FINAL REPORT TO THE PORT OF SAN DIEGO

IDENTIFYING CRITICAL HABITAT FOR AN ENDANGERED SPECIES IN SAN DIEGO BAY

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The goal of this project was to characterize the movements of East Pacific green turtles (*Chelonia mydas*) in San Diego Bay using a combination of active and passive acoustic telemetry. This was a Port-supported collaborative research effort between NOAA and SDSU. Using NOAA and Port-sponsored equipment, researchers at SDSU lead the efforts to track turtles using sonic telemetry and monitor the Bay for turtle activity. Scientists at NOAA were in charge of all turtle capture; telemetry equipment deployment in a combined effort between researchers from NOAA and SDSU.

Turtle presence and temperature data were used to calculate home range size, map movement patterns, and begin to assess these movements relative to thermal conditions across use areas. Variability in home range among individuals was examined based on size, sex, season, and association with high-traffic areas where density of human activities are highest. Temperature and location data was collected to determine variability in habitat usage based on temperature, time of day, and season. Knowledge of green sea turtle habitat usage in San Diego Bay will help to identify overlap between high activity areas of green turtles and human activities, such as shipping, cruise and marina traffic, construction, Naval training and military vessel movement.

1. **Turtle Capture and Tagging Efforts**
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4. **Active Tracking**
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1. Turtle Captures and Tagging Efforts

Year	Month	Day	ID	Sex	Tag Added	Freq. (KHz)	P.I. (ms)	Pattern	Weight (kg)	SCL (cm)
2009	11	05	1990	Female	Yes	36	930	5-5-5	121	100.4
2009	11	17	33145	Juv	Yes	38	950	6-7-8	50	70
2009	12	03	88129	Male	Yes	36	870	3-4-5	146	98
2009	12	03	13585	Female	Yes	38	890	3-7-7	147	102.5
2009	12	03	3004	Female	Yes	36	1130	4-4-6-5	153	101
2009	12	03	3005	Male	Yes	36	1210	5-6-5-8	89	86.9
2009	12	16	88329	Juv	Yes	37	1230	5-7-8-7	35	65.3
2009	12	16	8356	Male	Yes	39	1250	6-8-6-8	130	97.2
2010	01	05	88416	Female	Yes	37	890	3-7-6	81	87
2010	02	03	13690	Juv	Yes	37	1050	3-5-5-8	62	80.9
2010	02	03	88466	Juv	Yes	38	1070	3-6-3-6	18	54.9
2010	02	03	33149	Juv	Yes	40	1250	6-8-8-7	48	71.1
2010	02	03	4546	Female	Yes	39	1070	3-6-3-7	130	95.2
2010	02	18	1989	Male	Yes	40	1090	3-6-7-7	130	101.1
2010	03	03	11761	Female	Yes	39	1190	5-5-5-8	133	100.8

2010	03	03	8370	Female	Yes	36	1150	4-5-5-7	132	101.8
2010	04	15	4546	Female	Yes	40	1190	5-5-6-6	N/A	94.7
2010	09	07	97376	N/A	Yes	39	970	3-3-5-4	43	69.4
2010	09	07	23648	N/A	Yes	35	870	3-4-4	N/A	81.4
2010	12	02	98157	Juv	Yes	37	990	3-3-7-7	27	59.6
2010	12	16	1990	Female	Yes	38	1110	3-7-7-6	138	99.6
2010	12	16	5806	Male	Yes	39	1010	3-4-5-4	138	95.5
2010	12	16	2116	Male	Yes	38	1010	3-4-4-8	136	102.0
2010	12	16	33145	Juv	Yes	40	910	4-6-6	58	74.5
2011	01	06	13962	Male	Yes	38	1030	3-4-7-8	96	88.3
2011	01	06	23647	Female	Yes	39	990	3-3-8-4	140	103.1
2011	01	06	98310	Male	Yes	39	1050	3-5-6-5	138	98.5
2011	01	06	88129	Male	Yes	39	1210	5-6-6-8	115	97.7
2011	03	08	7218	Female	Yes	38	990	3-3-7-8	112	100
2011	05	25	33145	Female	Yes	36	970	3-3-4-6	63	74.6
2011	05	25	5806	Male	Yes	38	1150	4-5-6-6	N/A	96.7
2011	05	25	11395	Male	Yes	40	1010	3-4-5-5	109	95

2. Summary of Telemetry Activities

The following information provides a month-by-month summary of telemetry, capture, and field efforts of the SDSU and NOAA researchers. All active telemetry work was completed by SDSU; capture, tagging, and passive telemetry were a combined effort from SDSU and NOAA researchers.

January 2010

- Total Field Days: 9
- Capture Days: 2
- Active telemetry: 6 days
- Passive telemetry: SUR station maintenance

February 2010

- Total Field Days: 12
- Capture Days: 2
- Active telemetry: 8 days
- Passive telemetry: SUR station maintenance
- 24-hour tracking: 1 track on 2/25-2/26/2010 of Turtle #88329 (37 kHz, 5-7-8-7)

March 2010

- Total Field Days: 13
- Capture Days: 2
- Active telemetry: 8 days
- Passive telemetry: SUR station maintenance
- 24-hour tracking: 1 track on 3/24-3/25/2010 of Turtle #33145 (38 kHz, 6-7-8)
- Research presented at SDSU Graduate Research Symposium on 3/5/2010

April 2010

- Total Field Days: 11
- Capture Days: 2
- Active telemetry: 8 days
- Passive telemetry: SUR station maintenance
- 24-hour track: 4/22-4/23/2010 of Turtle #13585

May 2010

- Total Field Days: 12
- Capture Days: N/A (capture season was November 2009 – April 2010)
- Active telemetry: 10 days
- Passive telemetry: SUR station maintenance
- 24-hour track: 5/18-5/19/2010 of Turtle #3004
- Research presented at Joint Turtle Meeting – Southwest Fisheries Science Center on 5/27/2010

June 2010

- Total Field Days: 12
- Capture Days: N/A
- Active telemetry: 12 days
- Passive telemetry: No SUR station maintenance required
- 24-hour tracking: cancelled due to illness (rescheduled to July 2010)

July 2010

- Total Field Days: 10
- Capture Days: N/A
- Active telemetry: 9 days
- Passive telemetry: SUR station maintenance
- 24-hour tracking: 7/7-7/8/2010 of Turtle #13690 ("Goose")

August 2010

- Total Field Days: 13
- Capture Days: 1 on 8/16/2010; no new turtles
- Active telemetry: 11 days
- Passive telemetry: SUR station maintenance

September 2010

- Total Field Days: 5
- Capture Days: 1 on 9/7/2010; 3 new tagged turtles
- Active telemetry: 4 days
- Passive telemetry: No SUR station maintenance required

October 2010

- Total Field Days: 10
- Capture Days: N/A

- Active telemetry: 7 days
- Passive telemetry: SUR station maintenance

November 2010
- Total Field Days: 2
- Capture Days: 1
- Passive telemetry: SUR station maintenance

December 2010
- Total Field Days: 9
- Capture Days: 2
- Active telemetry: 6 days
- Passive telemetry: SUR station maintenance

January 2011
- Total Field Days: 14
- Capture Days: 2
- Active telemetry: 11 days
- Passive telemetry: SUR station maintenance

February 2011
- Total Field Days: 10
- Capture Days: 2
- Active telemetry: 8
- Passive telemetry: SUR station maintenance

March 2011
- Total Field Days: 12
- Capture Days: 2
- Active telemetry: 10
- Passive telemetry: SUR station maintenance

April 2011
- Total Field Days: 8
- Capture Days: 2
- Active telemetry: 5
- Passive telemetry: SUR station maintenance
- Research presented at the 31st Annual Symposium on Sea Turtle Biology and Conservation, San Diego, CA (annual meeting of the International Sea Turtle Society)

May 2011
- Total Field Days: 12
- Capture Days: 1
- Active telemetry: 11

- Passive telemetry: N/A
- Time/Depth Recorder (TDR) Deployment: 5/25/2011 on Turtle #397 ("Bulgie")

3. **Passive Telemetry**

Turtles were tracked passively using Sonotronics SUR-1 submersible ultrasonic receivers. The submersible ultrasonic receivers (SURs; Figure 1) were programmed to scan for a range of frequencies. Presence of acoustic tags is recorded into the SUR memory when a tag is within detectable range. Prior to initiation and deployment of SUR stations, we conducted a rigorous bench and field test to determine optimal equipment settings and acoustic ranges at sites in the South Bay (see Appendix 1).

SUR sites were deployed in South Bay based on areas of interest, including potential foraging areas (i.e. seagrass beds) and high-traffic areas (boating channels, marinas, & docks). HOBO U22 Water Temp Pro v2 temperature data loggers were deployed at each of the SUR sites. SURs were checked for proper functioning and battery life approximately every 8-10 weeks and data were downloaded at that time. These data helped to determine when and where turtles occurred over time, particularly with regard to diel patterns of presence/absence at sites.

Figure 1. Submersible ultrasonic receiver (SUR; Sonotronics, Tucson, AZ).

2009-2010

Submersible Ultrasonic Receivers (SURs) continuously monitored for turtle presence at six sites in San Diego Bay from December, 2009 – June, 2010 (Ramp, Elbow, Barge, R38, R36, SW Inlet; Figure 2). We sought to characterize differences in turtle presence between sites as well as within-site patterns of visitation throughout the day. Of particular interest was how presence at high boat traffic sites (R38, R36, SW Inlet) at the Sweetwater Marine Terminal (SMT) compared to low boat traffic sites (Ramp, Elbow, Barge) near the South Bay Power Plant (SBPP).

Figure 2: 2009-2010 SUR locations

Raw data of turtle detections were converted to turtle "visits" in order to minimize the effects that water depth, turbidity, and tide can have on rates of detections (MacDonald and Madrak, unpublished data). For example, a turtle present at a site might be detected 10 times over the course of 15 minutes during a normal or high tide, but only a few times during a lower tide (SURs detect with less efficiency at lower water depths). Rather than use raw data that could be heavily biased by environmental variables, we examined when a turtle arrived at a site and when it departed, characterizing a pattern of arrival, regular detections, and eventual cessation of detections as a visit. Based on careful examination of the data, we chose to define a visit as at least three consecutive detections of one individual at one site, not separated by more than 15 minutes between detections. In this way, a turtle that recorded, for example, 10 detections over the course of 20 minutes, would be treated no differently in our data analysis than a turtle that recorded 5 detections across 20 minutes, in that both turtles were present at the site for the same amount of time.

