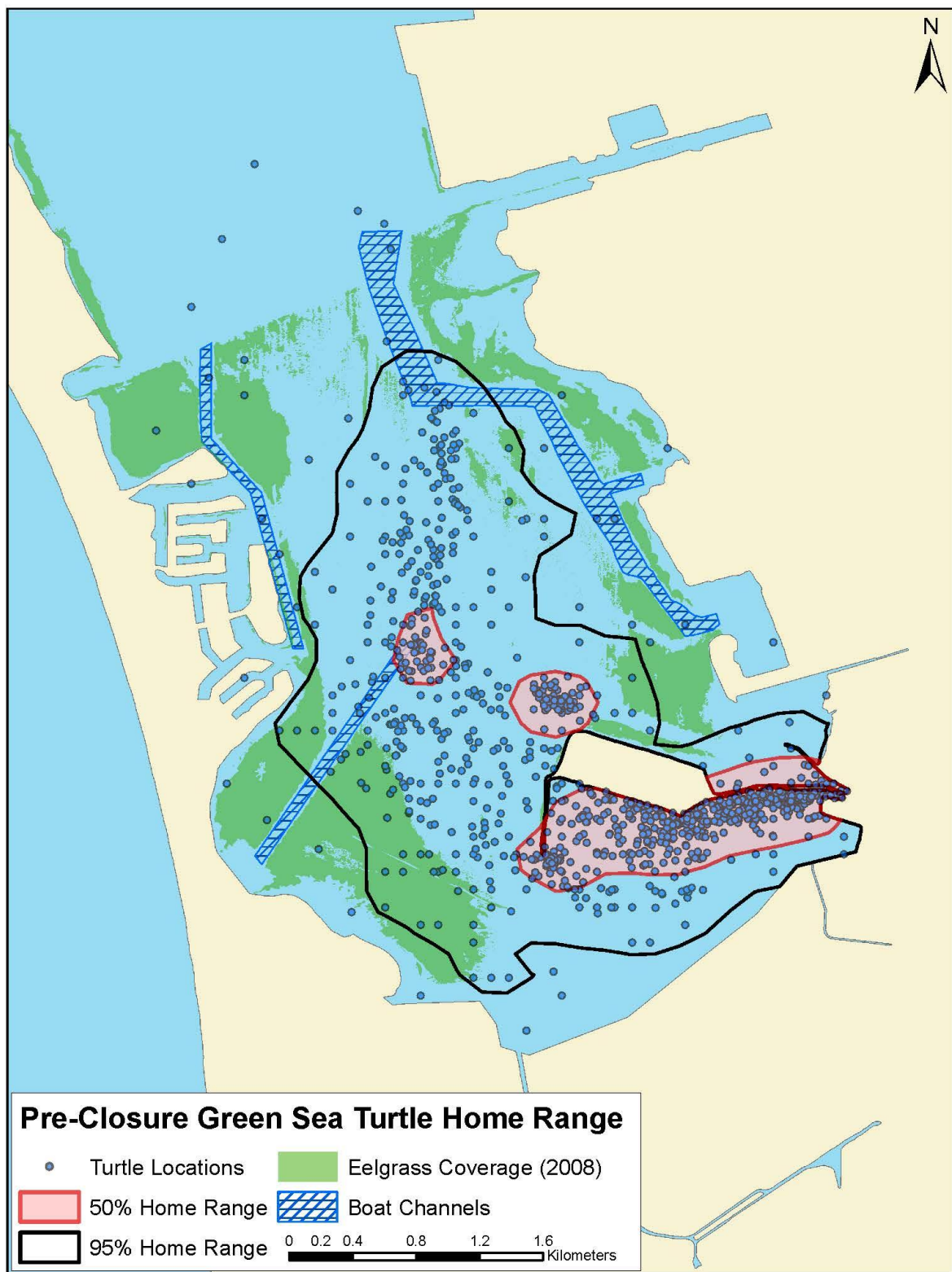


Figure 2: Cumulative pre-power plant closure home range map with 95% and 50% UD and location data.

