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Honu Count: How Shell-etchings, Participatory Science, and a Novel Online Survey are Improving Assessments of the Hawaiian Green Sea Turtle (*Chelonia mydas*) Population

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Abstract

The Hawaiian green sea turtle (*Chelonia mydas*; honu) subpopulation is listed as a Distinct Population Segment in the Central North Pacific Ocean under the U.S. Endangered Species Act, which mandates monitoring to understand population viability of threatened species. The honu population abundance has largely been determined by a census of nesting females at the main nesting site, Lalo (French Frigate Shoals), an atoll located approximately 1,000 km northwest of the main Hawaiian Islands (MHI) within the Papahānaumokuākea Marine National Monument. Researchers and later the National Marine Fisheries Service within NOAA (NOAA Fisheries) have monitored honu at Lalo since 1973. One monitoring method used includes etching an alpha-numeric identifier temporarily (6–12 months) onto the shell with a rotary tool and sealing it with non-toxic white paint. In 2017, NOAA Fisheries launched the Honu Count Participatory Science Project, facilitating public reporting on sightings of honu with shell etchings around the MHI. Honu Count evolved in the way it collected sightings data from the public, from employing a hotline (2017–2018), to an email address (2018–2022), and most recently, an online survey via ArcGIS Survey123 (2023–present). Within the first year of the new online survey, data collection from the public increased from an average of 435 sightings per year to a total of 1,227. The project's new format has increased the breadth of invaluable honu population data, including a greater understanding of sea turtle behavior, survivorship, habitat use and migration routes, all while improving NOAA Fisheries' engagement with the public.

Keywords: Conservation, critical habitat, migration

1 Introduction

Sea turtles are vulnerable to a multitude of threats which impact their population viability [1], [2], and researchers have identified global research priorities to guide conservation efforts [1], [2], [3]. One priority is to identify key foraging habitats and understand how they are connected to nesting sites via satellite telemetry or capture-mark-recapture efforts, which often includes scientists capturing the animal and applying some form of permanent identification, such as a microchip, to identify the individual upon future interactions/recaptures (e.g., [1], [4], [5]). Generally, in the sea turtle research community, confirmed global positioning system (GPS) locations of specific sea turtles are obtained by satellite tags [6], [7],[8], [9]. Satellite telemetry data provide consistent and accurate information on a sea turtle's entire migration and habitat use and address threats they may face [6], [8].

Extensive habitat ranges and long migrations can make collecting data on wildlife challenging, and tools to do so, such as satellite tags, can be costly. Participatory science relies on public participation to collect data for scientific research, and it engages and educates the participants of the community involved in the project [10], [11], [12], [13]. Participatory science has been used for the collection and assessment of data in the scientific community for many generations. However, it has recently gained popularity, especially in projects that span a large geographical area, such as the monitoring of migrating sea turtles [7], [10], [14], [15], [16]. Technological advancements have had a positive correlation in the public's increased participatory science activity, allowing for ease in access and connection to scientific research conducted by professional scientists [13], [15], [16]. Data collection via participatory science on population distribution, biodiversity, and population health or monitoring is a concept that has been employed by the scientific community since the 20th century [10], [16]. Wildlife data collected by the public can be extremely useful, for illuminating information such as habitat use and population abundance [7], [17], [18].

The Hawaiian Archipelago has the advantage of being one of three places in the world where green sea turtles (*Chelonia mydas*), specifically Hawaiian green sea turtles (known locally as honu), of all ages, sizes, and sexes bask on land [19], [20]. While basking, the turtles crawl onto the beach during the day and/or night and may stay there for several hours, or even overnight [19], [20]. This behavior provides a unique opportunity for scientists and the public to observe honu closely and easily identify them as they bask on land on or forage in nearshore waters of the main Hawaiian Islands (MHI) [20]. Honu can be found basking on beaches around the MHI and at their reproductive grounds in Lalo (French Frigate Shoals), an atoll used by approximately 96% of the population for reproducing [19], [20]. Both adult and immature honu are also uniquely identified around the MHI by NOAA's National Marine Fisheries Service (NOAA Fisheries) scientists during in-water surveys, basking surveys, or after stranding (found ashore/in-water injured) when they are rehabilitated and released. Rehabilitation takes place either on the island of O'ahu, at the NOAA Fisheries Pacific Islands Fisheries Science Center (PIFSC) or at the Hawai'i Marine Animal Response Care Center (HMAR), and on the island of Maui at the Maui Ocean Center Marine Institute (MOCMI) (USFWS and NOAA 2020).

Despite increased understanding of honu reproductive migration from satellite tagging and capture-mark-recapture efforts, there are still gaps in information on critical foraging habitats of this population [21]. Specifically, behavior of immature turtles that have begun to settle in nearshore foraging habitats and adult turtles returning to the foraging ground from their reproductive migration to/from Lalo are poorly understood. Improving our understanding of sea turtle abundance and habitat use at foraging sites would inform population status assessments as well as help with identifying conservation measures needed in these critical foraging (in-water habitat) and basking (terrestrial habitat) areas.

