Micronesica 2017-04: 1–19

Ocean pathways and residential foraging locations for satellite tracked green turtles breeding at French Frigate Shoals in the Hawaiian Islands[1]

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Abstract— From 1992-2014 the breeding migrations of 20 green turtles, *Chelonia mydas*, were satellite tracked either from or to the colonial nesting site of French Frigate Shoals (FFS), a geologically ancient mid-point in the 2400 km arc of the Hawaiian Islands. Using the Argos System, ocean routes and travel schedules were mapped and the home ranges of foraging area destinations were calculated and portrayed by Minimum Convex Polygons. None of the turtles migrated outside the Central North Pacific (CNP) region of Hawai'i. Fifteen of the 17 turtles tracked from FFS migrated to the Main Hawaiian Islands (MHI) to the southeast, while one turtle went directly south to the foraging site of Johnston Atoll within the CNP, and another ceased transmitting midway between FFS and the MHI. Transit times from FFS to the MHI ranged from 16-94 days. Distances covered during each migration ranged from 830-3936 km with travel rates of 1.2-2.5 km/hr. Upon arrival at residential locations transmissions continued for 2-314 days. The post-breeding pathways taken by the turtles comprised two general corridors. Thirteen of the turtles traveled well offshore south of the island chain. In contrast, two turtles traveled a more direct pathway over the banks and reefs of the Hawaiian Islands chain. After arriving in the MHI, all but one traveled coastally until crossing the deep channels separating each island. Nine widely separated home range foraging destinations were identified. Two of the largest bays in the Hawaiian Islands, Kane'ohe Bay on O'ahu and Kahului Bay on Maui, were the destinations for ~50% of the turtles, thereby emphasizing the conservation importance of these two locations for adults in the Hawaiian green turtle population. Our study brings together for the first time Hawaiian green turtle tracking data collected over the span of 22 years.

Introduction

Separation of colonial nesting beaches and disjunct residential foraging pastures is an ecological characteristic globally for populations of the herbivorous green turtle, *Chelonia mydas* (Hirth 1997). Distances of separation involve 100s to over 1000 km. The disappearance of green turtles following seasonal mating and egg laying at breeding sites prompted early researchers of the 1950s to devise and attach metal identification tags to nesting turtles (Harrison 1956, Hendrickson

[1] Citation: Balazs, G.H., D.M. Parker & M.R. Rice. 2017. Ocean pathways and residential foraging locations for satellite tracked green turtles breeding at French Frigate Shoals in the Hawaiian Islands, *Micronesica* 2017-04, 19 pp. Published online 15 January 2018. http://micronesica.org/volumes/2017

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1958, Carr 1967). These pioneering steps resulted in tag re-sightings by fishers at an array of faraway neritic foraging locations. Also, after gaps of several years, tagged turtles were seen again back at the same nesting beaches. The expansive multi-national range of greens turtle stocks - breeding within the jurisdiction of one country - and residing as adults and immature life stages within one or more other national boundaries - continues to be the greatest complication for effective conservation and sustainable use.

Applying and re-sighting metal tags to green turtles over the years has resulted in a wealth of demographic information, e.g. see Hirth 1997 and Balazs et al. 2015. However, starting in the early 1990s detailed spatial and temporal movement data, often on a daily basis, became possible with the advent of Argos satellite-linked transmitters attached to green turtles and other marine turtle species. The advancement of this technology to the sophisticated point it now exists has been referred to by Hays et al. (2016) as the 'Golden Age' of animal movement studies.

Within the 2400 km linear chain of Hawaiian Islands (Figure 1) metal flipper tags were first applied to nesting green turtles in the 1960s thereby showing point-to-point movements mainly from the mid-archipelago colonial breeding site of French Frigate Shoals (FFS), to coastal areas of the geologically younger islands in the southeast known as the Main Hawaiian Islands (MHI) (Balazs 1976, Nurzia Humburg & Balazs 2014). From 1992 - 2014 the movement schedules, routes of travel, and home range of foraging destinations of green turtles undertaking these lengthy movements were investigated using Argos satellite telemetry. Herein for the first time we report detailed results of this comprehensive tracking research conducted over the span of 22 years.