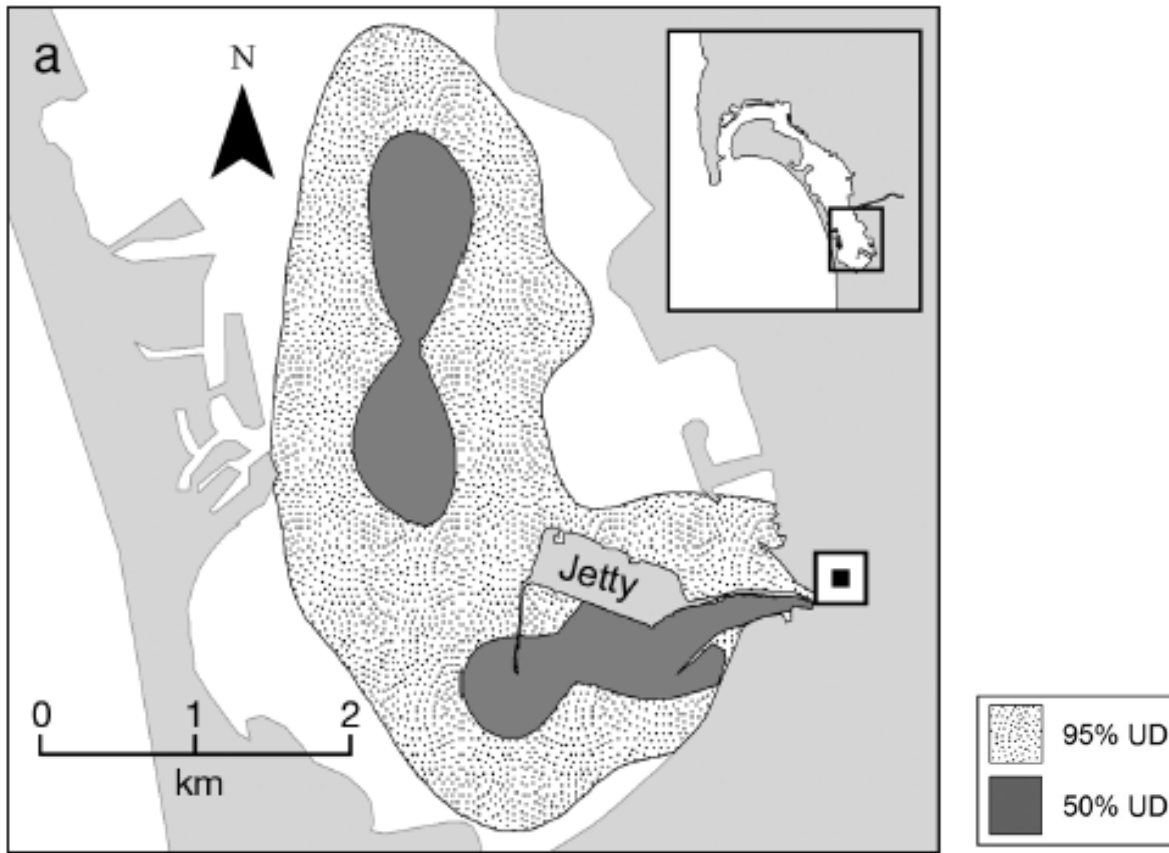


Figure 3: Cumulative home range map using acoustic telemetry tracking from 2009-2011 from MacDonald et al. 2012; UD = utilization distribution.