Since the early 1990s, scientists within NOAA Fisheries have utilized shell etchings during nesting surveys at Lalo to temporarily identify individual reproductively-active female honu from a distance greater than previously possible with small permanent tags [9], [22]. Green sea turtles, along with other hard shelled sea turtle species (Cheloniidae), have a carapace that is composed of bone overlaid by keratinous plates called scutes [23], making the application of an etching on the surface of the carapacial scutes similar to a human manicure. The etchings can last anywhere from 6 to 12 months, and in some unique cases up to three years [22]. Shell etchings provide unique identification throughout the nesting season, ensuring little to no disturbance to the female during nighttime nesting surveys and allow identification when the honu are back at their foraging grounds within the MHI [9], [22]. Applying the temporary shell etchings became regular practice by the early 2000s to both adult and immature honu that were captured for research during in-water surveys, terrestrial/basking surveys, and post-rehabilitation after stranding around the MHI [9], [22] (Figure 1).

In 2017, the PIFSC's Marine Turtle Biology and Assessment Program (MTBAP) launched a participatory science project called The Honu Count Participatory Science Project, or Honu Count. The goal was to enlist the community's help and explain the shell etchings on the honu around the MHI. Honu Count began as a hotline for the public to call in their sighting and report the alpha-numeric identifier they observed;

Fig. 1: The shell-etching, "MA100", was applied to this immature honu on Maui by NOAA Fisheries partners at the Maui Ocean Center Marine Institute using a dremel and non-toxic white paint. The etching can be seen clearly, even underwater, months after application. Photo taken by Honu Count Sighting Survey Participant D. McLeish.

by 2018 the public could email their report and share photos. With the high volume of sightings reported and data collected, a new and more efficient process was needed. MTBAP launched a new online survey through the ArcGIS Survey123 platform called The Honu Count Sighting Survey (HCSS) as well as a new website that detailed the project and provided information on honu life history within the Hawaiian Archipelago [24].

Satellite tags are more expensive and require more time to apply to the carapace than a shell etch, therefore increasing animal disturbance [8], [21]. Shell etchings combined with participatory science projects like Honu Count have demonstrated that reliable locations of specific turtles can be attained while significantly decreasing cost and animal interaction times. With the launch of the online survey in 2023, Honu Count has become more accessible to the public and increased honu sightings and GPS location data around the MHI.

2 Methods

2.1 Shell etching application

A tool known as a 'mototool' has been used since the early stages of applying shell etchings [22]. Since 2017, MTBAP has used a DremelR Cordless Rotary Tool, with a High-Speed Cutter 7,2 mm (134) bit (Robert Bosch Tool Corporation, Mount Prospect, Illinois). The alpha-numeric identifier is etched onto the fourth lateral scute about 1–2 mm deep and sealed with a non-toxic white spray paint (Figure 1) [9], [22]. NOAA Fisheries scientists successfully apply the etchings via three methods: 1) on a nesting female while she is laying eggs in a trance-like state [25], 2) to basking turtles restrained within a wooden box, 3) to a sleeping, basking turtle, or 4) before a turtle is released post-rehabilitation. Along with the shell etching, non-visible permanent passive integrated transponder (PIT) tags (i.e., microchips) are inserted under the skin on each hind flipper, as well as visible (at a close distance) metal tags on the hind flippers [9], [22], [26].

2.2 The Honu Count Participatory Science Project

MTBAP published an article in 2017 on the NOAA Fisheries website describing the Honu Count project and MTBAP's research around the Hawaiian Archipelago, encouraging the public to report their sightings of shell-etched adult turtles as they returned to their foraging grounds [27]. Between 2017 and 2022, emails and phone calls were collected from the public and entered into a Microsoft Excel spreadsheet to conduct quality control checks. After sightings were verified, they were manually entered in MTBAP's Microsoft Access database. Verification included cross-checking the shell-etching ID with MTBAP's database, reviewing any photos submitted via email with the report, and verifying GPS coordinates if reported with the sighting. If GPS coordinates were submitted with the report, they were vetted using ArcGIS and then input to density plots with RStudio [28], [29]. Notable packages that were used to analyze data included ggplot2, ggspatial, mapdata (maps), and rnaturalearth [30], [31], [32].

On February 1, 2023, MTBAP launched an online survey via Esri ArcGIS Survey123 (version 3.20) to replace the original hotline and email address as a way for the public to report their sightings of numbered honu. A new website was also created that further described the participatory science project and embedded a link to the HCSS for ease of access [24]. A map was embedded into the HCSS that requires a pin to be dropped on the reported location providing GPS coordinates for every sighting (Figure 2). Other data included in the HCSS are date and time of sighting, shell etching identification, island of the sighting, area of the sighting, and behavior/activity of the honu during the sighting (e.g., swimming, basking, foraging). Photos could also be uploaded and stored on the back end of Survey123 to confirm the identification of the turtle and gather other information on the overall body condition and behavior.