Materials and Methods

Study Area

French Frigate Shoals (FFS), located at 23.7°N 166.1°W, 900 km from Honolulu in the Northwestern Hawaiian Islands (NWHI), consists of a 32 km long crescent-shaped reef hosting several small sand islets where green turtles seasonally nest (Amerson 1971). One of these sandy islets, 5-hectare East Island, historically accounts for about half of the annual nesting at FFS (Amerson 1971, Balazs 1980, Balazs & Chaloupka 2004). Nesting by green turtles also occurs in the MHI and at other remote NWHI, but in lower numbers than at FFS (Frey et al. 2013, Roberson et al. 2016)

Data Collection & Procedures

Twenty green turtles, 17 females and 3 males, were satellite tracked either from or to FFS during 1992-2014. Carapace length (cm) was measured for each turtle and flipper tags were applied to identify individuals. In addition, unique numbers lasting 1-2 years were etched on the carapace for easy visual recognition from a distance (Balazs 1995, Bennett et al. 2002). Telonics, Inc. satellite tags (Mesa, Arizona, USA, Table 1) were deployed on 17 turtles at FFS (15 females, 2 males) and three turtles (2 females, 1 male) at Laniakea, O'ahu (21.6°N, 158.7°W), a neritic foraging site and shoreline area used for terrestrial basking (Rice & Balazs 2008). To test the performance of a tag where the external wire antenna was eliminated, experimental satellite transmitters with fully imbedded helix antenna were attached to two of the FFS females (Telonics GeoBar-14, Table 1). All satellite tags were securely and safely attached using layers of fiberglass cloth and polyester resin following the procedure of Balazs et al. (1996). Each satellite tag was programmed with a duty cycle specifying the number of transmitting hours on and off (Table 1). Location positions for each turtle were calculated by CLS-Argos using the Doppler shift method (Service Argos 2008). Kalman filtering of Argos data was not used due to collecting most of the data pre-2008; to keep the data standardized, all data were processed by Argos using the Least Square Analysis filtering method. To test if an artificial magnetic field would alter turtle swimming direction, experimental electromagnetic coils were affixed to the head region of three females at

FFS using the Balazs et al. (1996) method. Coils were programmed with a specific on/off duty cycle.

Generic Mapping Tools (GMT, Wessel & Smith 1998) was used to create maps for the migration pathways and foraging areas. CLS-Argos provided the positional data specified as Location Classes (LC) 3, 2, 1, 0, A, B and Z. LC Z data were not used as these positions are considered unacceptable by Argos. Positions were excluded from use if: 1) the location was on land – unless the position was reasonable at the FFS nesting area or basking area such as Laniakea, 2) the speed calculated between two positions was over 5 km/hr, for periods of migration as well as within foraging and nesting areas, and 3) for the migration period only - if the angle between three positions was greater than 90 degrees when the time between them was less than a 24-hour period. All data at foraging areas were plotted using a circle with a radius of 1 km to indicate the average error in accuracy for LC 1 positions which have the largest specific bounded accuracy assigned by Argos (500-1500 m). The accuracy of other positions was as follow: LC 3 = less than 250 m, LC 2 = 250-500 m, LC 0 = greater than 1500 m, and LC A and B have no accuracy estimates supplied by Argos. Higher accuracy positions (LC 3, LC 2, and LC 1) were plotted as smaller black circles. A black line was used to outline the home range areas.