Turtle visitation to SBPP (Figure 3) was quite high during the winter of 2009, regularly averaging higher than 1 visit per turtle each day and as high as 3 visits per turtle. The SBPP SUR locations and especially the Ramp SUR (the closest to the SBPP warm water effluent) are the warmest areas of the South Bay during the winter and likely a preferred area of visitation for turtles when ambient water temperatures drop in the rest of the bay. Visitation to SBPP SURs steadily dropped in conjunction with the onset of spring, likely as water temperatures became warmer in other areas of the bay. In addition, a large amount of within site variation was seen at SBPP SURs. Nearly 75% of turtle visitation to the Ramp SUR occurred during dusk and nighttime hours, a trend that diminished moving to sites farther away from SBPP

(Elbow and Barge), as seen in Figure 4. Daytime and nighttime visitation to the Elbow and Barge were substantial and roughly equal, while dawn and dusk presence at these sites were low.

Turtle visitation to SURs at SMT was substantially lower than visitation to the SBPP. Visitation was also quite sporadic in nature, which can be noted in Figure 3 by lack of connections between red squares. Notably, and in contrast with SBPP, there was no obvious seasonal component to turtle presence at SMT. The rarity of visitation to SMT suggests that while turtles occasionally visit Sweetwater, the area is not an integral component of turtle habitat usage in San Diego Bay. Nonetheless, Figure 4 highlights an important trend – turtles almost exclusively visited SMT during daylight hours, with daytime visitation accounting for between 77-100% of all visits at SMT SURs. Given that most boat traffic in San Diego Bay occurs during the daytime, turtles are present at SMT during the period of time when the threat of incidental boat strikes is highest. This is a trend that merits further scrutiny and may have significant implications for future management of turtles in San Diego Bay.

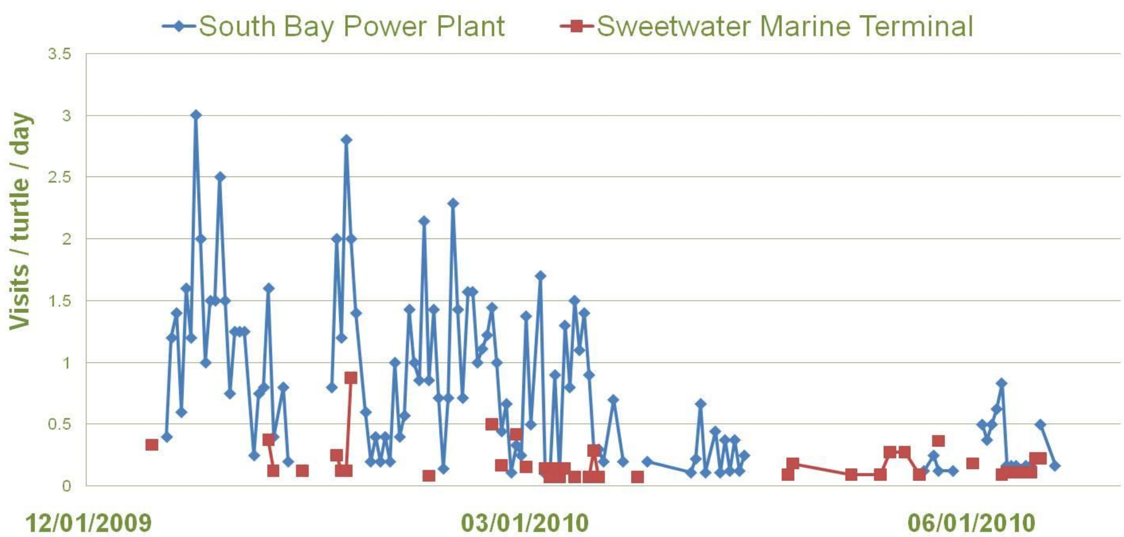


Figure 3: Turtle visitation to SBPP and SMT SURs. Dots connected by lines indicate visits across consecutive days.

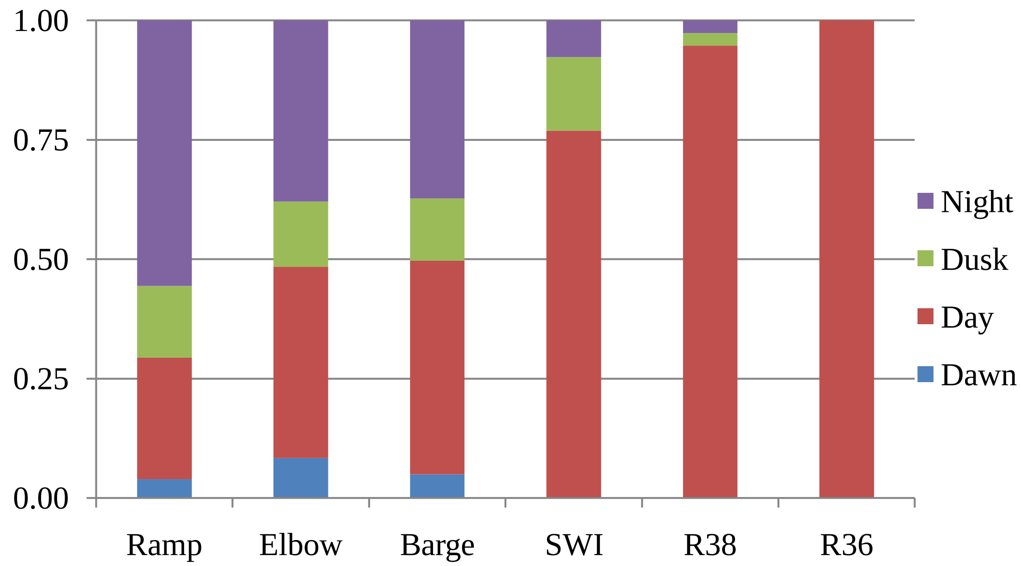


Figure 4: Proportion of 2009-2010 SUR visits by time of day: dawn (blue), day (red), dusk (green), night (purple).

2010-2011

An expanded array of SURs was deployed in December 2010 in order to better understand the diel (day/night) patterns of turtle presence in South San Diego Bay. SURs were deployed at all six sites from 2009-2010 and at an additional 8 sites, seen in Figure 5: 3 sites were located along eelgrass pastures in South Bay (NF5, NF4, NF3), 2 sites were located outside of marinas (G15, G21), and 3 sites were located along the South Bay's eastern boating channel (R18, NF2, NF1).

Figure 5: 2010-2011 SUR locations

We were unable to perform formal site comparisons due to theft of receiver station equipment, receiver malfunctioning, and a resulting mismatch in the deployment periods for numerous sites. Receiver malfunction occurred at the Ramp site SUR at the beginning of December, preventing data collection through February, 2011. Theft of station equipment appears to have been limited to surface buoys that connected to SURs anchored to the bottom. However, loss of a surface buoy prevented us from being able to directly access an SUR. Surface buoys were observed to be absent in December 2010 at sites NF2 and NF3. A NOAA diver searched for and recovered an SUR from NF2 but could not locate any at NF3. Following these thefts, a smaller (~3" in diameter) yellow buoy was chosen as an alternative surface float that would be less visible to boaters. In April, yellow floats were missing at sites NF1 and NF2. No SURs have been recovered from the area. During SUR retrieval and deployment at the South Bay Power Plant on April 19th, an SUR attached via lead line to a hidden, shore-based anchor was missing at the Barge site.

Despite the equipment issues, it was still possible to assess use across the expanded SUR array. Based on the preliminary results from 2009-2010, turtles appeared to utilize SBPP at night (conclusions from SUR data) and moved into the South Bay's eelgrass foraging pastures during the daytime (revealed by manual telemetry). Figure 6, which shows within site patterns of visitation at SUR sites for 2010-2011, bears out that hypothesis. Turtles continued to visit the SBPP Ramp primarily at night, accounting for an average of 71% of their presence in the area and 84% when including Dusk. Nighttime visitation to the Elbow site was higher, 51%, than the 38% observed in 2009-2010. Visitation patterns were roughly the same at the Barge site in 2010-2011. Figure 6 also confirms that turtle presence in eelgrass foraging pastures (NF3, NF4, and NF5) occurs almost exclusively during the day. Turtle visitation to these areas during daytime accounted for 72-89% of overall visitation to these areas.

No data is shown in Figure 6 for other 2010-2011 SUR sites (G15, R18, G21, NF1, NF2, R36, R38, SWI) because visitation to these areas was extraordinarily low. Only one visit was ever recorded at G15 (adjacent to Coronado Cays Marina) and only 3 visits were recorded at G21 (adjacent to Chula Vista Harbor, CVH), results that strongly agree with our lack of detections during manual tracking near these sites, a conclusion also addressed in our *Home Range* discussion. Only 9 visits were recorded at R18, located on the eastern boating channel in South Bay. Only one turtle (ID# 13690) visited site NF2 – 8 times during the day and twice at night – and no turtles visited NF1. Perhaps most surprising of all was the lack of visitation to the Sweetwater Marine Terminal - no visits were recorded at sites R36 and R38 and only 3 visits occurred at SWI.

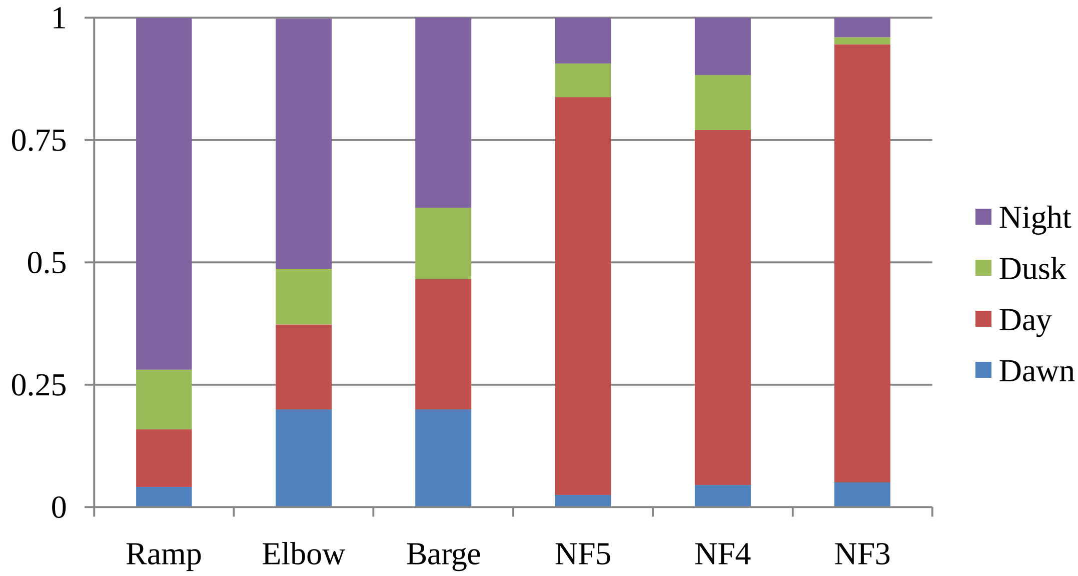


Figure 6: Proportion of 2010-2011 SUR visits by time of day: dawn (blue), day (red), dusk (green), night (purple).