Raw data from the HCSS were downloaded from Survey123 to a spreadsheet to conduct quality control, including correcting misidentified shell etchings and removing GPS locations that were incorrectly reported by the public. This was done by manually reviewing individual reports by the public via a Microsoft Excel spreadsheet

Fig. 2: The embedded map within the online Honu Count Sighting Survey, hosted on ArcGIS Survey123. Reporters must place a pin on the location of the shell-etched turtle sighting before submitting their entry, ensuring GPS coordinates are provided.

downloaded from Survey123. Specifically, incorrect GPS coordinates are considered points that do not match the island or area description reported, points that are too far inland, and reports where the observer could not confirm the shell etching and there was no accompanying photo for identification; the incorrect reports of shell etchings were confirmed by NOAA Fisheries scientists via photos that were submitted with the report. Latitude and longitude data were uploaded onto ArcGIS Pro (version 3.1.2) to view individual and total data points and remove GPS locations that were not accurately captured by the public. These data were also analyzed via RStudio (version 2023.06.02) using packages ggplot2, ggspatial, mapdata (maps), and rnaturalearth, to compile sightings density information (Figures 4–6), conduct calculations, and visualize data [30], [31], [32].

2.3 Pre-HCSS (2017–2022) and post-HCSS (2023–2024) comparisons

In RStudio, the annual sightings data for the pre-HCSS period (2017–2022) and post-HCSS period (February 1, 2023, to February 1, 2024) were analyzed using a Poisson general linear model (GLM) to determine the success of the new reporting method (Table 3). Calculations included: a) annual number of reports made by the public, both with and with-out GPS, b) annual number of unique individual honu reported, and c) annual number of reports made per island (MHI), along with the associated percentages. These calculations included all sightings of honu with shell etchings, regardless of where the etching originated. The same calculations were made for the subset of reports of adult honu (both male and female) that received their shell etching at their primary reproductive grounds (Lalo). Presence at that location confirmed the turtle to be an actively reproductive adult honu migrating between Lalo (reproductive grounds) and the MHI (foraging grounds); calculations were also made for adult Lalo-etched males and females separately.

Post-HCSS calculations additionally included d) most common honu reported, and e) number of individual behaviors reported by the public via the HCSS (Figure 3). The behaviors listed for the public to choose in the HCSS include "basking" (honu on beach resting/sleeping), "swimming," "foraging" (in water, eating off of the reef or in shallow waters, eating off rocks/reef), and "other" (including reports where no behavior was listed or explained further in the report comments and did not fit the other three categories). Reports of honu that received an etching and returned from their reproductive grounds at Lalo were isolated and received the same calculations and analysis using a Poisson GLM (Table 3). Not all pre-HCSS reports contained GPS coordinates; however, all pre-and post-HCSS reports were included whether they had GPS data or not, as long as the identity of the honu could be confirmed via shell etching. Only reports with confirmed GPS coordinates from pre- or post-HCSS were used for the density map comparisons (Figure 3–5).

Table 1: The number of shell etchings applied to Hawaiian green sea turtles (honu) between the years 2017 and 2023 within the Hawaiian Archipelago by the NOAA Fisheries scientists or partners and the number of turtles reported by the public to the Honu Count Participatory Science Project.

Island	**Shell Etchings (2017–2023)**	**Pre-HCSS Reports (2017–2022)**	**HCSS Reports (2023–2024)**
Maui	381	222	126
Oʻahu	194	90	13
Hawaiʻi	331	75	118
Kauaʻi	0	0	0
Molokaʻi	0	0	0
Lānaʻi	0	1	0
Kahoʻolawe	1	0	0
Lalo (Females) 2017–2019, 2021–2023	2,897	56	29
Lalo (Male and immature) 2017–2019, 2021–2023	1,310	14	5
Total	**5,175**	**472**	**302**