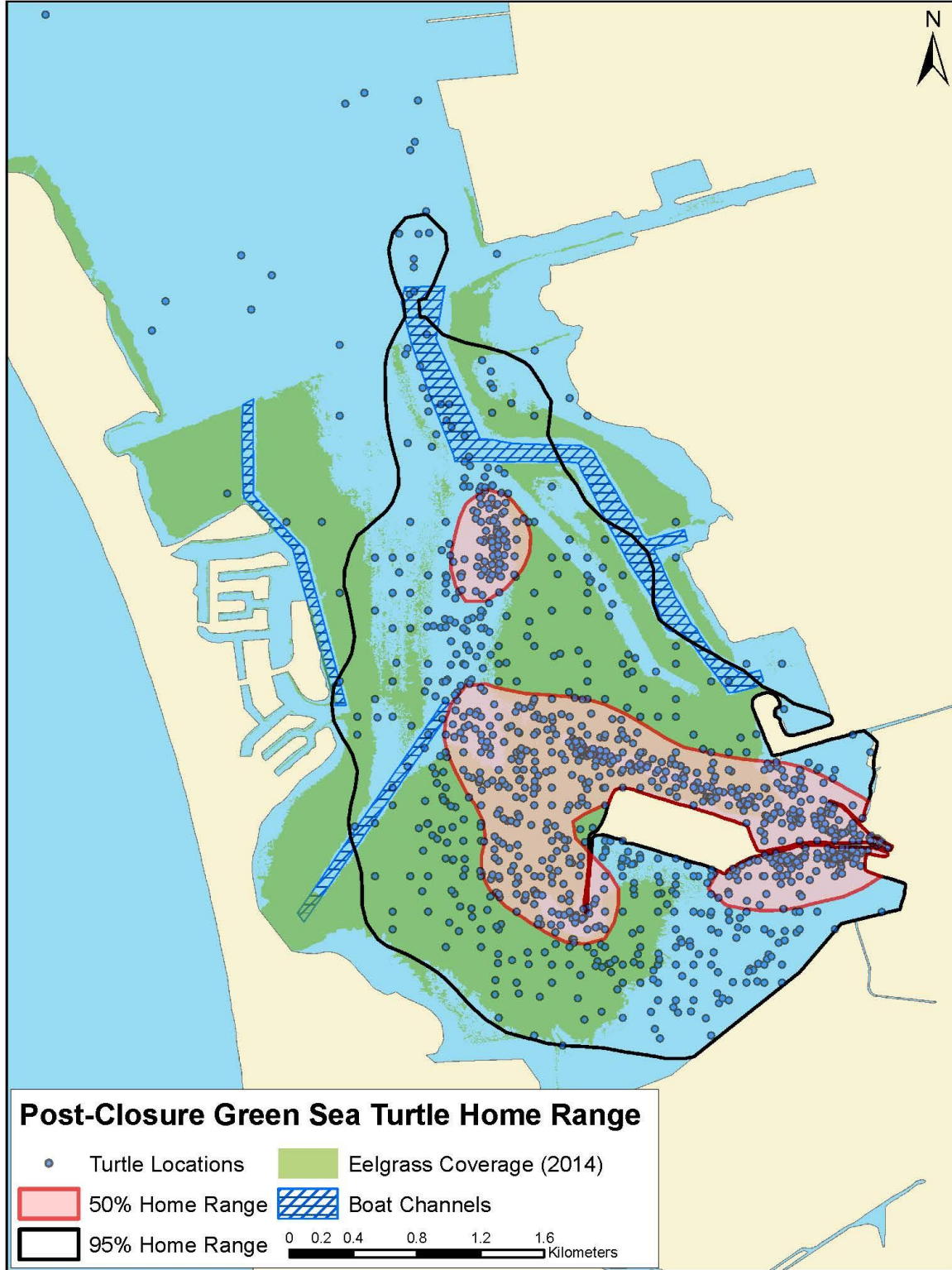


Figure 4: Cumulative post-power plant closure home range map with 95% and 50% UD and location data.

3.2 Continued Tagging Efforts

Between August and December 2015, six turtles were captured and tagged (Table 3). Preliminary tracks for each turtle have been downloaded and are included below. These data have not been post-processed but show the general movements of tagged turtles. Overall, four of the six tagged turtles have remained in south SDB but two turtles have left the bay. These data are preliminary and are intended to provide an annual summary of work to date and should not be used for any trends.

Table 3: Turtle and tag deployment information for turtles tagged in 2015.

Tag ID	SCL cm	CCL cm	Sex	Date Deployed
151375	102.5	109.0	F	8/27/2015
151378	89.2	93.2	M	8/27/2015
151381	75.2	81.8	U	8/27/2015
152322	93.5	97.6	M	11/5/2015
152323	94.8	101.0	F	12/8/2015
152314	101.0	107.0	F	12/15/2015

Tag 151375, a large female, exhibited similar behaviors to a majority of turtles in the 2011-2014 dataset (Figure 5) by remaining in south SDB and returning to the old power plant intake north of the jetty.