In summary, SUR data from 2010-2011 were in strong agreement with SUR data from 2009-2010. Turtle visitation to the SBPP was frequent and was strongest during the dusk and nighttime periods. Turtle visitation to eelgrass foraging pastures was strongly associated with daylight hours, the period during which these animals would be actively feeding. Finally, visitation to areas of increased boat traffic (harbors, boating channels, and the Sweetwater Marine Terminal) was low and sporadic. Our SUR results also support the hypothesis from our *Home Range* analyses that green turtles in San Diego Bay limit their activity to South Bay and utilize two core areas: a daytime core area along the South Bay's eelgrass pastures (likely for foraging) and a nighttime core area adjacent to the South Bay Power Plant (an area offering low traffic channel habitat for resting).

4. **Active Tracking**

Tagged turtles were actively tracked in the water using Sonotronics DH-4 directional and TH-2 omnidirectional hydrophones and a Sonotronics USR-96 ultrasonic receiver.

Bay-wide monitoring

San Diego Bay was systematically monitored for turtle activity using a "grid" of intersecting transect lines spaced at 500m x 500m intervals, creating a comprehensive series of listening stations across the entirety of San Diego Bay. Each location on the grid was visited weekly or bi-weekly to determine presence/absence of tagged turtles. Regular visitation to all locations accounts for spatiotemporal sampling biases common to traditional telemetry studies. When a turtle's transmitter was detected, the research vessel tracked and located the exact position of the detected individual. A turtle was considered to be in close proximity when the transmitter was heard uniformly through a 360-degree rotation of the directional hydrophone at the receiver's lowest gain setting. A GPS coordinate was recorded using a handheld Garmin GPS unit (accuracy 3-5 m); water temperature at the location was recorded at a depth of 1m. Once a turtle's location was determined, the research vessel continued to the next listening station.

Individual follows

Over the course of the project, we conducted 40 individual turtle follows across 4 time periods: dawn, day, dusk, and night. Two field days each alternating week were spent tracking an individual turtle for a period of 2-6 hours. These individual follows provided higher resolution information about turtle movement patterns across the different time periods. Multiple short follows provide high-resolution data for comparisons in daily turtle movement behavior.

Turtle ID	Dawn	Day	Dusk	Night	Total
1990	0	1	1	0	2
2116	0	0	1	1	2
3005	1	0	0	0	1
5806	1	0	1	0	2
13585	0	2	1	1	4
13690	1	4	3	1	9
13692	1	0	0	1	2
23648	0	1	0	0	1
33145	1	1	1	1	4
33149	0	2	0	0	2
88329	1	1	1	1	4
88416	0	1	0	0	1
88466	0	2	0	0	2
98157	1	1	0	0	2
98310	1	0	0	1	2
Total	8	16	9	7	40

Home Range

A population home range estimate and core activity areas were calculated for resident East Pacific green turtles using GPS locations acquired from manual acoustic tracking of tagged individuals between Fall 2009 and Spring 2011. A total of 382 individual locations were pooled from 23 tagged individuals. All locations were temporally separated by at least 4 hours in order to minimize serial autocorrelation (Swihart and Slade 1987, Seminoff et al. 2002). All home range mapping and analyses were conducted in ArcGIS 9.3 using the HRT Tools extension. Population home range estimates were calculated using the fixed kernel density (FKD) method. FKD is less influenced by outlying data points and allows for the identification of intensely utilized areas (often referred to as core areas) based on high concentrations of animal locations (Swihart and Slade 1987). The FKD estimates calculated here are represented as 95% and 50% utilization distributions (UD's). The 95% UD, shaded in blue in Figure 7, indicates that 95% of the locations for the population occurred within the displayed area, and is representative of the overall size, shape, and extent of the population's home range. The 50% UD (shaded in red) indicates that 50% of all turtle locations occurred within these two, shaded "core" areas.

Figure 7: 95% (blue) and 50% (red) utilization distributions for resident East Pacific Green turtles in San Diego Bay, CA. Shaded circles show actual turtle locations, and different colored shadings correspond to different turtles.

The total area of the 95% UD was 8.00 km^2 and was entirely limited to South San Diego Bay. This estimate represents the overall home range of resident green turtles in the Bay. Although some turtle locations occurred north of Sweetwater Inlet, generally considered to be the starting point of Central SD Bay, these locations were few in number and were outside of the population 95% UD as well as the 95% UD's of the individual turtles to which the points belonged. The total area of the 50% UD "core area" was 2.01 km^2 – this area was actually split between two core areas, one of which was located in the middle of South Bay and the other running west from the SBPP along the plant's effluent outfall channel.

The general shape of the home range is characterized by a broad, North-South section covering the central section of South SD Bay, including the western channel that provides access to the Coronado Cays marinas and much of the eastern channel that provides access to and from Chula Vista Harbor. Interestingly, the 95% UD does not include a large "bubble" of area surrounding the entrance to Chula Vista Harbor. Turtles may avoid areas of boat traffic convergence, especially when those levels of convergence are higher – Chula Vista Harbor functions as both a public and private point of access to San Diego Bay, and thus may experience higher degrees of boat traffic than either boating channels or the private harbors on the western shore of South Bay.

Turtle activity in the South Bay also has a high degree of overlap with recent eelgrass distributions, as shown in Figure 8 (Merkel & Associates 2004). The northern core area, displayed as the 50% UD, lends further insight into turtle utilization of South SD Bay. Located in the center of South Bay, the northern core area overlaps with a Degree of overlap should not be assumed to be exact, as eelgrass distributions vary greatly between years and seasons, but it is nonetheless apparent that turtle activity co-occurs with eelgrass beds in much of the South Bay (Merkel & Associates 2009). The diet of East Pacific green turtles in San Diego Bay is largely comprised of eelgrass as well as invertebrate species that inhabit eelgrass beds (Lemons et al., in press). Turtle locations in this area of the bay occurred almost exclusively during the daytime, when turtles are known to feed, suggesting that the northern core area constitutes essential foraging habitat in South San Diego Bay.

The second core area abuts the SBPP, running west from the Plant's warm water effluent outfall channel. The warm effluent water historically emitted by the plant is likely a strong component of turtle visitation to the area. Turtle visitation to the SBPP channel and its surrounding area may also be influenced by the channel's bathymetry. Because the channel is rarely dredged, it is characterized by muddy caves, nooks, and ledge habitat not found in the rest of San Diego Bay (Dutton pers. comm., Seminoff pers. comm.). These features structurally mirror the outer reef slope habitat that turtles use to rest in other regions (Mendonca 1983, Taquet et al. 2006). Most nighttime locations of turtles in San Diego Bay occurred in this second core area, suggesting that it may be crucial resting habitat for the population, regardless of the SBPP's recent decommissioning.

It should be noted that although turtles appear to exclusively use South Bay during periods of residency within San Diego Bay, they must pass through the central and northern sections when undergoing migrations to and from their nesting grounds outside of the Bay. As such, North and Central San Diego Bay should not be viewed as "turtle-free" zones, as transient or migratory turtles may regularly pass through these areas during temperate months.

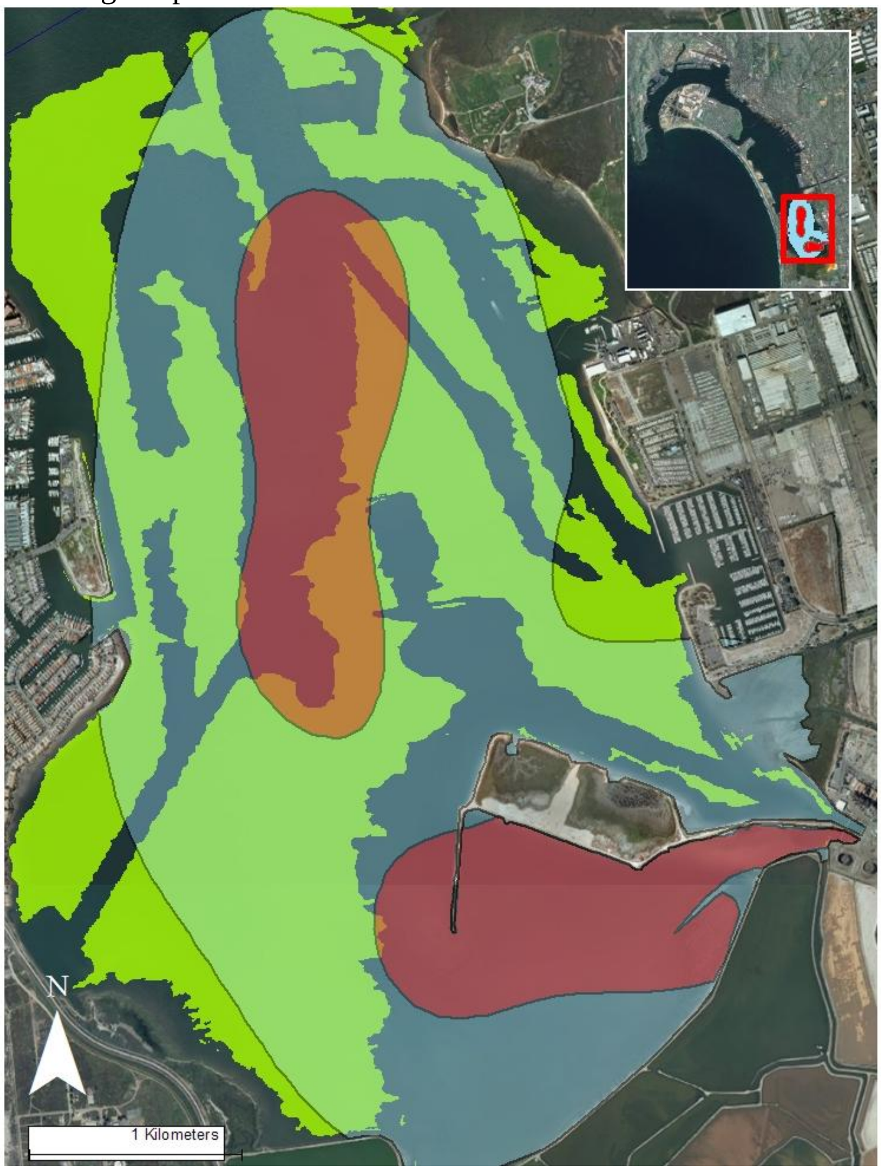


Figure 8: 95% (blue) and 50% (red) UD's for EPGT's in San Diego Bay overlaid atop 2004 eelgrass distributions (green)

Individual Follows

GPS data from turtles that were followed for extended periods (>2 hrs) throughout the day were mapped in ArcGIS 9.3. The paths of these turtles are displayed in Figure 9, grouped together by the time of day during which the individual was tracked (Dawn, Day, Dusk, Night).