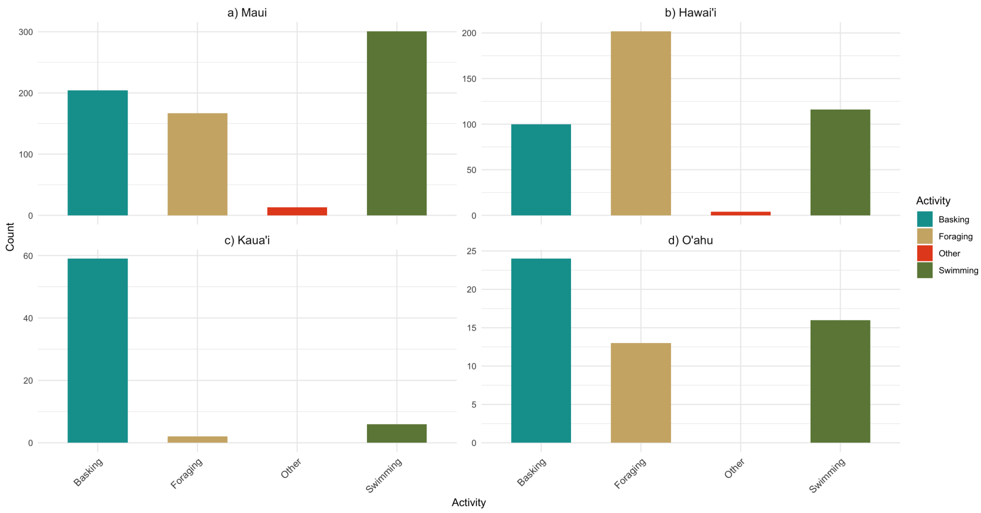

Fig. 3: Total behaviors observed per island, submitted by the public via the online Honu Count Sighting Survey (HCSS) between February 1, 2023, and February 1, 2024. **a)** Swimming made up 44% of reports from Maui Island (n = 301). **b)** Out of the 422 sightings reported around the island of Hawai'i, 48% of were foraging (n = 202). **c)** Kaua'i's honu are almost always reported as basking (88%; n = 59), and **d)** O'ahu shows swimming (30%; n = 16) and foraging (25%; n = 13) activities/behaviors to be secondary to the main activity of basking (45%; n = 24).

3 Results

3.1 Pre-HCSS vs. post-HCSS Results

The launch of the online survey increased the annual number of honu sightings reported that include reliable GPS locations and important behavioral data that was previously not reported before the creation of the survey (e.g., basking vs. foraging or swimming; Figure 3). Between the years 2017 and 2023, there were 5,175 shell etchings applied to honu by researchers at Lalo during the nesting seasons and at basking or foraging grounds around the MHI (Table 1). Over a 6-year period (2017–2022), 2,177 sightings were reported through Honu Count (hotline and/or email) of 472 unique honu with shell etchings (Table 2). Within one year (February 2, 2023, to February 2, 2024) of the launch of the online HCSS, 1,227 reports were documented (Table 1) of 302 unique honu. On average, 435 reports per year were submitted by the public via hotline or email pre-HCSS. Post-HCSS, an increase in the total number of reports also included an increase GPS coordinates reported, 95% (n = 1,160), that were used for data analysis after quality control measures were taken (Figure 4). Pre-HCSS, only 23% (n = 506) of reports had GPS coordinates that could be used for data analysis.

A Poisson GLM was run on the data to show the significance between the total yearly reports pre- and post-HCSS (Table 3). For the total counts per year, the yearly

Table 2: Annual number of shell-etched turtles reported by the public per island via the (hotline and/or email) Honu Count Participat[illegible] Science Project (2017–2022; pre-survey) and the online Honu Count Sighting Survey (2023–2024; post-survey). This includes repeat sighti[illegible] made by the public of the same honu.

Island	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023–2024**	**Mean repo[illegible] 2017–202[illegible]**
Maui	17	5	13	239	1,045	399	685	343.4
Oʻahu	22	21	35	21	101	19	53	38.9
Hawaiʻi	2	0	86	37	2	54	422	86.1
Kauaʻi	1	0	24	21	1	10	67	17.7
Molokaʻi	0	0	1	0	0	0	0	0.1
Lānaʻi	0	0	0	0	0	1	0	0.1
Kahoʻolawe	0	0	0	0	0	0	0	0
Annual Total	**42**	**26**	**159**	**318**	**1,149**	**483**	**1,227**	—

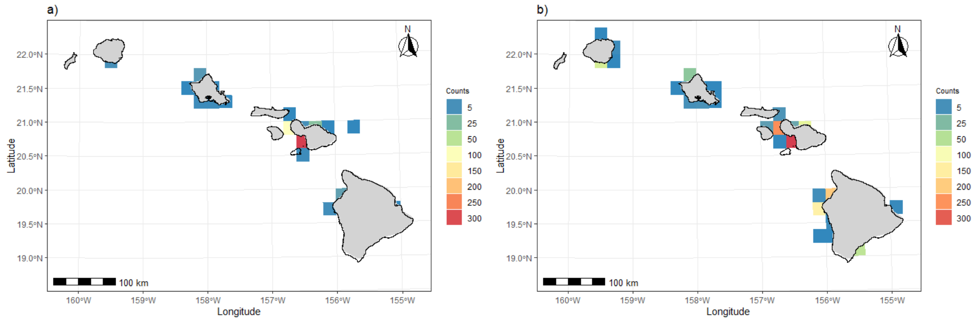

Fig. 4: Counts per 40 km^2. **a)** Map of the main Hawaiian Islands (MHI) that shows the density of the total number of reports (n = 2,177) pre-Honu Count Sighting Survey (HCSS) from 2017–2022. **b)** Map of the main Hawaiian Islands (MHI) that shows the density of the total number of reports (n = 1,227) via the HCSS from February 1, 2023, to February 1, 2024.

