Sea Turtle Surveys and Satellite Tracking in the Naval Defense Sea Area (Pearl Harbor) O‘ahu, Hawai‘i, United States

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PIFSC Data Report DR-24-14

August 2024

U.S. Department of Commerce
Gina Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, Ph.D., NOAA Administrator

National Marine Fisheries Service
Janet Coit, Assistant Administrator for Fisheries

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Edited by Revere Wood.

Recommended citation

Gaos, A.R., Staman, J.W., Martin, S.L. (2024). Sea Turtle Surveys and Satellite Tracking in the Naval Defense Sea Area (Pearl Harbor) O‘ahu, Hawai‘i, United States. Pacific Islands Fisheries Science Center. PIFSC Progress Data Report. DR-24-14. 13 p. https://doi.org/10.25923/szq3-dq02

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Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
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Executive Summary

The Naval Defense Sea Area (NDSA) in Hawai‘i includes Pearl Harbor and nearby coastal waters. The NDSA is a major strategic area for the U.S. military, particularly the the Navy, while also serving as important habitat for an amalgam of marine species including green *Chelonia mydas* and hawksbill *Eretmochelys imbricata* sea turtles. Both of these species are protected under the U.S. Endagered Species Act and their presence can impact military and commercial operations in the NDSA, thus understanding sea turtle distribution and habitat in the NDSA is needed to inform decision making processes.

In 2023 the Navy and NOAA entered into an interagency agreement (IAA) that focused on conducting in-water surveys to observe, hand capture, and attach satellite tags to sea turtles in Pearl Harbor. Over the course of two months in early 2024, NOAA was able to conduct six survey days in Pearl Harbor, during which time they observed a total of 85 sea turtles including 84 green turtles and one hawksbill turtle. A total of 30 green turtles were captured, 23 of which were equipped with satellite tags. Most turtles were captured while resting in caves or under ledges, or while emerging from these habitats. A large proportion (33.3%) of the turtles captured were greater than 65 cm (straight carpace length), indicating Pearl Harbor is an important habitat for large size classes, which high conservation value.

Turtles used most of the channels and lochs of Pearl Harbor, with movements particularly concentrated along the main channels where they were originally captured, indicating general fidelity to these areas. Larger turtles tended to move more and exploit a greater proportion of Pearl Harbor than smaller turtles, the latter tending to utilize habitat in the immediate vicinity of where they were captured. Two turtles left the NDSA, inlcuding a sub-adult turtle that migrated to the southern coast of Kauai, and an adult female that migrated approximately 1,700 km to Lisianski Island in the Northwest Hawaiian Islands. This study represents the first directed effort to track sea turtles via satellite telemetry in Pearl Harbor. The project is ongoing and this progress report provides a summary of the work and results to date.

Introduction

Pearl Harbor is a geographically protected lagoon located on the Hawaiian island of O‘ahu. For approximately the past 120 years, Pearl Harbor has been the site of the largest U.S. Navy base in the central or western Pacific Ocean (Coles, 1999) and the area has undergone major industrial urbanization since Hawai‘i was annexed by the U.S. in 1898 (Wolanski, 2006). Despite the environmental degradation that accompanied much of the industrialization, Pearl Harbor continues to be a resource rich habitat hosting an amalgam of important marine species.

This includes green *Chelonia mydas* and hawksbill *Eretmochelys imbricata* sea turtles, both of which are protected under the U.S. Endangered Species Act (ESA). The Navy is required to manage and protect sensitive biological resources as mandated by the Sikes Act of 1960, and has conducted vessel-based and dive transect surveys of sea turtles (Marcelin, 2021) within the Navy Defensive Sea Area (NDSA) of O‘ahu. The NDSA includes Pearl Harbor, the Pearl Harbor Entrance Channel, and the waters immediately south of the Pearl Harbor Entrance Channel (Figure 1). Although these surveys provide important insights into the distribution of sea turtles within Pearl Harbor, due to the limitation of such approaches, detailed information on sea turtle movements, spatial ecology and habitat use remains lacking.