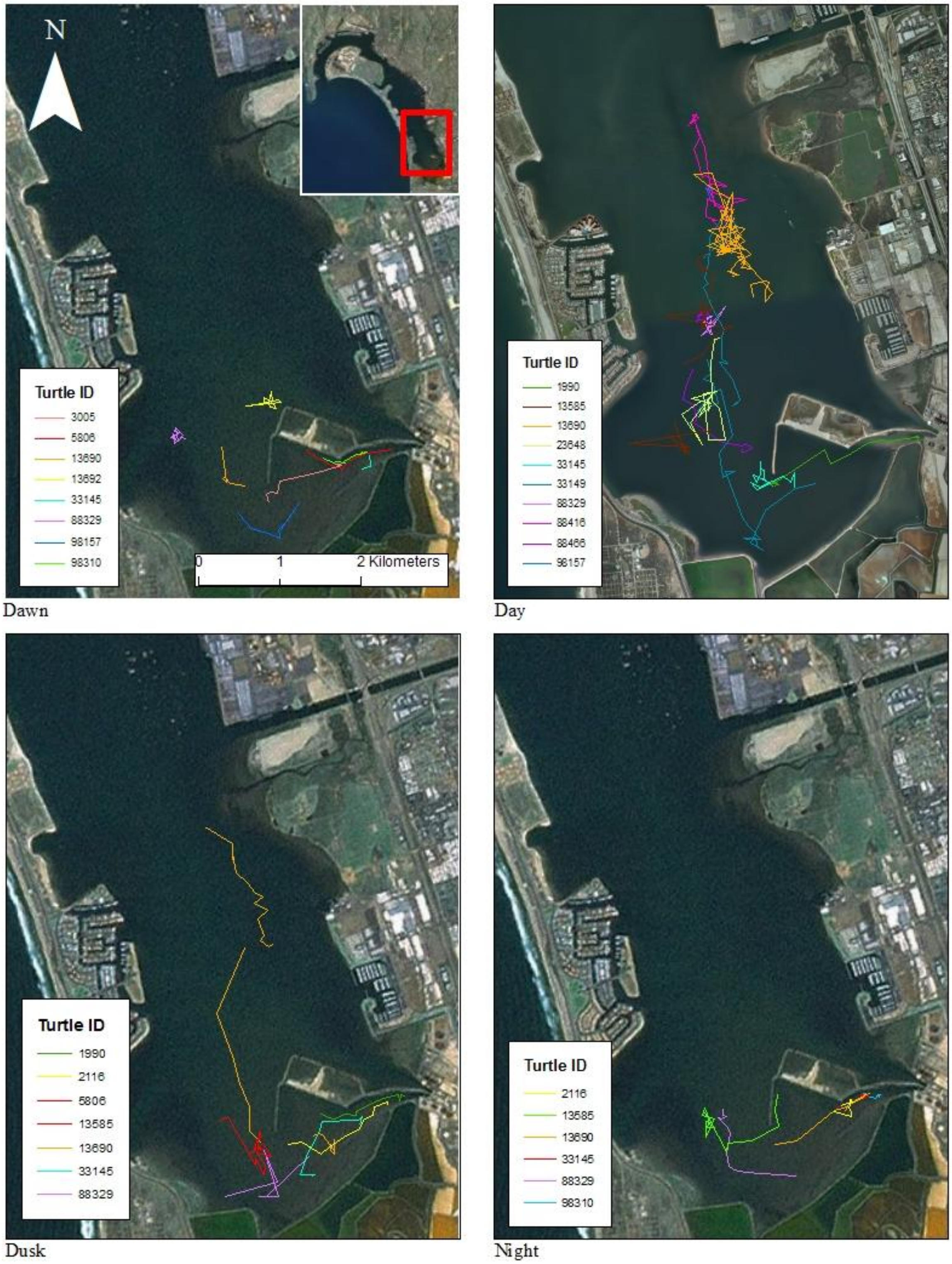


Figure 9: Follows of individual turtles, grouped by time of day.

Turtle activity during the day was clearly dispersed over a larger area of South Bay, while night follows all appear to be associated with the South Bay Power Plant the long, east-west jetty extending from it. This trend supports the hypothesis that turtles are more active during the daytime, and that turtles in San Diego Bay utilize different core areas during the day and night. Based on a number of tracks that have a roughly linear shape at both dawn and dusk, turtles appear to exhibit directed movement during crepuscular periods, a trend that is likely associated with a transition between daytime and nighttime activity areas.

We characterized movement patterns for each turtle follow via a suite of movement metrics: average speed, activity area, movement straightness index, and mean turn angle. Average speed was measured in km/hr, and was computed as an average of the turtle's speed during each time step of the follow. Activity area was measured in km^2/hr, and was calculated as the total area of the follow divided by the total time of the follow. Total area was calculated using minimum convex polygons (MCPs). Dividing by time was done in order to normalize against the fact that not all follows were of the same temporal duration. MSI was calculated as the animal's final displacement from its original location divided by the actual distance travelled over the course of the follow. MSI is a measure of path tortuousity, and is thus expressed as a proportion, where numbers closer to 1 indicate relatively straight-line movement, while numbers closer to 0 indicate circular, tortuous, or non-directed movement. Mean turn angle, measured in degrees, was calculated as the average of all turn angles in a follow. A turn angle of 0 indicates perfectly straight movement, while a turn angle of 180 degrees indicates a complete change in direction. Thus, turn angles between 0-90 degrees represent relatively straight, directed movement, while a turn angle of 90-180 indicates increasingly circular, non-directed movement. All movement metrics were calculated in ArcGIS 9.3 using the Hawth's Tools extension and are visible in Figures 10 and 11.

Average speed is variable across dawn, day, and dusk, but that all three periods are higher than night speed, when movement is reduced (Figure 10). This trend is mirrored in activity area, where the same relationships are retained. Figure 11 shows that MSI was lowest (most tortuous) during the day, indicative of the circular, non-directed movement that would be expected when an animal is actively foraging. MSI was highest (closest to straight line movement) during dusk, likely a result of directed turtle movement between daytime and nighttime activity areas. Mean turn angle is also displayed in Figure 11. Dawn and dusk shared the lowest mean turn angle (closest to straight line movement), though mean turn angles were not drastically different between times of day. This is likely because mean turn angles were calculated from data that was highly variable and occurred across many time steps; this was also noticed in the calculation of average speed.

In order to qualitatively assess such variability, we produced graphs that plot all recorded points for speed and turn angle as a function of time (Figures 12 and 13). Figures 12 and 13 both use the central point of the time period (for instance, sunrise for dawn) as the midpoint of the graph. Despite the large amount of variation, certain trends become noticeable.

Based on a careful examination of speed data (Figure 12), we placed limit lines at 0.5 km/hr, below which we considered to movement to minimal, and at 2.0 km/hr, above which we consider movement to be high. Large concentrations of points lie below the 0.5 km/hr limit for the dawn and night periods, with comparatively few points in the intermediate or high speed regions. During night, most high speed points come from one turtle and come much earlier in the evening period. During dusk, more points land in the intermediate region, though a fair amount still lie in the minimal movement area. Finally, during day, speed is far more variable, with concentrations of points occurring at all speeds and far more points landing in moderate and high speed regions than during other times of day.

Graphs of similarly plotted turn angle data are shown in Figure 13. For turn angle graphs, we placed a limit line at 90 degrees, below which movement is more straight or directed, and above which movement is non-directed and more circular. During dawn, very few points lie below 90 degrees during the pre-sunset period. Following sunset, there is a wider spread of points and a greater clustering in the lower degree, directed movement portion of the graph. This correlates well with the idea that as the sun rises, turtles gradually become more active and exhibit directed movement as they transition to daytime foraging areas. Daytime turn angles are incredibly variable, with a broad distribution of points and no discernable pattern. Dusk turn angles are spread evenly leading up to sunset, but become distinctly clustered in the <90 degree quadrant after sunset. Similar to dawn, this corresponds with turtles returning to nighttime resting locations as the sun sets. Finally, nighttime turn angles are more varied in the early evening, when some turtles may still be active or transitioning between activity areas. As night progresses, fewer and fewer points are located below 90 degrees, suggesting that turtles show less directed movement, a pattern that agrees with night speed data (which show reduced levels of movement as the night progresses).

Taken together, our activity and straightness data both support and give nuance to our home range and SUR analyses. They agree with the general trend of turtles circularly foraging in South Bay during the day, resting at night, and showing greater amounts of directed movement in between diurnal and nocturnal periods. Our movement data also highlight the wide amount of variability and plasticity in turtle behavior – a reminder that underneath general population trends, individual turtles deviate from expected patterns and do not always conform to a “one size fits all” behavioral model.

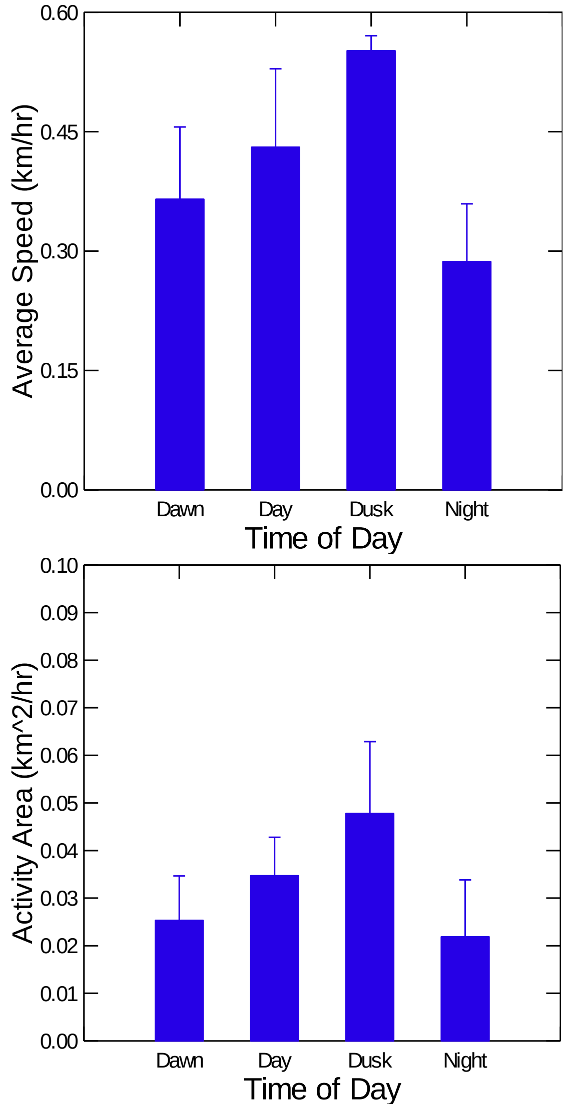


Figure 10: Average Speed and Activity Area for turtle follows across times of day.