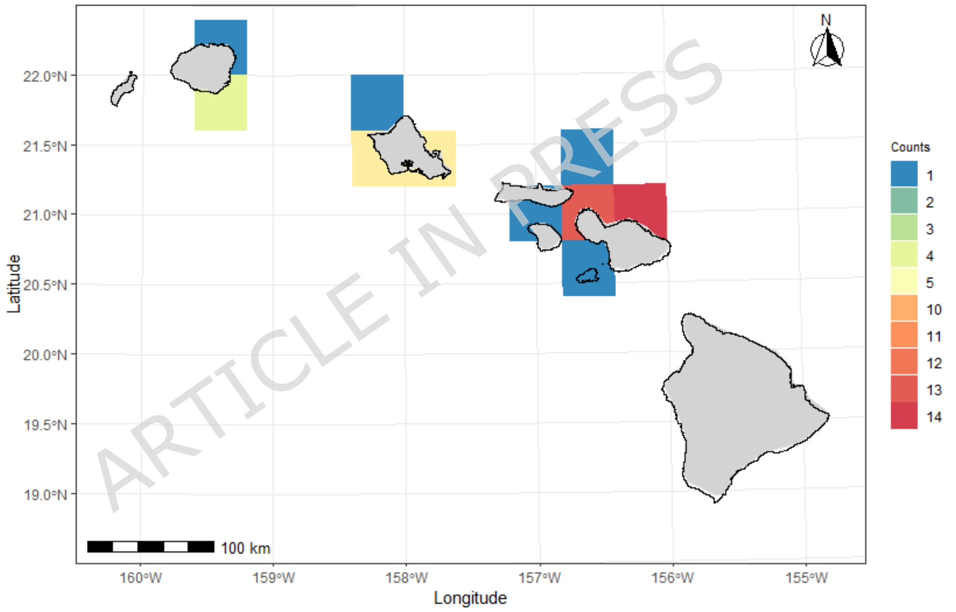

Fig. 5: Counts per 40 km^2. Density map of reports of shell-etched honu adults returning from their migration (n = 50) from Lalo to their foraging grounds around the main Hawaiian Islands (MHI), post-2023 nesting season. Reported via the online Honu Count Sighting Survey (HCSS) from February 1, 2023, to February 1, 2024.

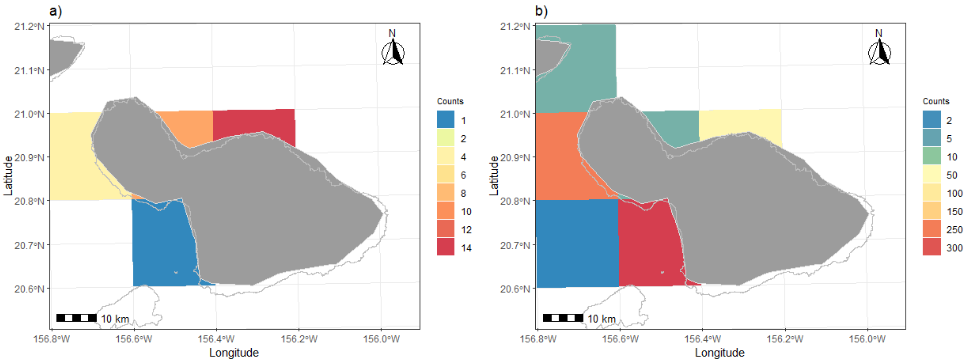

Fig. 6: Counts per 20 km^2. **a)** Total number of adult honu tagged at their reproductive grounds at Lalo returning to their foraging grounds around Maui, concentrated mostly in the northern Maui region. Reports made through the HCSS (February 1, 2023, to February1, 2024). **b)** Total number of honu (immature and adult) that were not tagged at the reproductive grounds at Lalo but were reported around Maui through the HCSS (February 1, 2023, to February 1, 2024).

rate of reporting was significantly higher post-HCSS ($p \approx 0$); there was also a significantly higher yearly reporting rate of unique individuals post-HCSS ($p \approx 0$) (Table 3). For total counts by island, the results of the GLM also showed a higher yearly reporting rate post-HCSS on the islands of Hawai‘i ($p \approx 0$), Kaua‘i ($p \approx 0$), Maui ($p \approx 0$), and O‘ahu ($p = 0.0148$) (Table 3). When reports with GPS data were compared pre- and post-HCSS within the Poisson GLM, the rate of reports with GPS were significantly higher ($p \approx 0$) post-HCSS (Table 3). This implies a significant increase in the proportion of reports that included GPS data post-HCSS. Through the GPS data provided by the public, we found that the island with the most sightings both pre-HCSS (n = 1,718) and post-HCSS (n = 685) was Maui (Table 1). Pre-HCSS reports which included GPS coordinates show the highest density (80% of sightings) of honu reported came from Maui and post-HCSS 56% of sightings were reported around Maui (Table 1; Figure 4). Data on behavioral observations of honu throughout the MHI were reported through HCSS as: (a) 36% (n = 439) swimming, (b) 31% (n = 384) foraging, (c) 32% (n = 387) basking, and (d) 1% (n = 17) other. Of the 384 honu reported foraging, 43% (n = 167) were reported to be foraging around Maui (Figure 3). This data was not collected pre-HCSS due to it not originally being requested as well as the informalness of the process of collection (e.g., email, hotline).