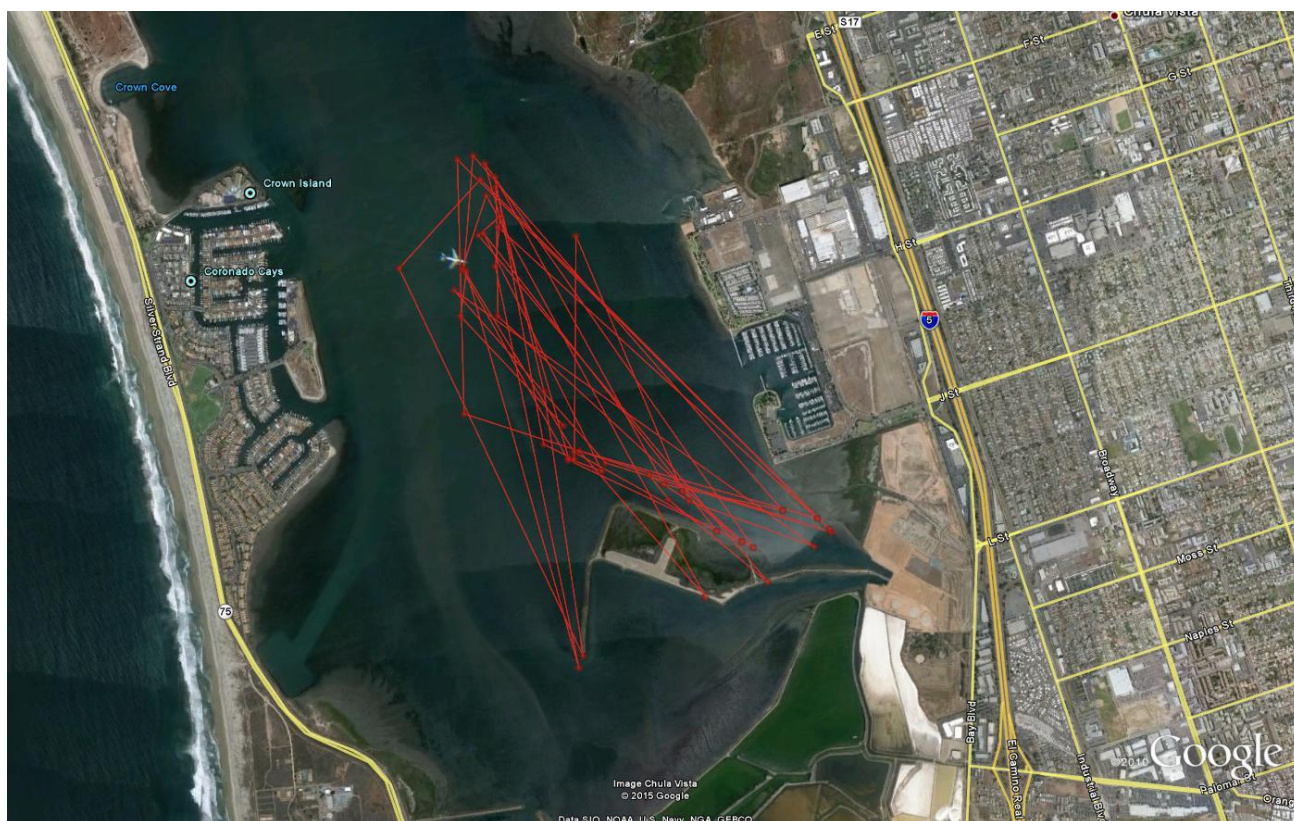


Figure 5: Satellite tracks of tag 151375 from 27 Aug-14 Sep 2015.

Unfortunately the tag from turtle 151378 was not functioning properly and only provided a few tracks after the turtle was released (Figure 6).

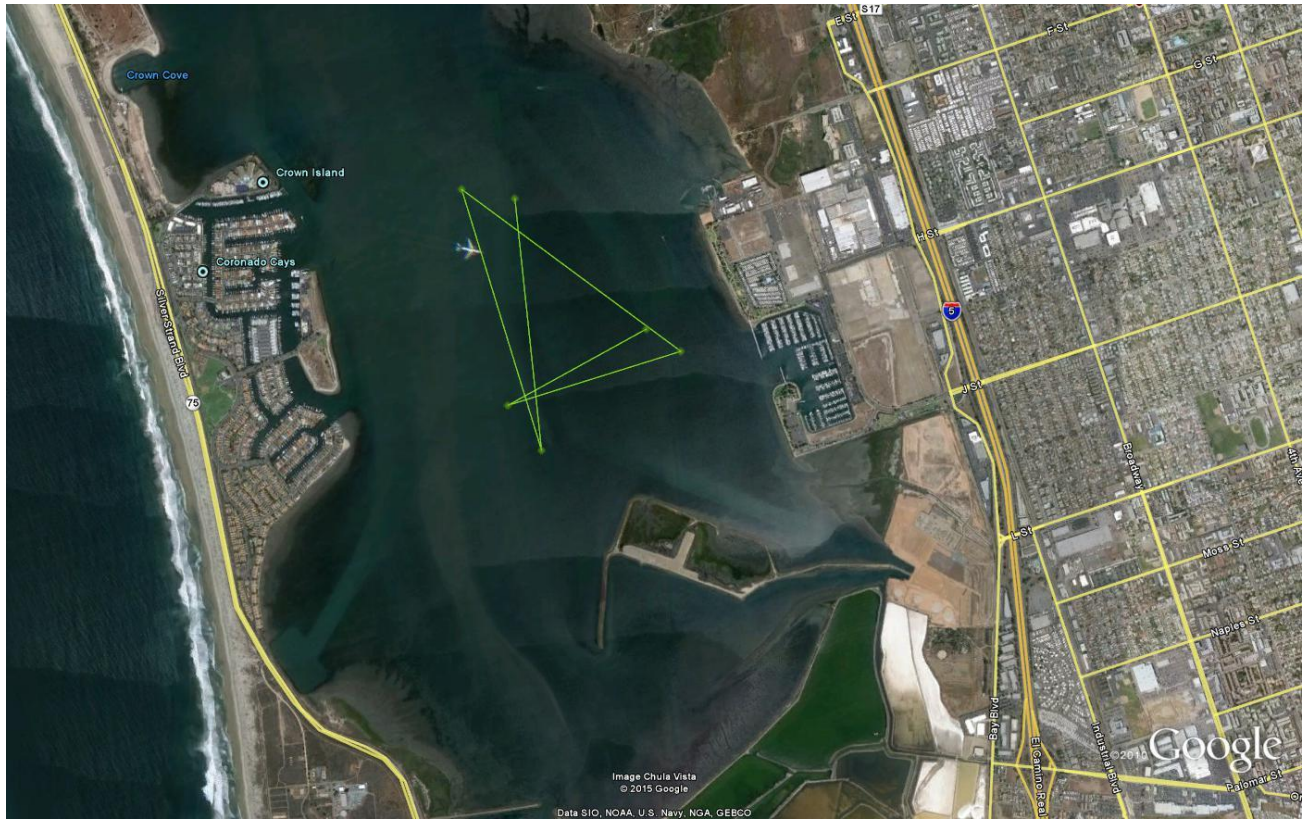


Figure 6: Satellite tracks of tag 151378 from 27 Aug-14 Sep 2015.