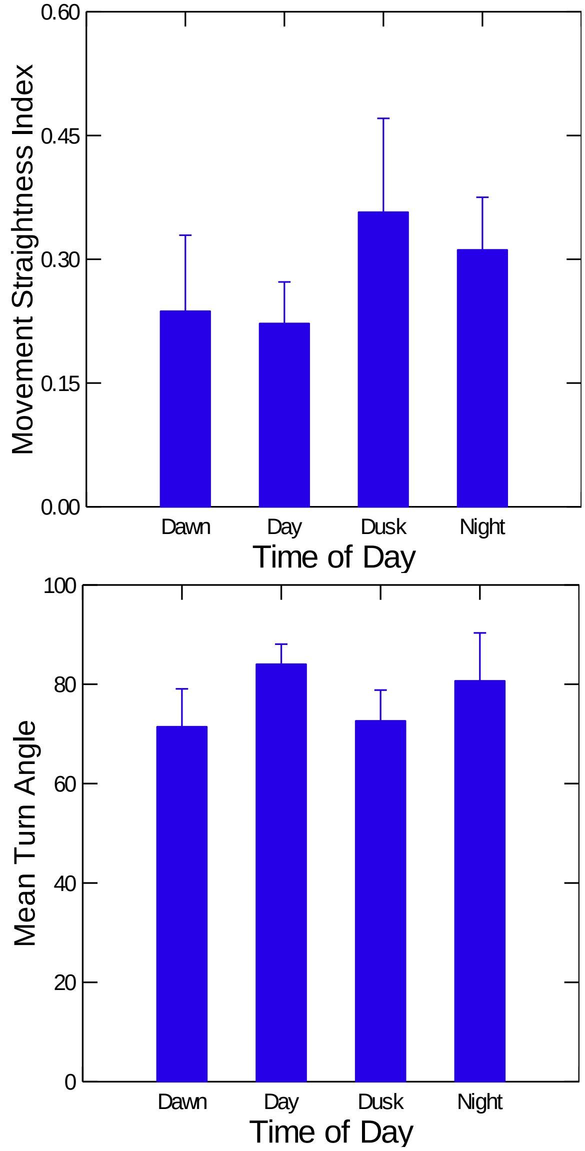
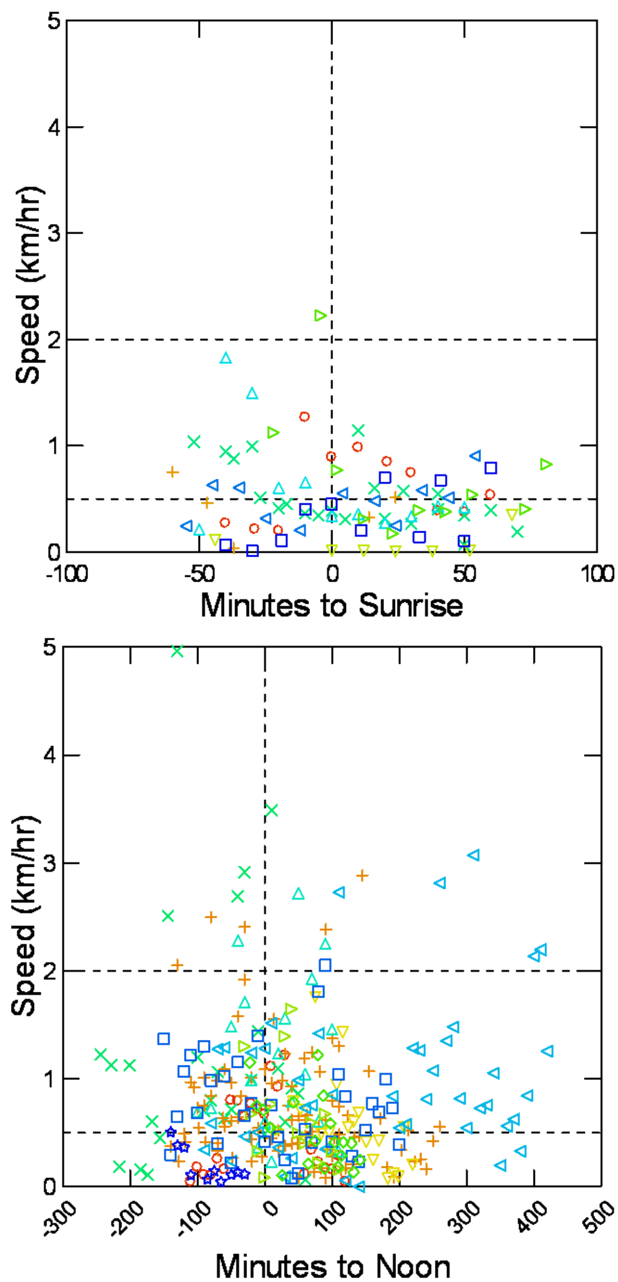


Figure 11: Movement Straightness Index and Mean Turn Angle for turtle follows across times of day.



Speed (km/hr)
Minutes to Sunrise
Speed (km/hr)
Minutes to Noon

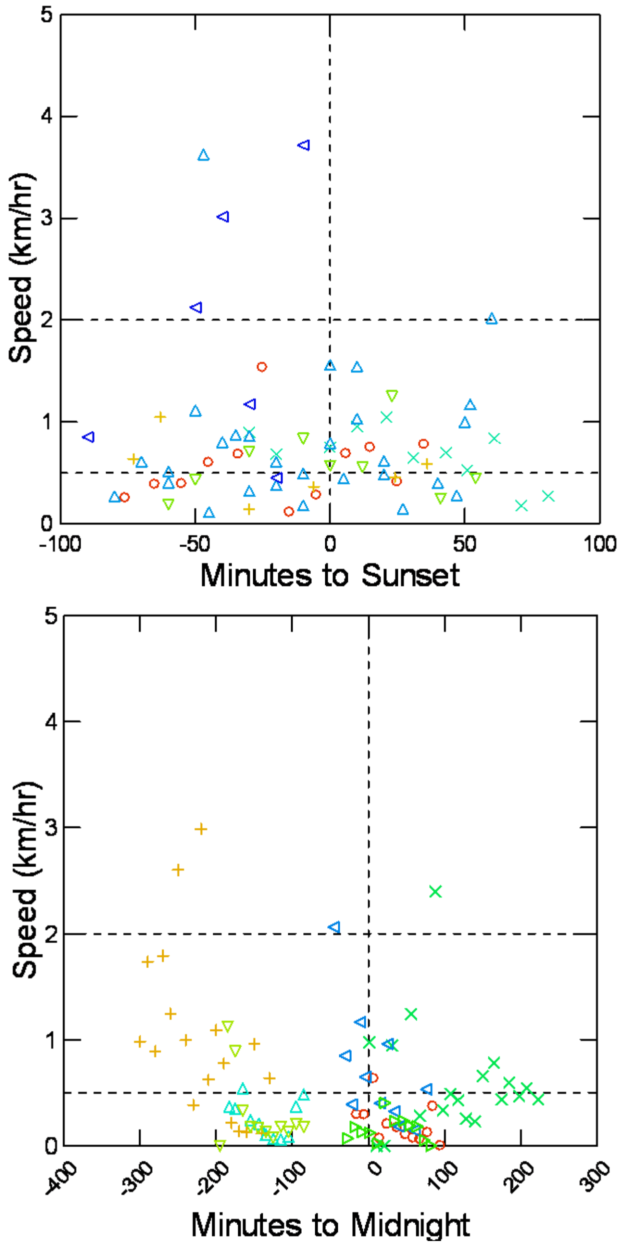
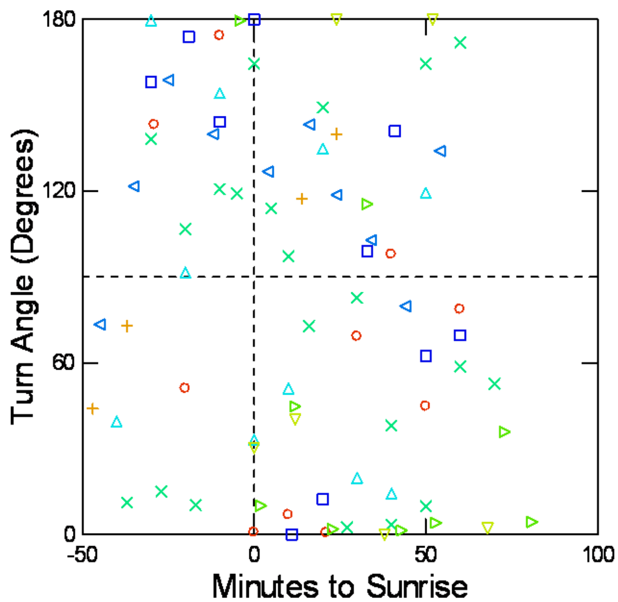
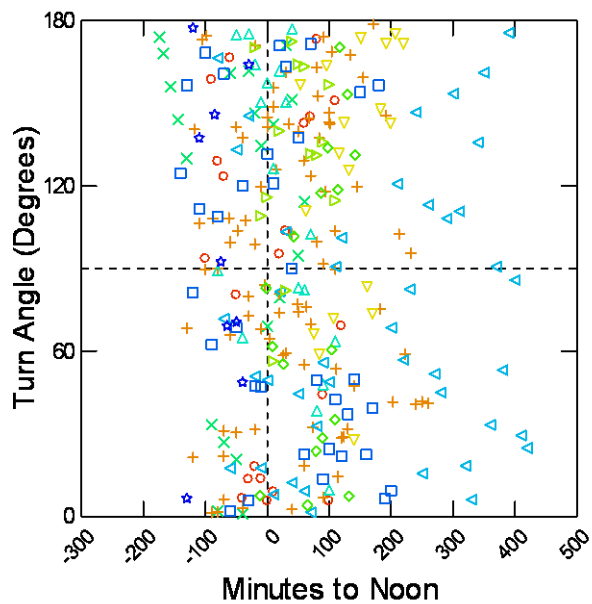


Figure 12: Speed plotted for dawn, day, dusk, and night; individual turtles are represented as different colors.