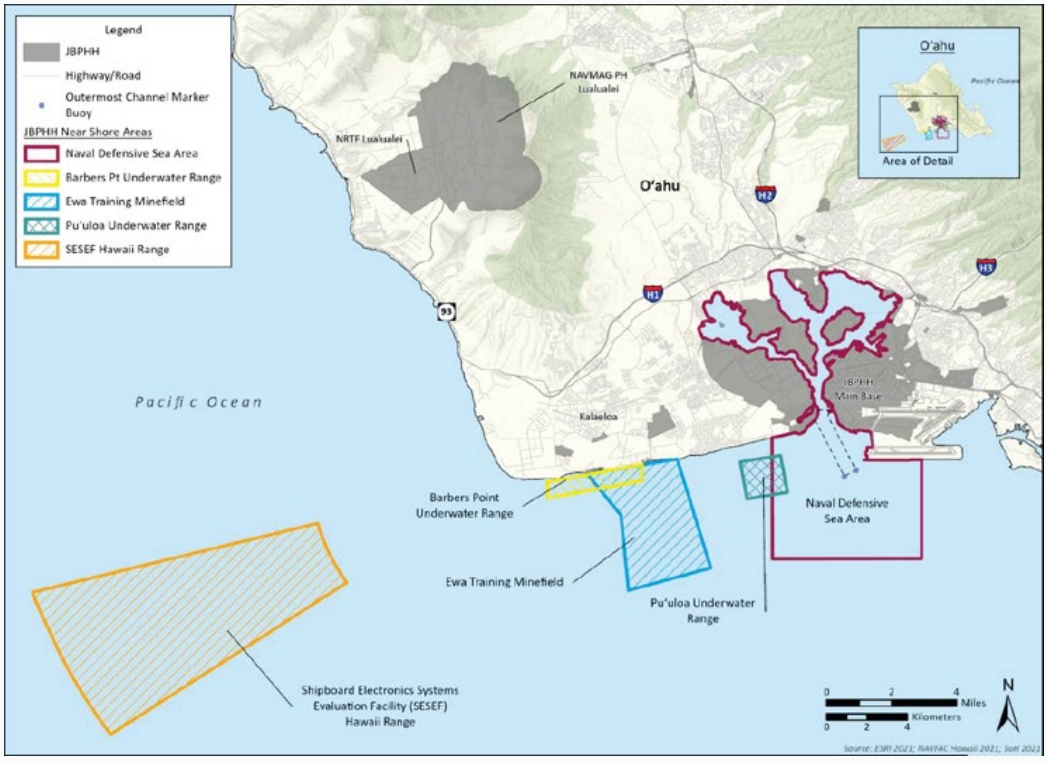

Figure 1. Nearshore areas of Joint Base Pearl Harbor Hickam, including the Naval Defense Sea Area (NDSA; red outline) where this study took place.

To fill these data gaps, in 2023 the Navy and NOAA entered into a multi-year interagency agreement (IAA), under which NOAA's Marine Turtle Biology and Assessment Program (MTBAP) was tasked with conducting fieldwork to better understand sea turtle movement ecology in Pearl Harbor. In this study we outline the preliminary results of this research, which represents the first attempt to satellite track sea turtles in Pearl Harbor. Given both the military relevance of Pearl Harbor and the ESA threatened or endangered status of the sea turtles contained therein, this study has important implications to future development and management efforts in the region.

Methods

Snorkel survey transects to observe, identify, and capture sea turtles were conducted using a NOAA small boat along coastal waters within the NDSA. Information on species, size, and sex of turtles was communicated via hand signals to staff on-board the small boat, who then recorded that information as well as time and location (GPS). Whenever feasible, attempts were made by free diving (1–10 meters) to capture turtles resting/foraging on the seafloor, under ledges (Figure 2), in caves, or swimming in the water column. Captured turtles were immediately brought to the surface, lifted into the boat, then processed on deck or on shore.

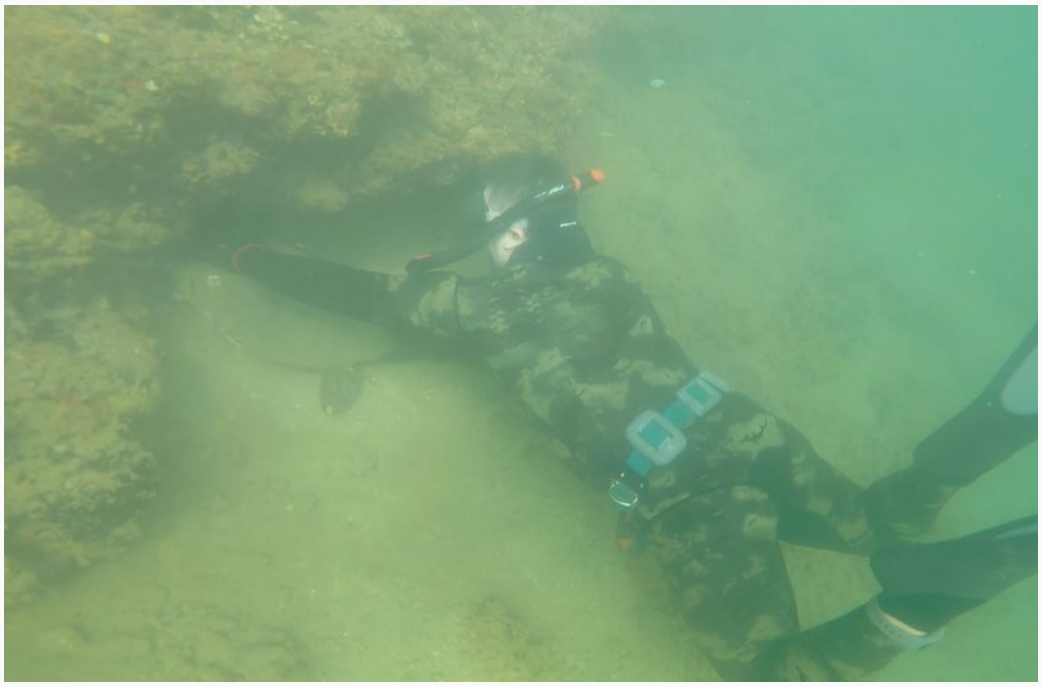

Figure 2. NOAA researcher hand capturing a small green turtle partially wedged under a small ledge. Photo credit: NOAA Fisheries.