The turtle with tag 151381 (Figure 7) was the smallest turtle captured during the 2015 efforts. This turtle also remained in south SDB just north of the jetty.

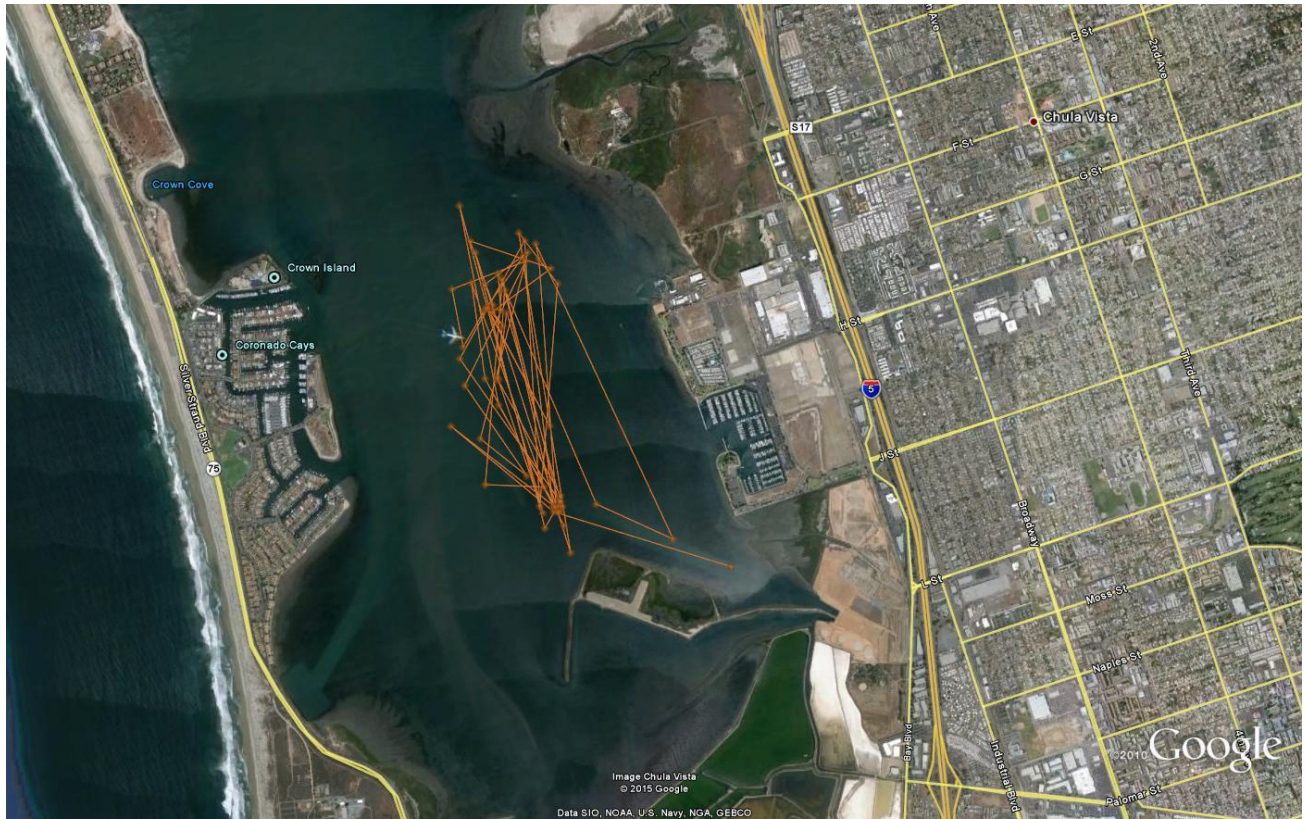


Figure 7: Satellite tracks of tag 151381 from 27 Aug-14 Sep 2015.

In contrast to the first three tagged turtles, a male turtle (tag 152322) that was tagged in November left the bay multiple times and returned to the bay before heading south off the coast of Mexico (Figures 8-9). The most recent tracks of this turtle are around Isla Clarion (Figure 10). Isla Clarion is part of the Revillagigedo Island Archipelago a well-known breeding ground for green turtles.