180
120
60
0
-50
0
50
100
Turn Angle (Degrees)
Minutes to Sunrise


180
120
60
0
-300
-200
-100
0
100
200
300
400
500
Turn Angle (Degrees)
Minutes to Noon

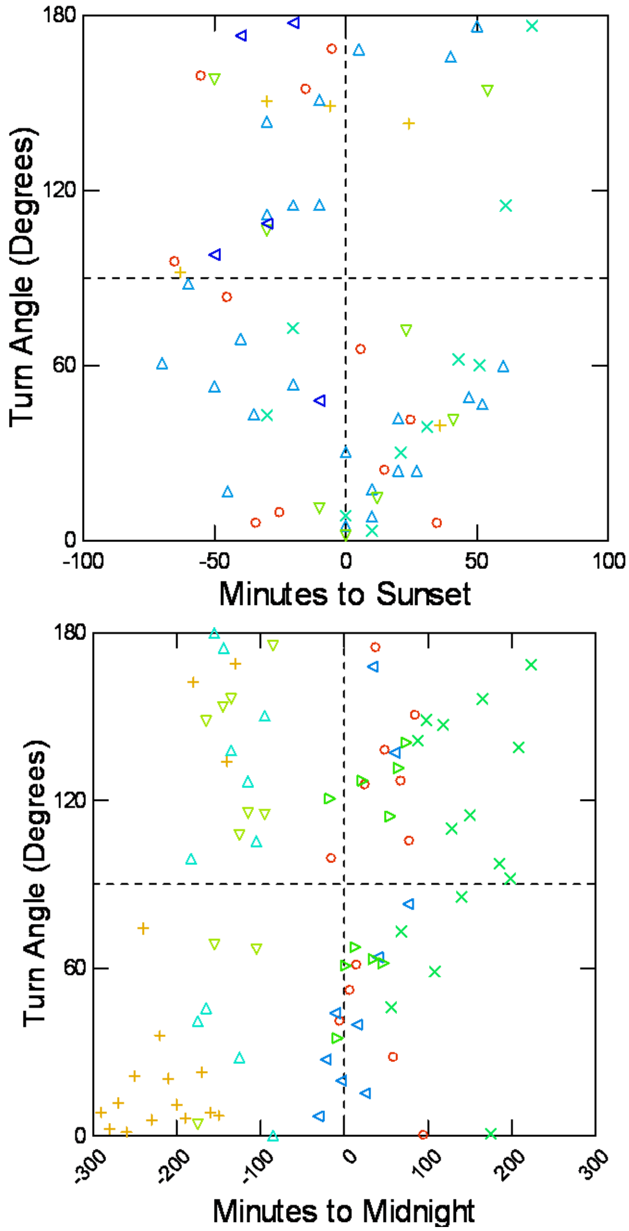


Figure 13: Turn angle plotted for dawn, dusk, day, and night; individual turtles are represented as different colors.

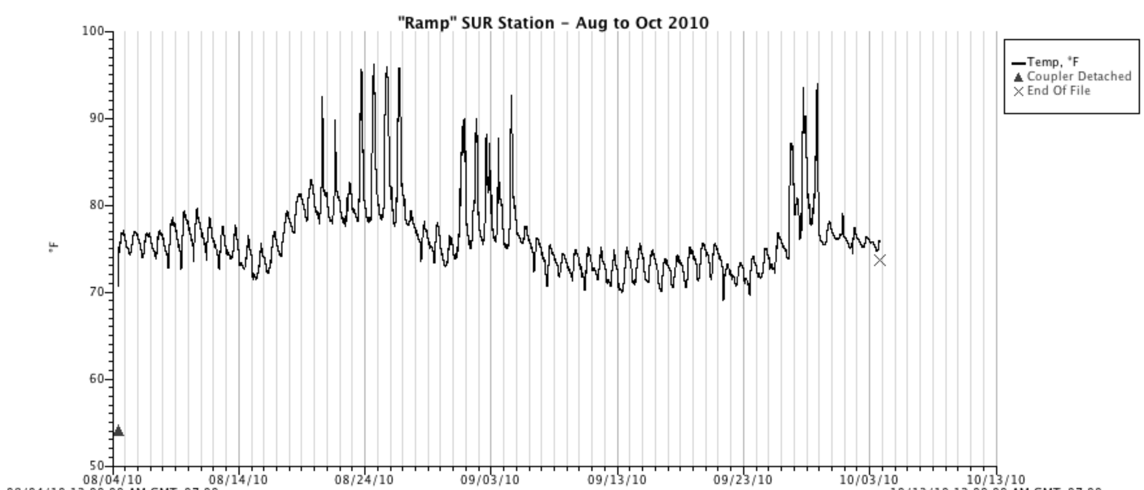
5. **Temperature**

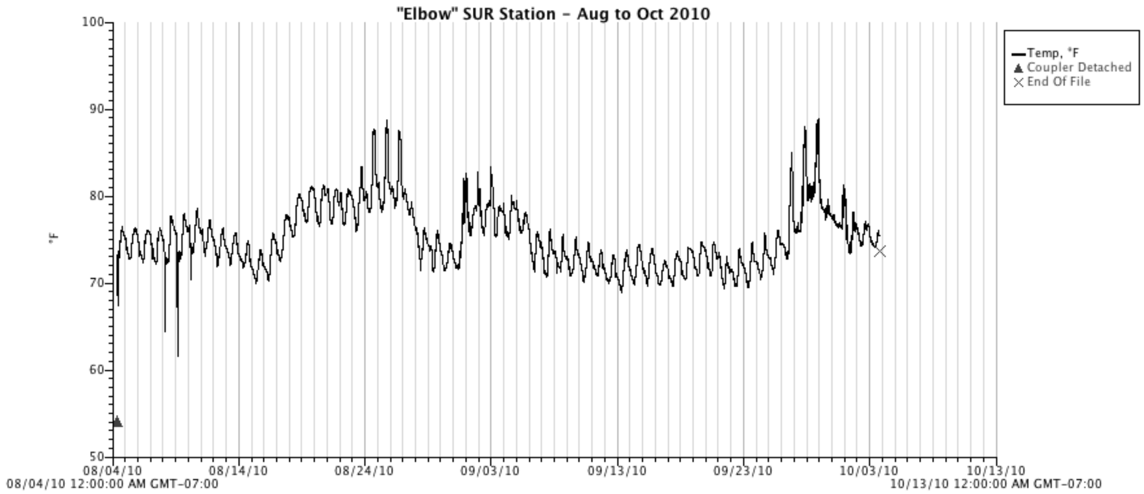
The warm water outfall area generated by the South Bay Power Plant (SBPP) has been the hub for turtle capture and tracking efforts for the history of green turtle research in San Diego Bay. On December 31, 2010 the SBPP was permanently shut down, ending a source of unnatural thermal refuge that the turtles have utilized for decades. It is presumed that turtles used the outfall area for thermoregulatory purposes. Although historical records are indicative that green turtles have inhabited San Diego Bay since at least the late 19th century, research has only been conducted in the era of the SBPP's operation. This return to "natural" thermal conditions in South Bay will no doubt reveal some interesting information about the response of turtles as they re-adapt to thermal ranges more reflective of those prior to SBPP operation.

During the course of this study, temperatures in the outfall area were monitored regularly before and after the shutdown of the SBPP. Included below are 5 graphs representative of thermal conditions in the outfall area – those typical during SBPP operation and those post-SBPP shutdown.

Thermal Conditions Prior to SBPP Shutdown

HOBO temperature data loggers that were deployed from August 4 – October 4, 2010 in the SBPP outfall area – "Ramp," "Elbow," and "Barge" – demonstrated marked fluctuations in temperature, presumably associated with release of warm water effluent from SBPP (Figure 6). Temperature spikes occurred on August 24-28, 2010, September 1-4, 2010 and October 27-28, 2010. These spikes were most dramatic at the "Ramp" location – as expected, due to proximity to effluent release point. These spikes were evident at the "Elbow" and "Barge" locations, however the fluctuations were less dramatic as temperature dissipates with increasing distance from the effluent release point.





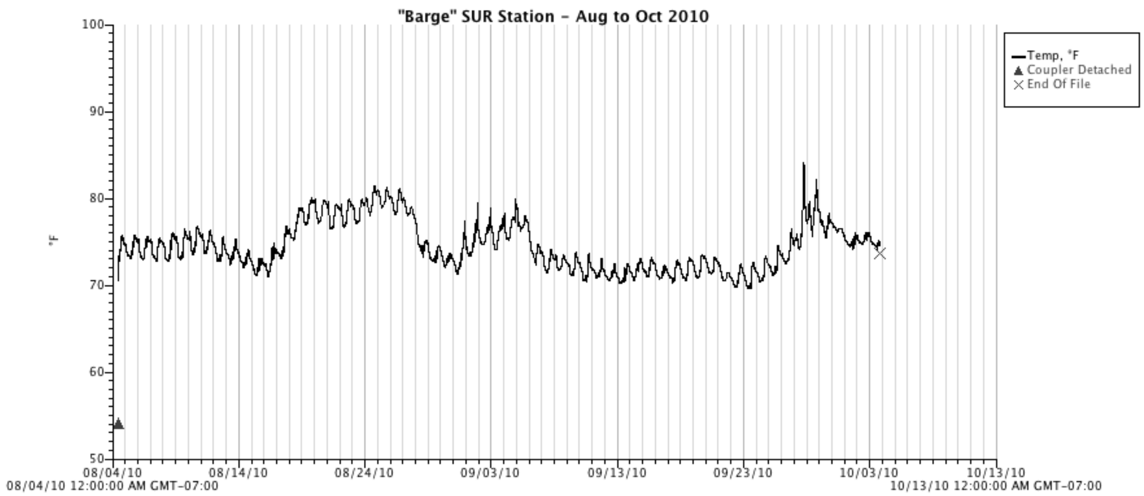
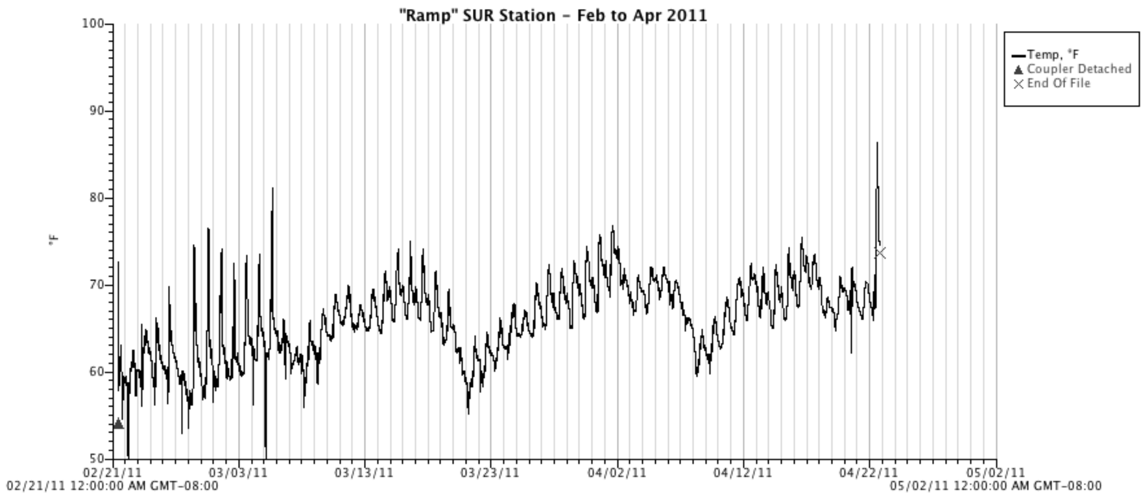