All turtles were tagged with metal Inconel tags or “flipper tags” (Style 681, National Band and Tag Company) using globally standardized techniques (Eckert et al., 1999), and with Passive Integrated Transponder (PIT) tags (Biomark, Inc., Boise, Idaho, USA). The Inconel flipper tags were attached to the trailing edge of the fore flippers and the PIT tags were injected subcutaneously into the rear flippers. Skin samples were obtained from the neck, shoulder, or hind flipper of each turtle (Dutton et al., 1996) for future molecular analysis. Straight carapace length (SCL) and curved carapace length (CCL) were measured (nuchal notch to posterior-most tip of marginal scutes) and turtles of appropriate SCL (see Jones et al., 2013) and condition were outfitted with a satellite tag.

Satellite tag attachment procedures followed methods described in the Wildlife Computers tag attachment protocol. Turtles with SCL greater than 45 cm were equipped with Wildlife Computers SPLASH satellite tags, which have both Fastloc-GPS and Argos location capabilities, as well as temperature and depth sensors. Turtles with SCL less than 45 cm were equipped with Wildlife Computers SPOT satellite tags, which are smaller and only have Argos location capabilities. Tag preparation included covering each tag with multiple layers of anti-fouling paint (Micron66; see Wildlife Computers anti-fouling paint protocol) to inhibit the growth of algae that can cover sensors and interfere with tag operation.

All satellite tag locations were acquired and transmitted via Argos (Landover, Maryland) satellites. This included both Fast-loc GPS locations (when equipped) and Argos locations derived using the Kalman geoprocessing algorithm, the latter being categorized into one of six location classes (LCs; 3, 2, 1, A, B, Z). Note that location points on land are a result of accuracy variances of different LCs. Future iterations of this report will include kernel density estimates to account for area use, as well as removal of locations on land.

We categorized all satellite tracked turtles into one of four movement behavior categories.

- Movement behavior A: highly localized movements.
- Movement behavior B: broader localized movements.
- Movement behavior C: inter-main Hawaiian Island movements.
- Movement behavior D: departure from the main Hawaiian Islands.

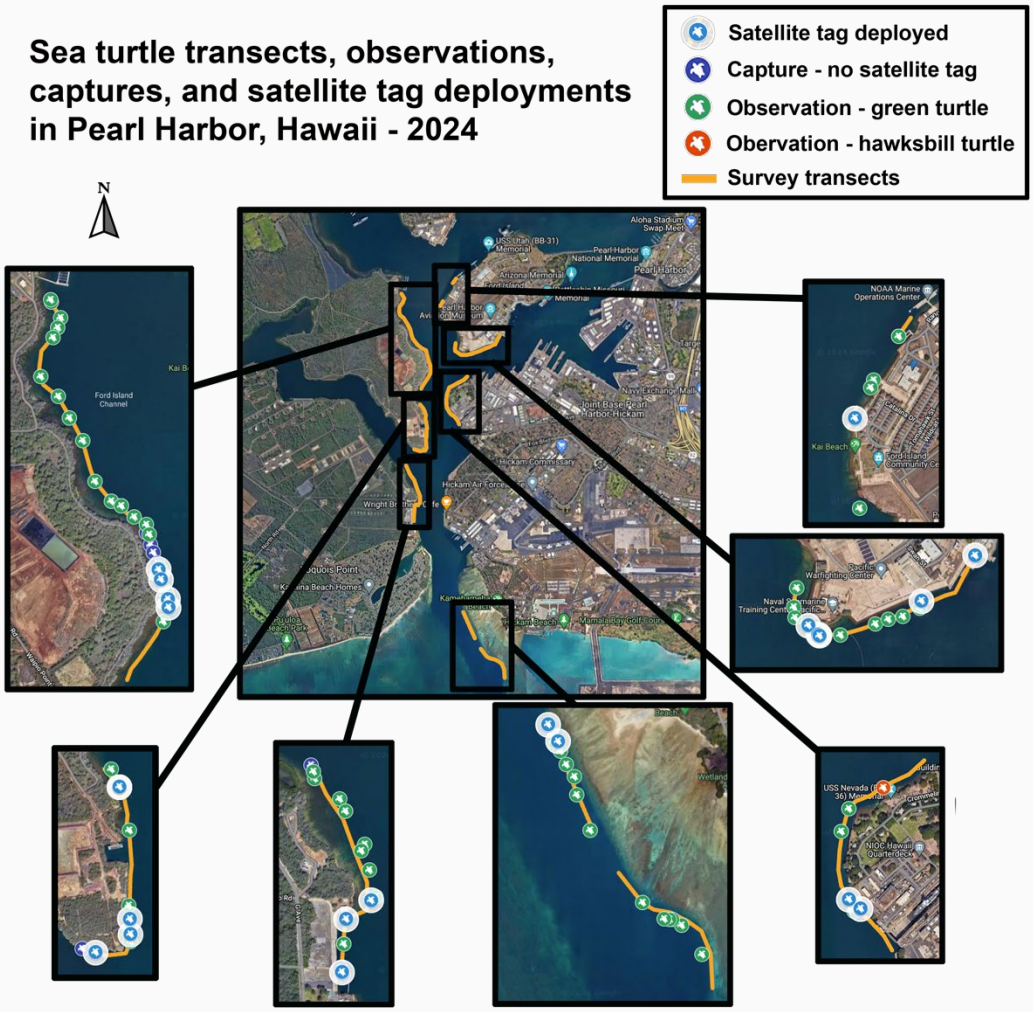

Figure 3. Sea turtle transects, observations, captures, and satellite tag deployment locations in the NDSA study area.