3.2 Sightings of adult honu returning from Lalo

There was a significant increase in reports of adult honu that were shell-etched at Lalo with the new HCSS compared to pre-HCSS ($p < 4.21 \times 10^{-10}$) (Table 3). From 2017–2023, 4,207 honu were shell etched during the nesting seasons on Lalo; many

Table 3: Poisson generalized linear model results evaluating the effect of treatment on yearly reporting rates pre-HCSS (2017-2022) and post-HCSS (2023-2024). The treatment coefficients represent the log-scale change in expected reporting rate post-treatment (2023-2024) relative to pre-treatment (2017-2022), and the positive treatment coefficients (β_{treat}) indicate increased reporting rates following treatment.

Response	β_{treat}	SE	z	p-value
Total counts	1.218	0.036	34.13	$< 2 \times 10^{-16}$
Unique individuals	1.345	0.074	18.25	$< 2 \times 10^{-16}$
GPS sightings (non-GPS)	−1.425	0.125	−11.44	$< 2 \times 10^{-16}$
GPS × treatment	4.046	0.136	29.86	$< 2 \times 10^{-16}$
Lalo individuals (all)	1.079	0.173	6.25	4.1×10^{-10}
Lalo males	0.388	0.442	0.88	0.38
Lalo females	1.134	0.188	6.04	1.6×10^{-9}

of the honu received a different alpha-numeric identifier upon a subsequent nesting season, generally every 4 years [33]. This included immature honu that were found around Lalo and tagged to understand population abundance, even though they were not going to be migrating back to the MHI. Pre-HCSS, 102 reports of 70 adults (male and female) who had been etched at Lalo were recorded by the public around the MHI, which is 5% of all reports made over 6 years (Table 1). Pre-HCSS, 65% (n = 46) of the 70 Lalo shell-etched honu returned to Oʻahu.

Within the first year of HCSS, 50 reports were submitted of 34 unique Lalo shell-etched adult honu, making up 4% of the sightings made that year (Table 1; Figure 5). This doubled the annual average pre-HCSS (n = 21/year; $p < 4.21 \times 10^{-10}$) (Figure 5; Table 3). The reports of Lalo shell-etched adults from HCSS all have GPS coordinates and also include data about honu activity and behavior at their foraging grounds in the MHI after reproduction. Out of the 34 individuals seen after migration in 2023 (post-HCSS), 17 honu returned to Maui, 12 returned to Oʻahu, and 5 returned to Kauaʻi. Similar to the overall results, the HCSS shows 56% (n = 29) of the Lalo shell etched adults reported come from Maui foraging grounds on the north shore (Figure 6a); the majority of reports (n = 23) indicate that the Lalo honu were seen exhibiting basking in the MHI. When comparing Lalo individuals by sex reported pre- and post-HCSS, the Poisson GLM showed no significant change in yearly reporting of males post-HCSS ($p = 0.38$), but a significantly higher yearly reporting rate of females post-HCSS ($p < 1.61 \times 10^{-9}$) (Table 3).

4 Discussion

Public sightings of known turtles via Honu Count were already incorporated into conservation efforts for honu. The GPS location data obtained via the online HCSS are incredibly valuable to further our understanding of the areas where honu are foraging and for identifying both terrestrial and in-water coastal habitats of high use by turtles and where likelihood for human-turtle interactions is greater. The publicly-obtained

Honu Count data were recently used in the proposed designation of critical habitat for the Hawaiian green sea turtle subpopulation under the U.S. Endangered Species Act [27], [34]; once the proposal is accepted, the critical habitat designation requires all federal agencies – not the public – to ensure their actions do not harm the designated habitat.

Satellite tagging has historically focused on reproductively active adult females because of the ease of access access to them during their onshore nesting [35]. However, in Hawaiʻi, honu of all ages and sexes can be seen ashore basking, allowing for more opportunities to attach tags. Though satellite tags can produce consistent location and dive data, there are risks of damage or malfunction to the physical tag attached to the carapace of the sea turtle [6], [35]. The expensive nature of satellite tags also poses a challenge for those in the sea turtle research community with limited funding to support research projects. While there are cheaper satellite tag options, they are not as precise and/or the data often need to be physically retrieved. With the highly migratory nature of sea turtles within the open ocean, retrieving a tag is often not feasible [35].