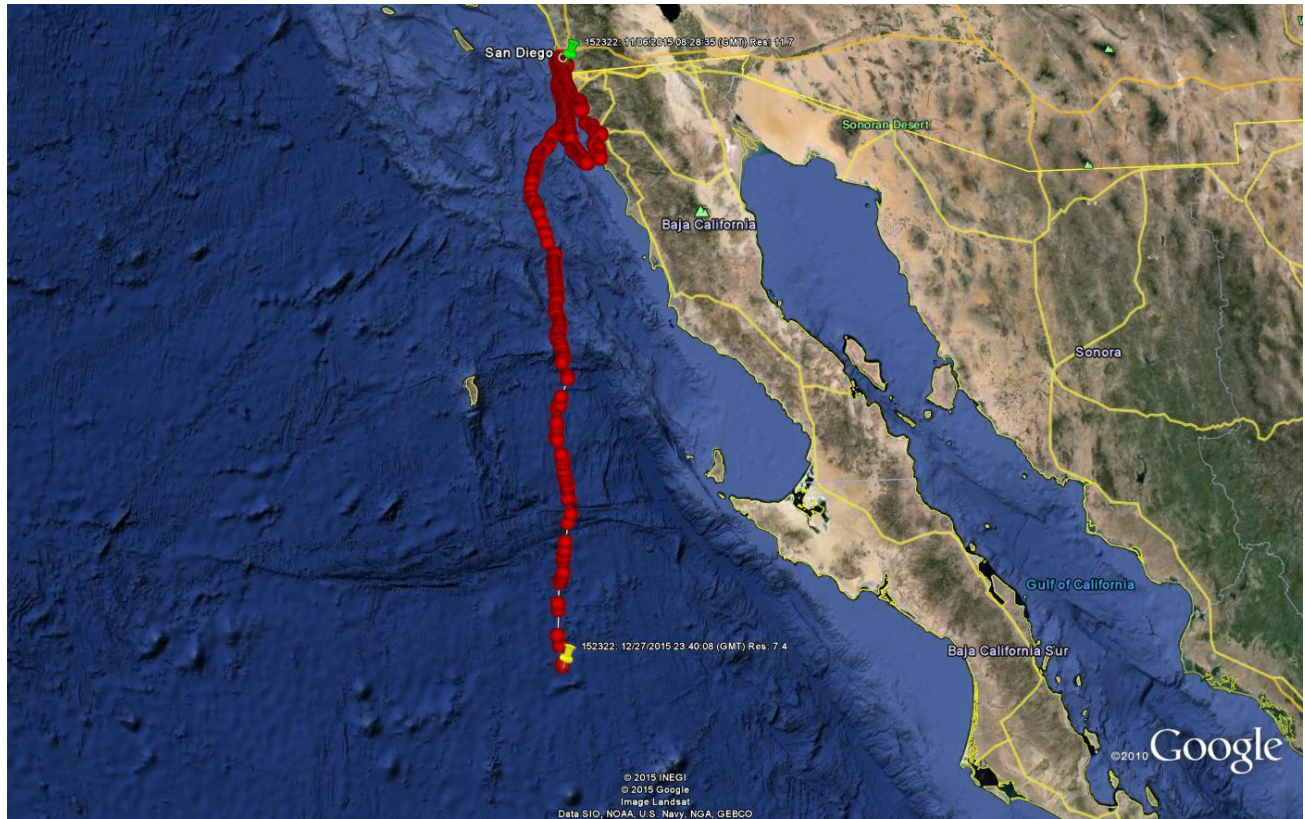


Figure 8: Satellite tracks of tag 152322 from 5 Nov-27 Dec 2015.