Results

We conducted 4–6 hour surveys on a total of six days between January 16 and February 14, 2024. A total of 115 turtles were encountered over the course of the study period, 85 of which were observed (i.e., not captured) and 30 of which were captured (Figure 3). Only 1 (0.9%) of the encounters was of a hawksbill turtle, while all others were green turtles. All 30 turtles that were captured were green turtles, 23 of which were equipped with satellite tags including 20 SPLASH tags and 3 SPOT tags (Table 1). Of the 30 satellite tags deployed, 8 were still transmitting at the cutoff date for data used in this report (July 23, 2024). When including these tags, the average tag duration to date has been 121 days (SD = 61.5 days), with a minimum of 13 days and a maximum of 189 days, but the latter will increase as the tags continue to transmit.

The frequency distribution of SCL for the captured turtles in 10 cm increments is shown in Figure 4. Captured turtle sizes (SCL) averaged 60.4 cm (SD = 14.9 cm) and ranged from 37.5 cm to 94.7 cm (n = 30). A total of 5 putative adult turtles were captured, including 3 females and 2 males, while the remaining 25 turtles were juveniles for which sex could not be determined.

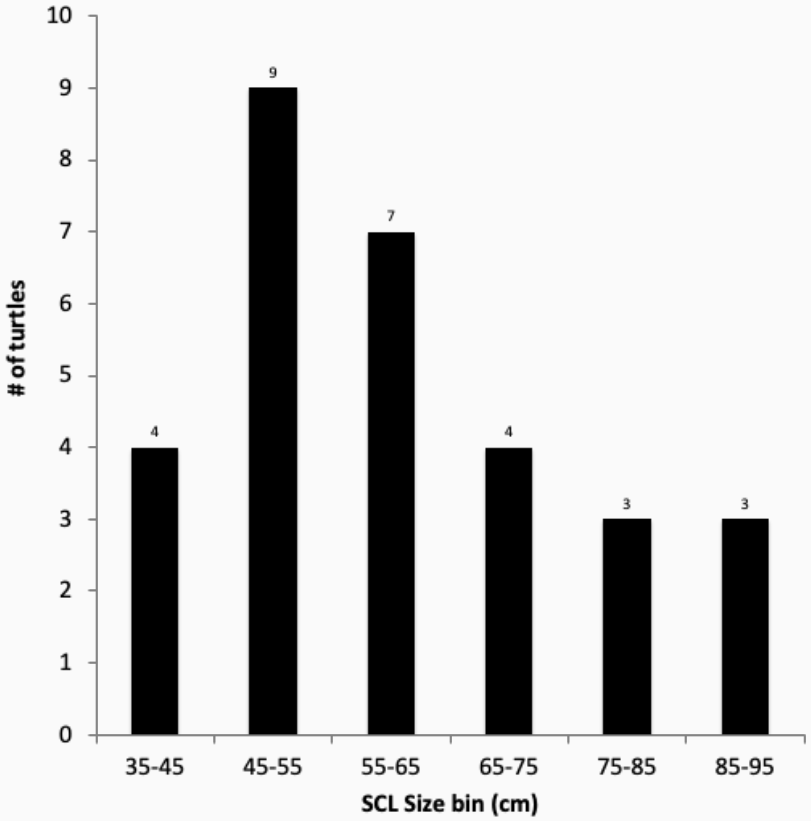

Figure 4. Frequency (number of turtles) distribution of SCL for green turtles and captured (excluding re-captures) during the study period.

Turtles were successfully encountered and captured during all surveys and the majority of location transmissions from satellite tagged turtles came from the general area where they were captured. Despite this finding, turtles used habitats throughout the NDSA (Figure 5) and demonstrated various movement behaviors. Some turtles exhibited highly localized movements concentrated in a single area (i.e., movement behavior A), while others exhibiting broader localized movements using various locations within the harbor (i.e., movement behavior B). We also tracked two turtles that exited the NDSA completely, including one turtle that moved among several islands within the main Hawaiian Islands (i.e., movement behavior C), and one turtle that migrated approximately 1,700 km to Lisianski Island in the northwest Hawaiian Islands (i.e., movement behavior D) (Figure 6).

Table 1. Summary data on sea turtles captured in Pearl Harbor including turtle #, species, Argos ID #, tag serial #, turtle size (SCL and CCL), sex, capture latitude and longitude, result (i.e., turtle equipped with a tag or not), tag model, deploy date, last Argos signal, and tag life as transmission days. Rows highlighted in blue indicate tag still transmitting at the time this report was compiled.