Reported sightings of shell-etched turtles by the public can provide much of the same data that satellite tags can (e.g., precise location data), except for complete reproductive migration data (e.g., the specific route taken by a honu from foraging to reproductive grounds). Honu Count has provided a cost-effective solution for capturing valuable mark-recapture/resighting data that can inform our understanding of a) connections between reproductive grounds and foraging/basking sites, b) behavior, c) survivorship, and d) habitat use, which will contribute to better management practices for the species. All of the Honu Count data were provided by the public, and the amount of these data has only increased since the inception of the online HCSS. The data analysis shows that post-survey there was an increase in yearly reports that include GPS locations ($p \approx 0$), as well as an increase in yearly reports post-HCSS for islands that normally had a low number of reports (i.e., Hawaiʻi, Oʻahu, Kauaʻi) (Table 3). The ease of reporting from a mobile device that requires GPS data of the sighting, has increased the total number of reports as well as increased the distribution of reports (Figure 4; Table 3).

Results from the numerous reports of honu on the island of Maui have stayed consistent both pre- and post-HCSS, and demonstrate how the GPS location data that Honu Count provides sheds light on habitat use and foraging hotspots (Table 1; Figures 3–4, 6). One explanation for these totals could be due to a higher number of basking beaches in the more populated tourist areas. The main basking beach for honu on Oʻahu resides on the north shore, 56 km from the tourist-favored area of Waikiki. Maui Island may elicit the most reports of honu due to increased efforts to shell etch rehabilitated and basking turtles compared to any other MHI (Figure 4). MOCMI became a prominent stranding response and rehabilitation center in 2016, and they began applying shell etchings to their rehabilitated and basking Maui honu in November of 2019 (USFWS TE-72088A-3). Between 2019 and the end of 2023, 381 shell etchings were applied by MOCMI making Maui the MHI with the highest number of of shell etchings deployed. MOCMI also increased rehabilitation and release of rehabilitated sea turtles from all of the MHI starting in 2020 during the Covid-19 pandemic, which led to an increase in shell etchings (Table 1).

The most frequently reported honu both pre- and post-HCSS (170 sightings pre-HCSS; 142 sightings post-HCSS) was the 100th shell etched sea turtle on Maui, MA100 (Figure 2). The immature honu, MA100, was originally brought into MOCMI in March 2021 from Lahaina, Maui, for rehabilitation due to a circle hook with fishing line embedded in the lower right side of the jaw. MA100 stranded again in the same area in October 2021, December 2021, January 2023, May 2023, June 2023, and September 2023, all due to interactions with fishing gear. All reports via the online HCSS have shown that MA100 resides within the same area of Lahaina, Maui, and has been observed successfully swimming, foraging, and basking in between stranding events (Figure 2). The ease with which the public can submit a report via cell phone, tablet, or computer has increased annual reports (Table 3) and helped track the survivorship of rehabilitated honu like MA100. Such data can also inform and guide educational outreach efforts to raise community awareness and reduce fishery interactions.

Because of the many recreational activities in and around the ocean in Hawaiʻi, there are many opportunities for members of the public to observe honu with shell etchings and report their sightings. According to the Research and Economic Analysis Division, in 2023, Maui County (the islands of Maui, Molokaʻi, Lānaʻi, and the uninhabited Kahoʻolawe) had a total of 164,264 residents, making it the third most populous county in the state. Honolulu County, which is only made up of the island of Oʻahu, has a total 989,408 residents, followed by Hawaiʻi County (Hawaiʻi Island) with 207,615 residents [36]. The MHI are an incredibly popular tourist destination, with 5.61 million tourists visiting the island of Oʻahu in 2023, and about half that amount (2.5 million) visiting the island of Maui in the same year [37].

Along with reports of immature and rehabilitated honu around the MHI, the Honu Count Participatory Science Project provided valuable data on adults returning from their reproductive migration from Lalo to foraging grounds in the MHI (Figures 5-6; Table 3). These reports have become essential in providing a better understanding of the primary foraging hotspots and spatial distribution of adult honu post-migration. The high numbers of sightings on Maui indicate that area has a high number of adult honu returning from Lalo (Figure 6a), but their habitat use differs from the rest of the reported honu that were given shell-etchings around the MHI (Figure 6b). Out of the 17 Lalo honu that returned to Maui, 76% (n = 13) settled in the northern area of Maui. For honu that were given a shell etching around Maui, 94% (n = 236) were distributed around the eastern and southern areas of Maui (Figure 6b).

Maui's high density of Honu Count reports suggests that the foraging grounds, specifically northern Maui foraging grounds, may be ideal for turtles to garner enough mass (i.e., energy/fat reserves) to make the approximately 1,000 km round-trip migration and reproduce. However, consideration must be given to the potential for disproportionate reporting provided by the public due to certain areas (southwest and west Maui) having high numbers of tourists. Or potentially, a greater number of reports occurring during the daytime when the public is most active at the beach despite a greater number of turtles basking at dusk or at night on Maui's northern beaches (NOAA PIFSC unpublished data). Areas with low tourism or beaches with limited accessibility - which may have a large number of basking turtles - may influence over-interpretations of basking and foraging hotspots at locations with high public activity.