Figure 14. Temperatures recorded in the SBPP outfall area in the months prior to power plant shutdown.

The thermal conditions demonstrated in Figure 14 are representative of the collective data recorded during this study prior to the SBPP shutdown. During operation, warm water effluent was periodically released into the outfall area – a result of the cooling processes necessary for proper plant function. These periods of warm water release were clearly evident through marked spikes in thermal conditions.

Thermal Conditions Subsequent to SBPP Shutdown

Thermal conditions in the SBPP outfall area since the shutdown of plant operation demonstrate a more even thermal range. Temperatures at the "Ramp" location – closest to shore – remain slightly higher than those at the "Elbow" location (Figure 15). Additionally, temperatures in the SBPP outfall area remain slightly higher (sometimes greater than 3° C) than the surrounding South Bay based on temperature measurements taking during active telemetry. These higher temperatures are likely a result of the unique and anthropogenically altered geography and bathymetry of the outfall area. The jetty, constructed to separate the SBPP intake from the outfall, creates a barrier that disconnects the outfall area on nearly three sides – likely restricting water movement in and out of this area. This, taken together with the shallow depths of the outfall area, creates an area conducive to greater radiant heating (and maintenance of that heat).



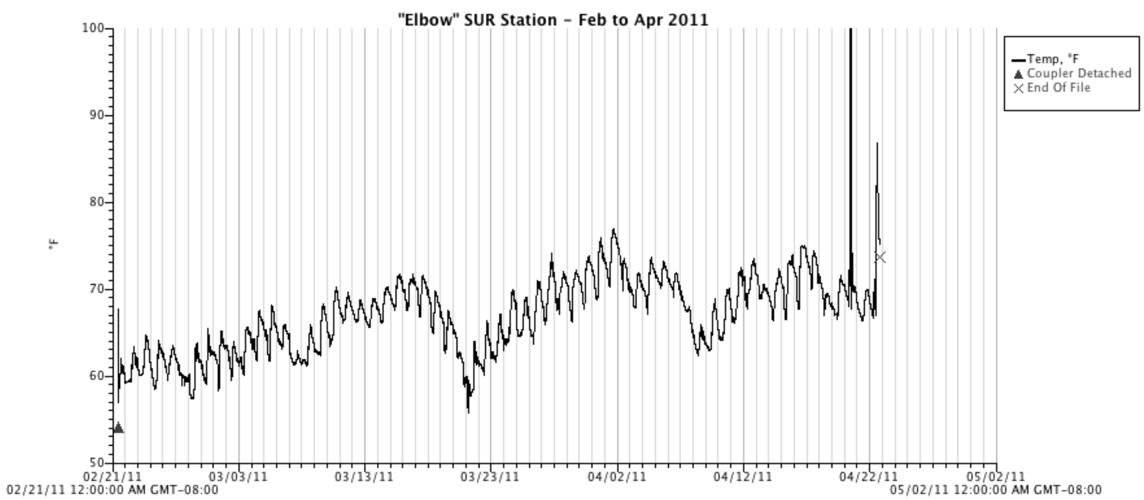


Figure 15. Temperatures recorded in the SBPP outfall area in the months following the power plant shutdown. No data was collected for the "Barge" due to equipment theft from this location.

6. **Future Directions**

The work conducted under this project characterizes and quantifies broad-scale movement of East Pacific green turtles in San Diego Bay. With this information, we now can turn our attention to developing a more complete understanding of how turtles use Bay habitat, with respects to thermal conditions, human activities and other factors. The closure of the SBPP also may alter use patterns so continued monitoring is necessary. Given their strong site fidelity, changes in movement and behavior may not be evident for months or years following the plant shutdown.

Previous studies have demonstrated relationships between dive depth and water temperature in green turtles, across daily and seasonal changes. Changes in dive depth based on thermal conditions likely reflect thermoregulatory behavior to minimize energetic costs. Preliminary data recorded prior to the SBPP closure suggest similar relationships in SDB. To examine how dive behavior changes following the complete decommissioning of the SBPP, time-depth recorders Data from TDRs will provide information regarding vertical movement of turtles in SDB, to compliment the horizontal movement information obtaining through passive and active tracking. Additionally, data recorded before and after the SBPP closure will reflect any changes to dive behavior.

The closure of the South Bay Power Plant provides a robust experimental opportunity to examine how a long-lived marine vertebrate responds to rapid changes in the thermal environment. By characterizing the responses to these sudden temperature shifts, this project can provide necessary data on the threats these species face from the effects of large-scale climate change. Eastern Pacific green sea turtles, like all other sea turtles species, are classified as endangered by the IUCN. San Diego Bay populations provides a model system to explore how other populations of marine turtles (and possibly other marine species) may respond in the face of global climate change.

By characterizing the behavioral responses of green sea turtles in San Diego Bay to changing environmental conditions, results from this project will improve our understanding of how a population of long-lived marine vertebrates will be affected by a thermally dynamic environment that is changing at rapid rate. Behavioral changes of species in response to non-natural warm-water areas may lead to local adaptation to those areas of thermal effluent, thus future management strategies are critical.

Results from this and future studies will also serve as the foundation to evaluate the direct risks that turtles may encounter from human activities, such as shipping, military vessels, dredging, construction and recreation boating. Having a fine-scale understanding of turtle movement horizontally and vertically within the Bay will provide the necessary data resolution to improve management and risk mitigation to the resident turtle population within San Diego Bay.

Appendix I. Equipment Testing

To assess performance of SURs in the field, we conducted a series of bench tests and field deployments. Ideally, a SUR detects and records a tag anytime the tag is within its range. However, because field conditions are never ideal, performance of SUR for detecting tags needed to be evaluated to understand equipment function and interpret data records.

SUR Bench Test

The first stage in evaluating SUR tag detection rates was to test a single tag and a single SUR in a bench test. The tag and SUR were aligned approximately 6 inches apart on the lab bench (per recommendation from Sonotronics technical support). The SUR was programmed to detect the single frequency at which the tag was transmitting, there was no scan delay, and the ping/response was turned off – all to simplify the process and eliminate unnecessary time in the scan cycle. Prior to data collection, SURsoft (communication software for SUR) was set to "debug on" mode thus allowing us to visualize detections (hits) and non-detections (misses) in real-time. When there is a hit during a scan, the software displays an "!" and when there is a miss, the software displays an "A." The test was conducted for 5 minutes.

The tag that was used in the bench test operated at a frequency of 38 kHz and had a acoustic pulse pattern of 4-4-6-7 (to the unaided ear, this sounds like a series of click and pauses). Visually, the test resulted in a repeating pattern of 4 "!" followed by 1 "A" - !!!!A!!!!A!!!!A!!!!A!!!!A…. The results thus showed an 80% detection rate. Further inquiry with Sonotronics technical support revealed that each individual tag has a short delay between pulse cycles, such that the pulse *cycles* (in this case 4-4-6-7) and then delays (no acoustic information transmitted) for 1 second or greater. The actual tag used in this bench test had an inter-cycle delay of approximately 3 seconds. Given this new information, the bench test was repeated and each scan cycle was timed to determine how long before either an "!" or an "A" appeared.

The results demonstrated that scans with hits (indicated by "!") took about 7-8 seconds and that scans with misses (indicated by "A") took about 3 seconds – exactly equal to the inter-cycle delay period. This means that the misses were as a result of the SUR scanning for a tag during the time that the tag was between pulse cycles (the inter-cycle delay). From this test, we learned that there is a likelihood that misses will occur (false negatives) for a given tag and that this will be dependent on (and can be calculated by) the inter-cycle delay for each individual tag.

SUR Scan Time

The SURs are set to scan for tags of each programmed frequency for 2 seconds, according to the operations manual. In actuality (according to personal communication with Sonotronics technical support), the scan time per frequency can range from 3-5 seconds depending on the frequency and whether a tag is detected. Based on the bench test, the scan time can actually be 7-8 seconds per frequency.

SUR Scan Delay (time between scans)

The rest time between scans, or the scan delay, can be manipulated via SURsoft to save battery life. The SURs for the San Diego Bay project scan for a wide range of frequencies and thus the total scan cycle is around 2 minutes in length. Eliminating this scan delay will save 3 seconds from the total cycling time. Although this seems like an insignificant delay, removing a scan delay will shorten the total scan cycle and thus increase likelihood of detection of tagged turtles. The impact on battery life should be inconsequential.

Field Trial Methods

Performance of SURs in the field was determined by the number of actual, recorded detections compared to the potential number of detections in a five-minute interval. Three sites within south San Diego Bay (SF3, SF1, and Jacuzzi Ramp) were selected for initial tests of detection during high tide. Detection rates are known to decrease as a function of increased distance between the SUR and acoustic transmitter. Consequently, several distances between SUR and transmitter were tested for detection at each site: 5m, 25m, 50m, 100m, and 200m.