Turtle #	Species	Argos ID #	Serial #	SCL	CCL	Sex	Latitude	Longitude	Result	Tag Model	Deploy Date	Last Signal	Tag Life
1	Cm	201637	19A0723	85.6	91	Male	21.31898	-157.96544	Satellite tag	SPLASH	1/16/24	7/23/24	189
2	Cm	201629	19A0692	74.1	84	Unknown	21.31955	-157.96581	Satellite tag	SPLASH	1/16/24	6/7/24	143
3	Cm	201638	19A0724	67.3	72	Unknown	21.33479	-157.97203	Satellite tag	SPLASH	1/17/24	7/12/24	177
4	Cm	166329	16U1979	44.1	46.5	Unknown	21.33414	-157.97295	Satellite tag	SPOT	1/17/24	3/28/24	71
5	Cm	224323	20U1422	40	42.2	Unknown	21.33232	-157.97310	Satellite tag	SPOT	1/17/24	7/23/24	188
6	Cm	-	-	42.9	45.5	Unknown	21.33221	-157.97305	Capture (no tag)	-	1/17/24	-	-
7	Cm	-	-	57.7	62	Unknown	21.33942	-157.97424	Capture (no tag)	-	1/17/24	-	-
8	Cm	-	-	51.9	55.5	Unknown	21.33246	-157.97316	Capture (no tag)	-	1/17/24	-	-
9	Cm	254091	23A1373	84.4	89.9	Male	21.34705	-157.96797	Satellite tag	SPLASH	1/18/24	3/8/24	50
10	Cm	254092	23A1374	76.1	83.4	Unknown	21.34673	-157.96754	Satellite tag	SPLASH	1/18/24	3/12/24	54
11	Cm	254096	23A1385	52.5	56.1	Unknown	21.36180	-157.96892	Satellite tag	SPLASH	1/18/24	7/23/24	187
12	Cm	254100	23A1389	47.2	50.5	Unknown	21.35508	-157.96649	Satellite tag	SPLASH	1/24/24	7/23/24	181
13	Cm	242142	23A0251	64.5	70	Unknown	21.35477	-157.96613	Satellite tag	SPLASH	1/24/24	7/23/24	181
14	Cm	166330	160981	37.5	39.9	Unknown	21.35473	-157.96608	Satellite tag	SPOT	1/24/24	3/17/24	53

Turtle #	Species	Argos ID #	Serial #	SCL	CCL	Sex	Latitude	Longitude	Result	Tag Model	Deploy Date	Last Signal	Tag Life
15	Cm	254097	23A1386	52	55	Unknown	21.35592	-157.96233	Satellite tag	SPLASH	1/24/24	5/27/24	124
16	Cm	254098	23A1387	45.5	47.8	Unknown	21.35749	-157.96036	Satellite tag	SPLASH	1/24/24	7/23/24	181
17	Cm	-	-	48.6	52.6	Unknown	21.35516	-157.97131	Capture (no tag)	-	2/13/24	-	-
18	Cm	-	-	66.4	72	Unknown	21.35474	-157.97116	Capture (no tag)	-	2/13/24	-	-
19	Cm	-	-	67.6	72.4	Unknown	21.35448	-157.97105	Capture (no tag)	-	2/13/24	-	-
20	Cm	-	-	49.9	52.6	Unknown	21.35412	-157.97092	Capture (no tag)	-	2/13/24	-	-
21	Cm	254105	23A1394	85.4	92.4	Female	21.35391	-157.97086	Satellite tag	SPLASH	2/13/24	2/26/24	13
22	Cm	254103	23A1392	49.8	54.2	Unknown	21.35289	-157.97052	Satellite tag	SPLASH	2/13/24	4/22/24	69
23	Cm	254106	23A1395	63.5	69.2	Unknown	21.35260	-157.97050	Satellite tag	SPLASH	2/13/24	7/21/24	159
24	Cm	254094	23A1383	94.7	101.3	Female	21.35356	-157.97078	Satellite tag	SPLASH	2/14/24	5/19/24	95
25	Cm	254093	23A1382	53.2	57.7	Unknown	21.34741	-157.97163	Satellite tag	SPLASH	2/14/24	3/14/24	29
26	Cm	254101	23A1390	55.2	58.5	Unknown	21.34741	-157.97163	Satellite tag	SPLASH	2/14/24	7/23/24	160
27	Cm	254095	23A1384	58.4	63.7	Unknown	21.34288	-157.97125	Satellite tag	SPLASH	2/14/24	7/23/24	160
28	Cm	254102	23A1391	63.1	68.5	Unknown	21.34235	-157.97124	Satellite tag	SPLASH	2/14/24	7/16/24	153
29	Cm	254099	23A1388	56.9	62.1	Unknown	21.34173	-157.97252	Satellite tag	SPLASH	2/14/24	3/30/24	45
30	Cm	-	-	76.9	83.9	Female	21.34185	-157.97302	Capture (no tag)	-	2/14/24	-	-