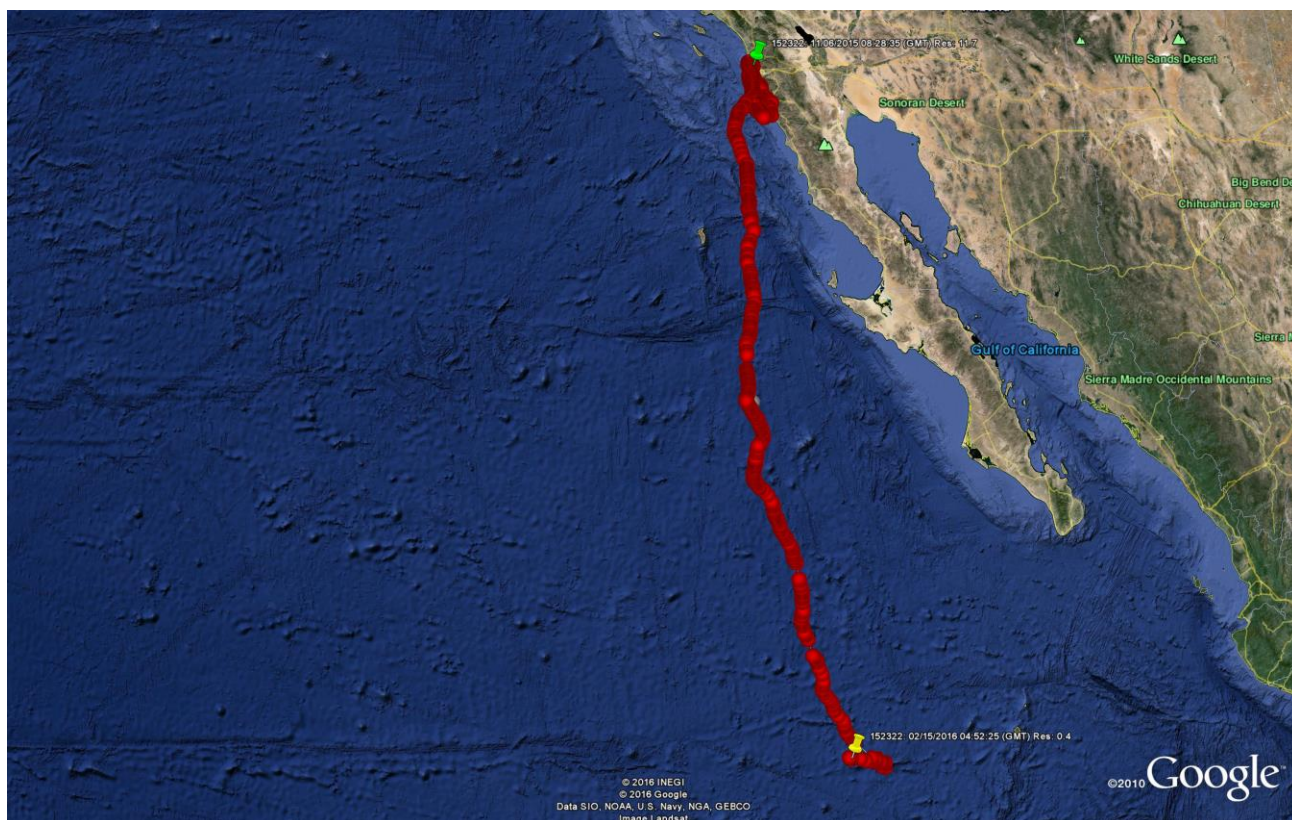


Figure 9: Satellite tracks of tag 152322 from 5 Nov 2015-23 Feb 2016.