Two SURs, attached to 8 x 8 in. cinder blocks, were deployed at each test site and GPS coordinates for that site were recorded. One SUR was encased in a protective PVC sleeve, while the other SUR was left unprotected, in order to examine what effects, if any, a protective casing might have on the performance of an SUR. The ability to place protective casings on SURs in future deployments would be beneficial for protecting the devices from potential boat propeller strikes at low tide and any other debris that might strike an SUR in the water column.

The boat and crew anchored the vessel at the approximate distance from the SUR and recorded GPS coordinates for that distance. An acoustic transmitter was then lowered approximately 1.5 m into the water for a period of five minutes. This process was repeated for each of the desired distances. Due to the fact that distances were only approximate in the field tests, actual distance was later calculated using the GPS coordinates recorded for each site.

Also, at each site, an additional test was conducted to test the potential effect of boat engine noise on the SUR's detection of a nearby transmitter. Lowering the acoustic transmitter into the water for five minutes at a distance of 5m from the SUR and running the boat engine during this period accomplished this.

Results

Percent Detection

Overall percent detection was high at site SF3, low at site SF1, and intermediate at site Jacuzzi Ramp (Figure A1). Although specific causal relationships cannot be established, it is possible that the depths may have affected the detection. Studies on passive acoustic telemetry arrays have indicated increased detection rates and ranges as a function of increased depth. SF3 is approximately 30% deeper than site SF1, while the Jacuzzi Ramp has a variable bathymetry and thus a range of depths between those of SF1 and SF3. Other variables that are known to affect performance of SURs include water temperature, thermoclines, turbidity, bathymetry, ambient noise, and bottom substrate.

Furthermore, relative detection rates were highest between 25-50 m, and percent detection for all sites followed a similar decreasing trend as distance from the SUR increased. Percent detection at site SF3 was notably high, detecting between 85-95% of possible detections between 25-60 m. It continued to detect the tag (~40%) up to the greatest tested distance of 130 m. Detection at site Jacuzzi Ramp was low (~30%) within 5 m, higher between 25-50 m (~75-90%), and ~70% at 100 m, which was the greatest distance tested. Detection at site SF1 was lower than other test sites: ~5% at 5 m, ~35% at 25 m and 50 m, ~20% at 100 m, and ~15% at 200 m. Low detection rates were found within 5 m of the SUR.

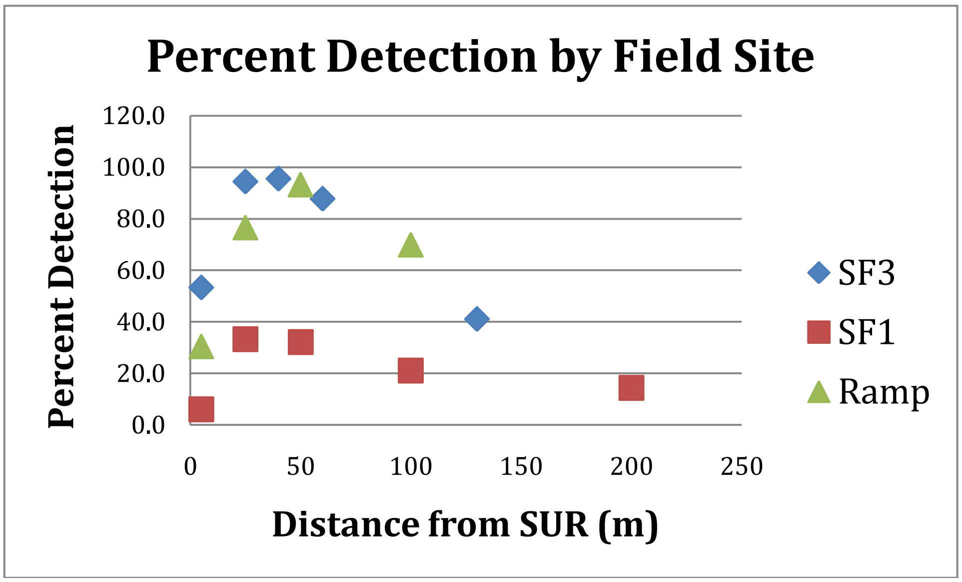


Figure A1. Percent detection as a function of distance from SUR and field sites

Effects of Protective Sleeve

SURs in protective sleeves appeared to perform as well as those that are not encased (Figures A2, A3, and A4). This finding is encouraging, because the protective casing will protect SURs from incidental boat propeller strikes, collisions with marine debris, and other unforeseen physical events that might damage or destroy an SUR.

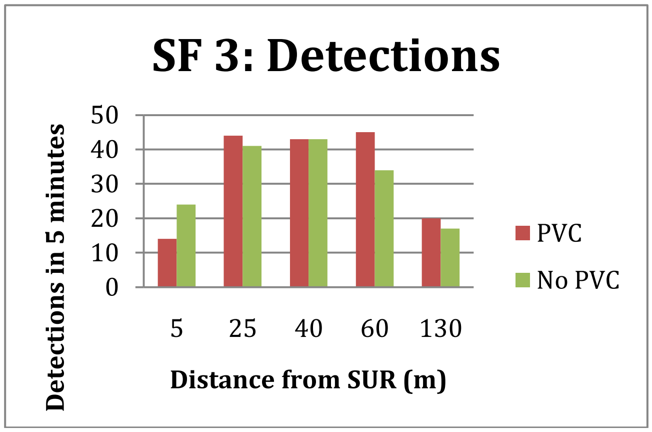


Figure A2. Effects of protective PVC casing around SUR on tag detections as measured by the number of detection per 5 minute interval at SF3.

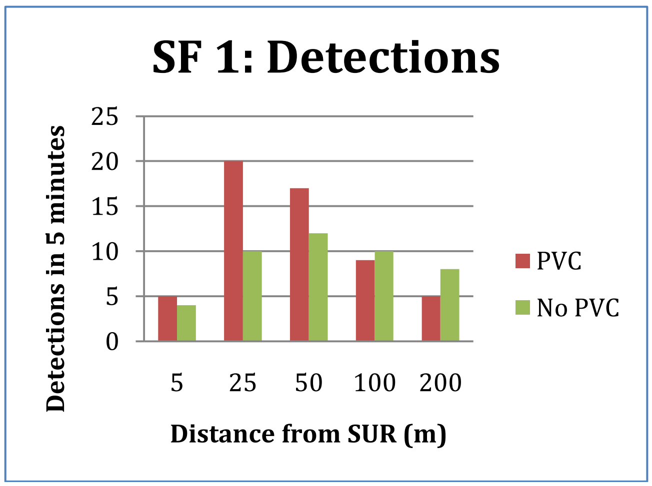


Figure A3. Effects of protective PVC casing around SUR on tag detections as measured by the number of detection per 5 minute interval at SF1.

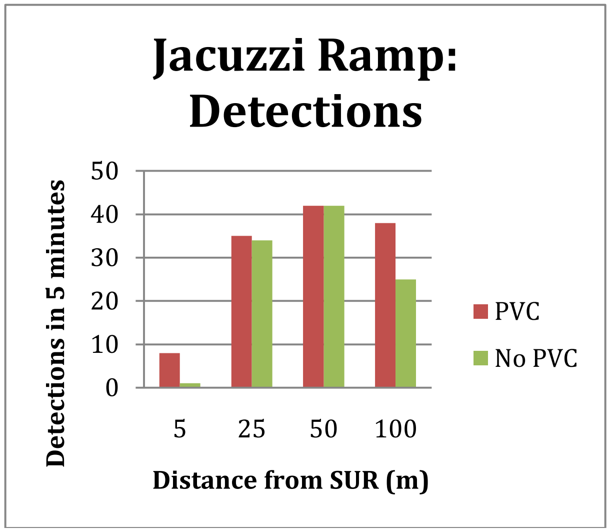


Figure A4. Effects of protective PVC casing around SUR on tag detections as measured by the number of detection per 5 minute interval at Ramp

Effects of Engine Noise

The operation of a boat engine within 5m of both an SUR and an acoustic transmitter did not result in a decreased number of detections by the SUR. This was the case for both SURs with a protective sleeve and those without (Figures A5 and A6). Although previous studies have suggested that noise from boat engines can destructively interfere with transmissions from acoustic transmitters, observed data did not support this.

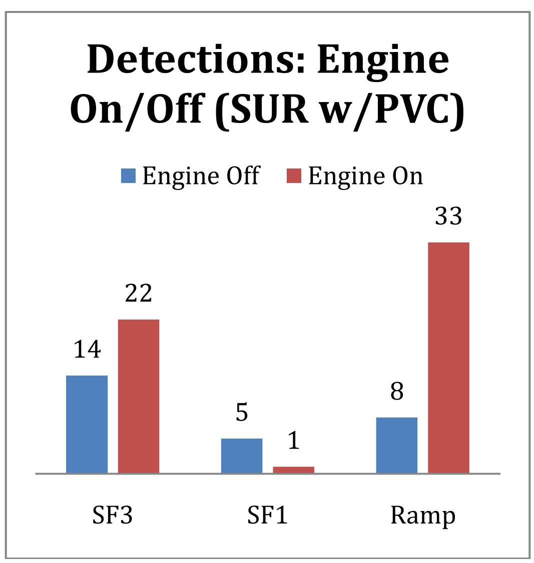


Figure A5. Effects of engine noise on acoustic tag detections by SUR. An SUR and acoustic tag were placed at 5 m from the boat engine. Numbers indicate the number of detections by the SUR per 5 min.

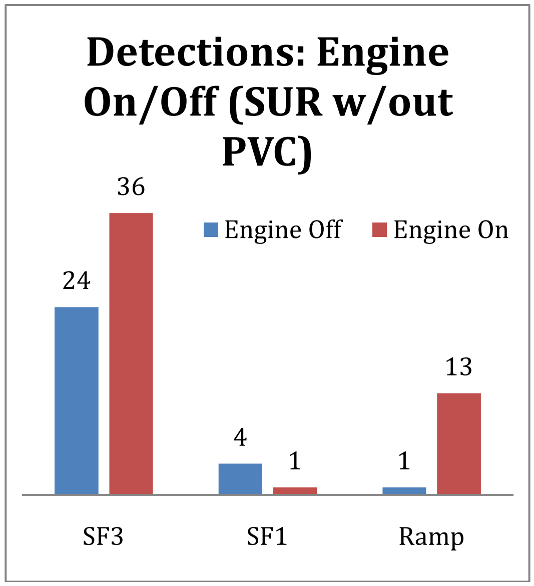


Figure A6. Effects of engine noise on acoustic tag detections by SUR. An SUR and acoustic tag were placed at 5 m from the boat engine. Numbers indicate the number of detections by the SUR per 5 min.