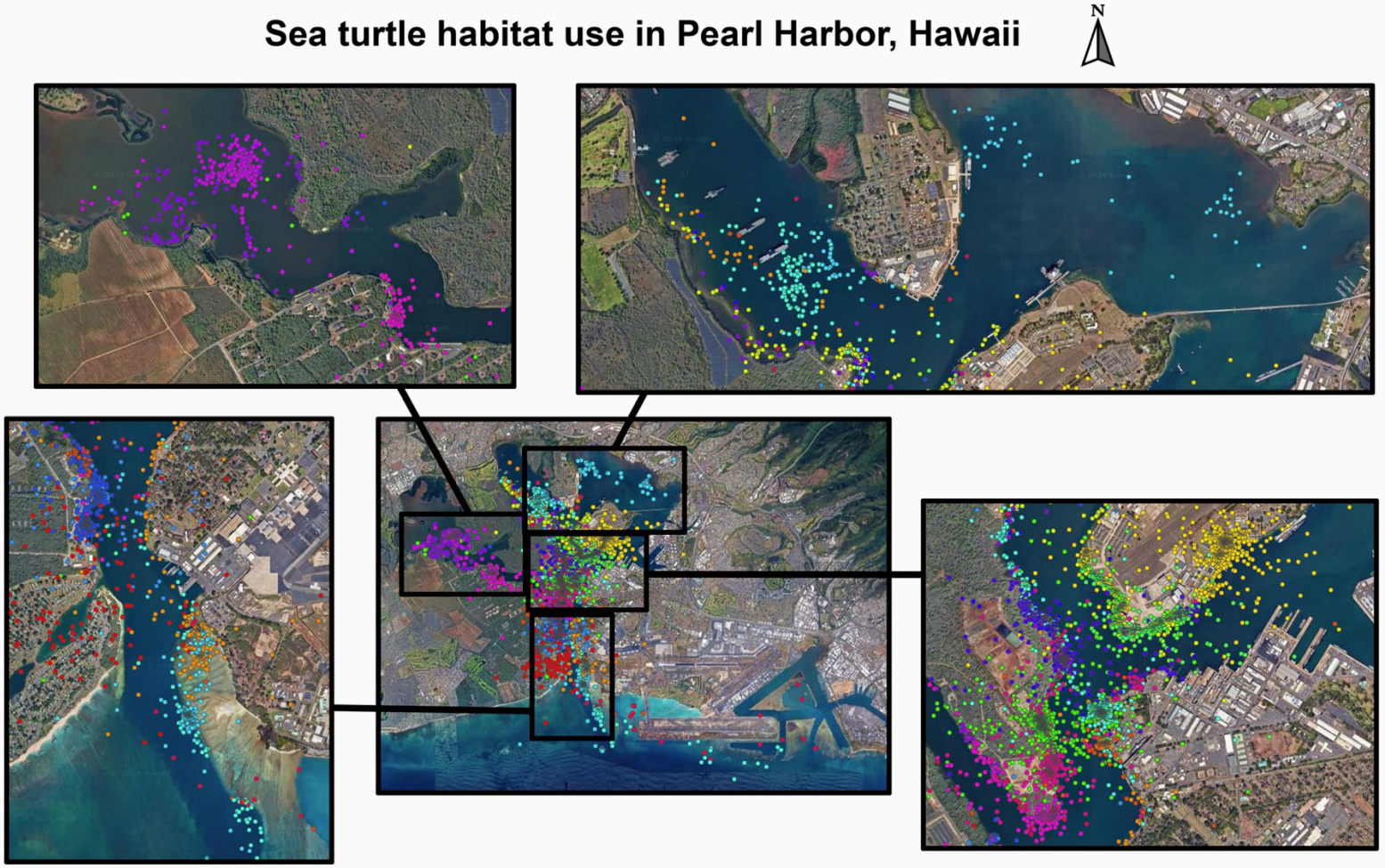

Figure 5. Sea turtle satellite tag locations (GPS and LC3 locations only) in the NDSA study area. Points on land are a result of accuracy variances of different positions. Future iterations of this report will include kernel density estimates to account for area use and removal of locations on land.