The total reports of adult honu returning from Lalo is steadily increasing, with numbers for 2024 totaling 215 reported sightings of 175 individual Lalo adult honu returning to their foraging grounds for the 2024 post-nesting season (NOAA PIFSC unpublished data). Knowing where the foraging habitats are of these valuable members of the honu population (i.e., reproductive adults) can help guide and inform management activities. Other regions outside of Hawaiʻi have begun to adopt the practices of applying shell-etchings as a means of tracking. With additional funding and resources, HCSS could one day become similar to the NOAA Fisheries Passive Acoustic Cetacean Map [38], providing an open database for the public to access sea turtle migration data.

The online HCSS is part of a growing movement to use publicly gathered data on sea turtles for research purposes. For example, NOAA Fisheries West Coast Regional Office and the Aquarium of the Pacific used 10 years' worth of participatory science data around the San Gabriel River in Southern California to assist with monitoring the east Pacific green turtle population [14]. Baumbach et al. [17] developed a similar participatory science project, emphasizing the use of technology to make it easier to get the public involved in gathering sea turtle migratory habits. Both fishing vessels and boats involved with tourism have been used to assess spatial-temporal distribution of foraging areas in loggerhead sea turtles (*Caretta caretta*) that are known to inhabit the Pelagie Archipelago, a small group of islands off the coast of southern Italy [7], [39]. Environmentally-focused participatory science projects not only have positive impacts on increasing the size of datasets, but those who participate become more involved in the community and in the caretaking of their environment [40], [41]. With the influx of tourists to Hawaiʻi comes the opportunity for them to become involved in a marine science project and gain a greater understanding of the environment, cultural importance of sea turtles in Hawaiʻi, and responsible public viewing behavior, which reduces animals disturbance, an important management objective for recovering species [13], [40], [41].

5 Conclusion

The new online HCSS has increased the community's engagement within Hawaiʻi by providing a more efficient and user-friendly system (online survey). The HCSS has enabled the public to become more involved in reporting sightings in real-time. These reports provide conservation scientists and managers with a more accurate and well-rounded dataset on foraging locations, post-migration behaviors, individual survival, and tracking of rehabilitated individuals. By making data collection more efficient and accessible to the public, more members of the community are engaged in sea turtle science and conservation. The publicly-obtained data were incorporated into the proposed critical habitat designation for green sea turtles [27], [34], which will help protect essential habitat from federal agency actions, ultimately for the conservation of the species. The low cost and ease of applying shell etchings combined with sighting reports by the public has proven to be a successful way to engage with the public while also increasing our overall knowledge of the behavior and habitat use of Hawaiʻi's honu.

Data Availability

The dataset(s) supporting the conclusions of this article are available through NOAA's Pacific Islands Fisheries Science Center Marine Turtle Biology and Assessment Program (MTBAP). Requests can be made to MTBAP program lead Summer Martin (summer.martin@noaa.gov). With additional resources and the adoption of this technique in other regions in the future, this project may be found publicly accessible in formats similar to the NOAA Fisheries Passive Acoustic Cetacean Map.

Abbreviations

- **PMNM**: Papahānaumokuākea Marine National Monument
- **MHI**: Main Hawaiian Islands
- **NOAA**: National Oceanic and Atmospheric Administration
- **NMFS/NOAA Fisheries**: National Marine Fisheries Service
- **PIFSC**: Pacific Islands Fisheries Science Center
- **MTBAP**: Marine Turtle Biology and Assessment Program
- **MOCMI**: Maui Ocean Center Marine Institute
- **USFWS**: United States Fish and Wildlife Service
- **HCSS**: Honu Count Sighting Survey
- **GPS**: Global positioning system

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Declarations

Ethics Approval and Consent to Participate

All data collected and animal handling was done under the U.S. Fish and Wildlife permit TE-72088A-3 and National Marine Fisheries Service permit 21260. The Honu Count Sighting Survey is authorized under the Paperwork Reduction Act and Privacy Act (OMB Control Number: 0648-0828).

Consent for Publication

Not applicable.

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Authors' Contributions

Brittany Clemans and Dr. Camryn Allen led the creation and management of the Honu Count Sighting Survey, and drafted the manuscript. Dr. Summer Martin oversaw the project and edited the manuscript as MTBAP program lead. Marylou Staman provided data and expertise on honu within Lalo, as well as edited the manuscript. Dr. Devin Johnson provided valuable data analysis by running Poisson general linear models and analysis explanation. Irene Kelly provided oversight of the project as Sea Turtle Recovery Coordinator at NOAA Pacific Islands Regional Office.