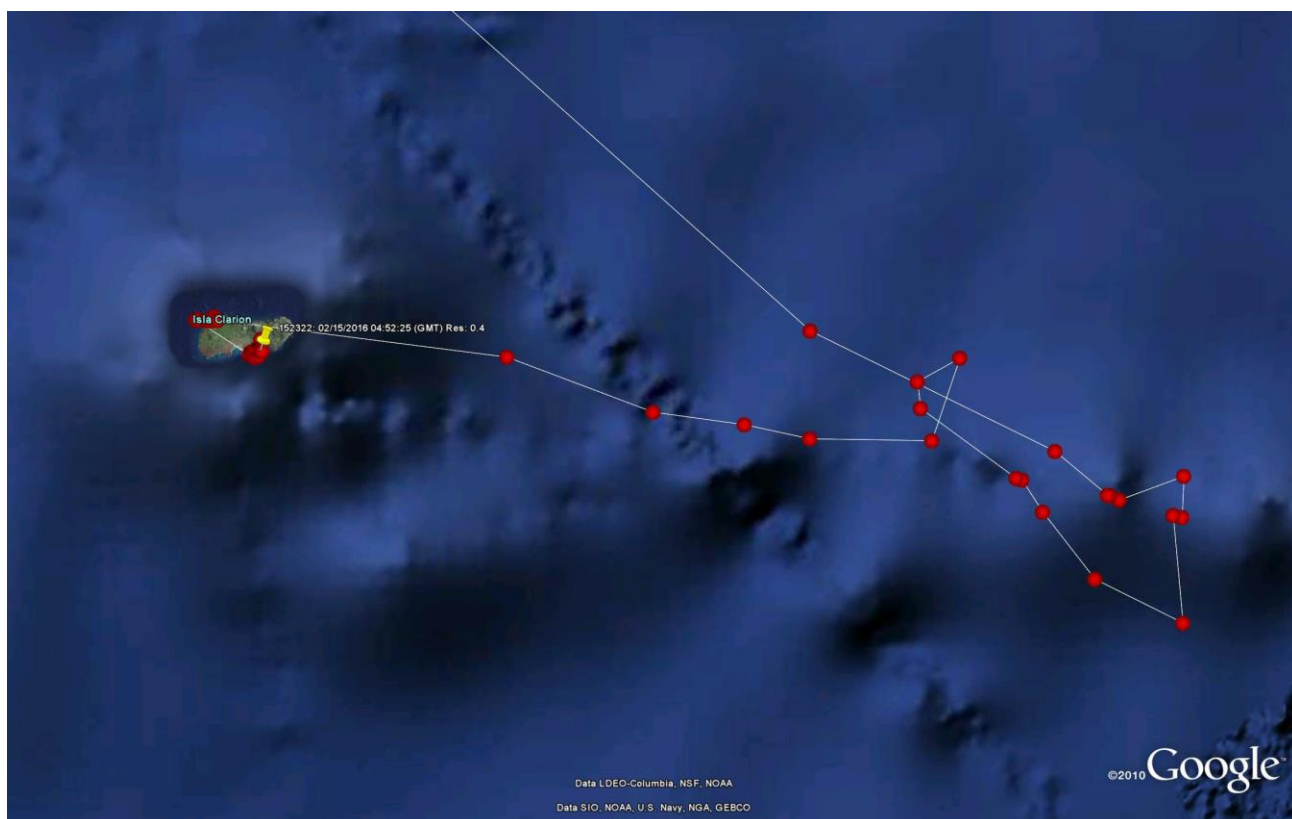


Figure 10: Satellite tracks of tag 152322 from 5 Nov 2015-23 Feb 2016.

Similar to the first three tagged individuals, turtle 152323 has also remained in south bay (Figure 11).



Figure 11: Satellite tracks of tag 152323 from 8 Dec 2015-16 Feb 2016.

Finally, the last turtle tagged in 2015 (152314) has also left San Diego Bay (Figure 12). This female headed north along Point Loma, turned south to just past the U.S.-Mexico border then returned to San Diego Bay.

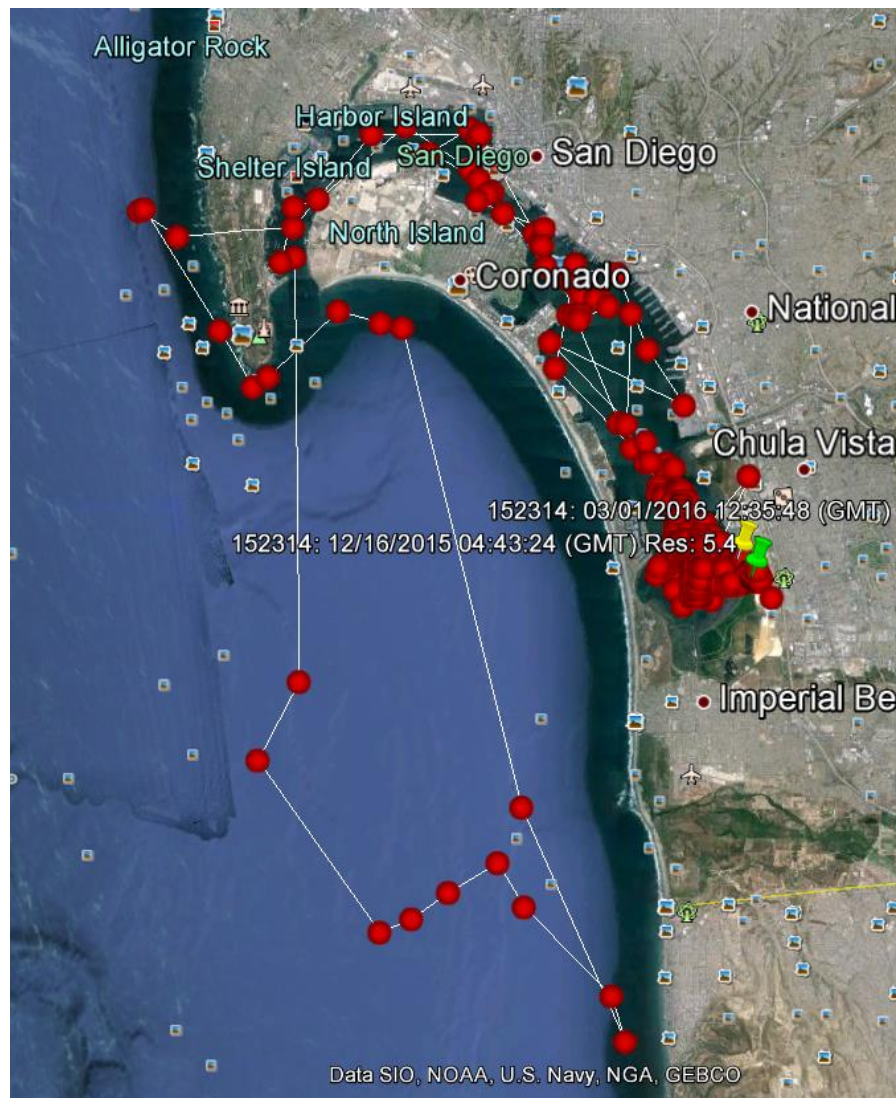


Figure 12: Satellite tracks of tag 152314 from 15 Dec 2015-1 Mar 2016.

5.0 References

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