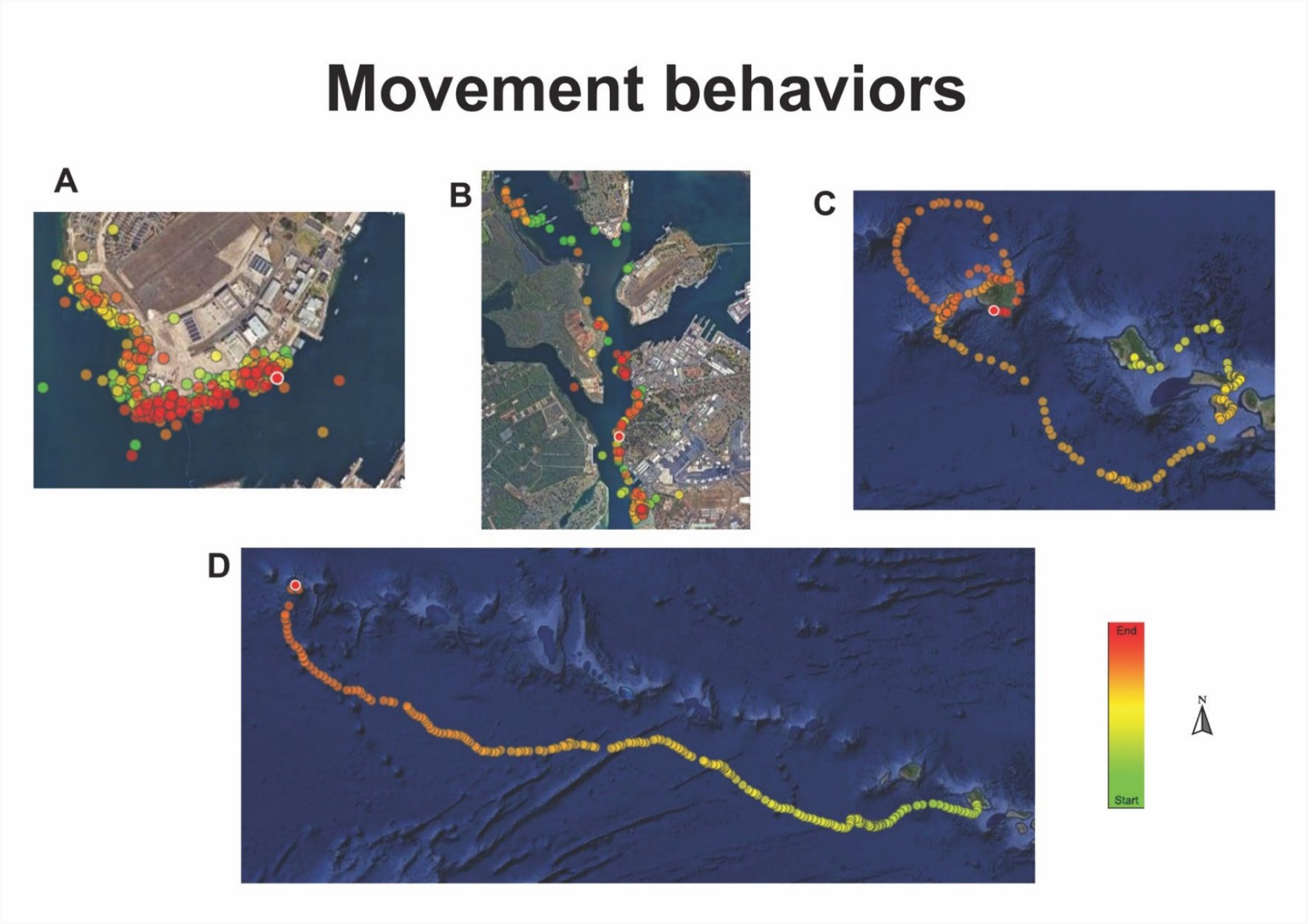

Figure 6. Four different general movement behaviors exhibited by turtles tagged in the NDSA including A) highly localized movements, B) broader localized movements, C) inter-main Hawaiian island movements, and D) departure from the main Hawaiian Islands.

Discussion

Our findings indicate that Pearl Harbor is an important habitat for green turtles of various life stages. Green turtles were found in all locations surveyed and spent most of their time within primary channel of Pearl Harbor (Figure 5). Although this could be partially due to survey effort in the same area, turtles were most commonly observed over relatively shallow areas consisting of hard-bottom substrates and these habitats are most common along the channel. There was less use of the inner lochs, which suggest these areas might be less viable habitat for turtles.

There were three locations that were observed to host particularly high concentrations of large turtles (Figure 7). Given the high conservation value of adult turtles (Crouse et al. 1987; Heppell, 1998), these areas warrant particular attention. These three sites were characterized by ledges with large caves. We found additional sites with numerous smaller caves, which were accordingly occupied by smaller turtles (Figure 7). Indeed, the overwhelming majority of successful turtle captures were achieved by pulling turtles out of such caves or grabbing the turtles as they exited caves. Given the limited visibility within much of Pearl Harbor and the highly vagile nature of turtles when swimming in the water column, turtle captures would have otherwise been extremely difficult.

Despite a relatively limited survey effort, the proportion of adult and sub-adult sized turtles observed within Pearl Harbor was intriguing. For instance, 10 of the turtles we captured were greater than 65 cm SCL, representing 33.3% of all captures. In contrast, similar research carried out in the Mariana Islands between 2013 and 2022 resulted in a total of only 6 turtles greater than 65 cm SCL, representing only 4.3% of the 139 turtles captured and measured for that study (Gaos et al., 2024).

We only observed one hawksbill during our transects (Figure 3), and this too was a putative adult. Hawksbills are rarer and have longer diver durations than green turtles in much of the eastern and central north Pacific (Gaos et al., 2012, 2020, 2024) and in the Mariana Islands have been found to utilize deeper depths (Gaos et al., 2024), which could combine to make observations more difficult. Notwithstanding this perspective, this study and recent reports (PIFSC unpublished data) indicate the species is present in the area.

Due to inclement weather, we only conducted surveys along the outer entrance to Pearl Harbor on a single occasion. However, we saw numerous putative adult turtles during that survey and future efforts to evaluate turtle presence and movements in the NDSA should be prioritize the area. Similarly, there were numerous additional sites that were not surveyed that warrant evaluation to better understand sea turtle habitat use within Pearl Harbor. This includes several areas that were off limits due to the recent outbreak in invasive octocoral.

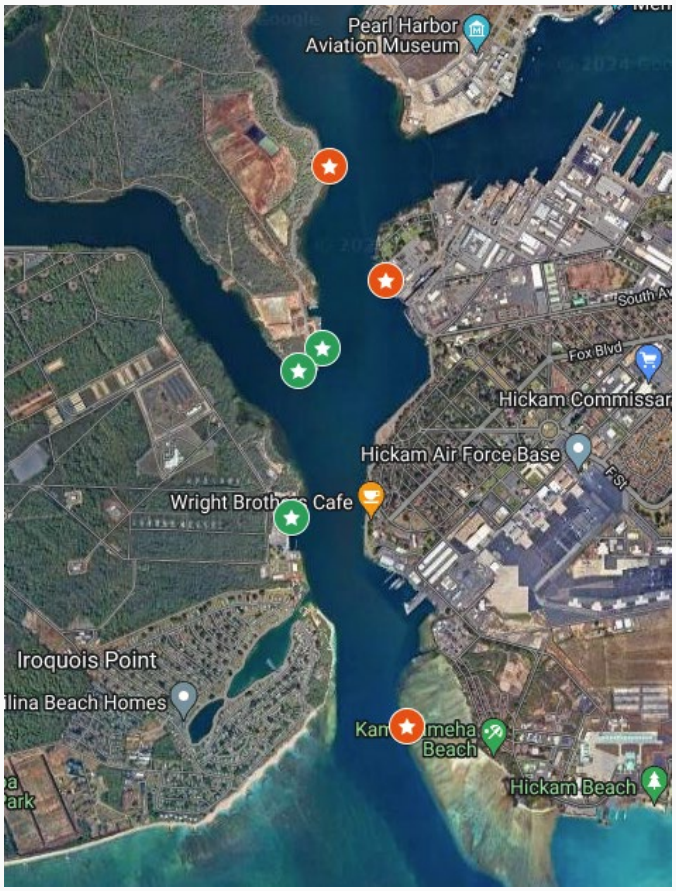

Figure 7. Particular areas with Pearl Harbor consisted of caves that harbored high concentrations of resting adult (orange stars) and juvenile (green stars) turtles.

We did see variations in turtle movements, with some turtles exhibiting highly localized movements concentrated in a single, relatively confined area (i.e., Movement Behavior A), while others tended to use multiple area (i.e., Movement Behavior B). In general, larger turtles tended to exhibit Movement Behavior B and smaller turtles exhibited Movement Behavior A, indicating that larger turtles move more and use a greater variety of habitats than smaller turtles. This increased movement may be a result of the greater resource requirements of larger turtles, which leads them to seek out food items at various locations.

Two turtles fully exited Pearl Harbor, including a large sub-adult (Argos ID# 201629) measuring 74.1 cm SCL that was originally captured on January 16, 2024 at the adult turtle “hotspot” near the mouth of Pearl Harbor (Figure 7). The turtle stayed in the vicinity of its original capture location for the first two months of tracking, then migrated further into Pearl Harbor for three weeks. It subsequently exited the harbor and undertook a migration that involved stops on Maui, Molokaʻi, Kauaʻi, and Niʻihau, before returning to the southern coast of Kauaʻi, where it remained for approximately three weeks until transmission ceased (Figure 6C). It is possible this turtle underwent some

sort of ontogenetic habitat shift as it was getting closer to maturity, which was also observed in a handful of subadult green turtle tracked in the Mariana Islands (Gaos et al., 2024).

The other turtle that fully exited Pearl Harbor was the largest turtle captured and satellite tagged, a female (Argos ID# 254094) measuring 94.7 cm SCL, which was the only turtle that exhibited Movement Behavior D. This turtle was also found in one of the adult cave "hotspots", this one located along the eastern Waipio Peninsula, directly across from the southern tip of Ford Island (Figure 7). This turtle moved into the West Loch and remained there for the approximate first month of tracking, then departed on a long-distance migration to Lisianski Island. The turtle was subsequently re-encountered by the NOAA Hawaiian monk seal *Neomonachus schauinslandi* team while basking on Lisianski. This is the first migration recorded via satellite telemetry of a nesting green turtle between the main Hawaiian Islands and Lisianski. The majority of Hawaiian green turtle nesting occurs on Lalo atoll (i.e., French Frigate Shoals) and, although green turtle nesting is known to occur on Lisianki, the origin of those nesters was previously unknown. Now we are sure at least some individuals of the nesting population come from the main Hawaiian Islands.

We made efforts to attach satellite tags to turtles in good health, thus we avoided capturing turtles that exhibited signs of the fibropapilloma virus (FP). Due to logistical challenges, we did not quantify the number of turtles observed with signs of FP. However, it was common to observe FP on turtles in Pearl Harbor and many of the turtles we captured were found to have FP once boarded. Although quantitative data are not available, MTBAP has conducted in-water and basking survey around many of the main Hawaiian Islands and observed that the proportion of turtles exhibiting FP within Pearl Harbor was much higher than in other areas. Although the causes of FP remain unclear, it has been suggested that areas with high levels of pollution and urbanization may contribute to the prevalence of the disease (Manes et al., 2022). Given the industrialized nature of Pearl Harbor and our anecdotal observations, our putative findings support this possibility. Future efforts could be directed toward quantifying the prevalence of FP in Pearl Harbor.

Upcoming analyses of individual and combined turtle home ranges will facilitate a better understanding and visualization of sea turtle habitat use within Pearl Harbor, including shared use areas (i.e., sites important to multiple turtles). Additional transects, captures, and satellite tagging would provide new insights into these and other aspects of sea turtle biology and movement ecology in and around Pearl Harbor and the NDSA.

Acknowledgments

The following NOAA staff were instrumental to successful field operations associated with this project: Shelbie Ishimaru, Brittany Clemans, Mark Sullivan, Marylou Staman, Camryn Allen, Jordan Wisner, Yvonne Barkley, Robert McLean, Calla Lloyd-Lim, Alexa Gonzalez, and Jamie Barlow. We recognize the following staff from the Navy for their administrative support of the study: Trevor Johannsen, Sarah Howard, Marie Ferguson, and Nicole Olmsted. All research associated with this work was conducted under the following permits: NOAA permit #21260, State of Hawai‘i PSP Special Activities Permit 2024-01, and IACUC permits SWPI2023-01 (NOAA Fisheries) and 18-2782-6 (University of Hawai'i).

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