Home range for foraging and underwater refugia (hence residential areas) was determined using the Minimum Convex Polygon (MCP) method (ArcGIS 10.3 2016). We designated foraging-refugia areas as the near-island neritic location where each satellite tag stopped, if a satellite tag did not stop near shore then a foraging-refugia area was not determined. For the three turtles satellite tagged at the known foraging area of Laniakea, Oʻahu, Argos positions collected prior to travel to FFS were used to estimate home range. At least three positions at the designated destination areas were needed to calculate home range estimates. Home ranges were calculated using only LC 1, 2 and 3 data with all land areas excluded (based on method by MacLeod 2013) and these were labeled as "Minimum Home Range". There were several tags which did not provide enough LC 1, 2, and 3 data to calculate a Minimum Home Range, therefore a "Full Home Range" was calculated for all tags which included all retained positions (LC 1, 2, 3, 0, A and B). A comparison was done between Minimum and Full Home Ranges to indicate difference in the calculated area of both. More than one Minimum Home Range area was indicated and calculated for a turtle if the spatial and temporal data warranted such designations.

Results

An overview of the movements of the 20 turtles tracked in this study is displayed in Figure 2. None of the turtles travelled outside of the Central North Pacific region of the Hawaiian Islands as defined by Seminoff et al. 2015. All pertinent collected and calculated data for the study are summarized in Tables 1 and 2. We describe these results in detail in the following sections.

FFS to MHI and Johnston Atoll

Fifteen of the 17 turtles tracked from FFS migrated to the MHI, while one turtle went south to the foraging site of Johnston Atoll, and another ceased transmitting midway from FFS to the MHI in oceanic waters (Figures 3, 4, and 5). Transit times from FFS to the MHI ranged from 16-94 days; the turtle that traveled to Johnston took 16 days. Distances traveled during each migration ranged from 830-3936 km with travel rates of 1.2-2.5 km/hr. Upon arrival at residential locations in the MHI transmissions continued for 2-314 days, and 145 days at Johnston (Table 2, Figure 5).

Four of the female turtles tagged at FFS traveled to Kāneʻohe Bay, Oʻahu (Figure 6A-D). One of these turtles also spent time near Malaekahana, Oʻahu, to the north of Kāneʻohe Bay (Figure 6B). Four females and one male traveled from FFS to Kahului Bay, Maui where residency ranged coastally from Waiheʻe-Waiehu to Haʻiku-Paʻuwele, concentrated between Kahului and Spreckelsville (Figure 7A-E). Two other females traveled to ʻEwa Beach, Oʻahu from FFS. Turtle

22132_95 (Figure 8A) moved between areas off of ʻEwa Beach and Hickam-Honolulu International Airport crossing the Pearl Harbor Naval Base entrance channel during transits back and forth. Turtle 25694_98 shown in Figure 8B moved between ʻEwa Beach and the Ko ʻOlina Disney Resort on Oʻahu.

Other foraging destinations turtles migrated to from FFS included individual females to Johnston; Keaukaha, island of Hawaiʻi; Lahaina, Maui; Mākaha Point, Kauaʻi; and a male to Pānahāhā, Molokaʻi (Figure 9A-E).

Two females and a male satellite tagged at the Laniakea foraging area on Oʻahu's North Shore migrated to FFS (Figure 4A-B). Travel times were 28 days each for the females and 34 days for the male. Distances covered were 1615 km, 1461 km and 1145 km respectively (Tables 1 and 2). The most direct ocean route from Laniakea to FFS would be 864 km.

All three Laniakea turtles traveled to the west of FFS before looping back for arrival within FFS. The male passed FFS to the north reversing course only 10 km to the west before reaching FFS. The two females passed to the south of FFS, one moving 88 km and the other a considerable 220 km to the west before turning eastward back to FFS. Tracking of the male was also accomplished for the return trip from FFS to Oʻahu. The turtle arrived first at Laniakea where it was observed basking, then moved to Kāneʻohe Bay (Figure 10C). However, insufficient positions were obtained to determine the route taken and related statistics.

Home Range of Foraging Areas

Figures 6-10 show MCPs for both Full Home Range and Minimum Home Range, when such ranges could be computed. Kāneʻohe female 4801_92 occupied two Minimum Home Ranges separated by 16 km (Figure 6B) and the two ʻEwa females each occupied two Minimum Home Ranges 8 and 14 km respectively from one another (Figure 8A-B). Due to a paucity of LC 1, 2, and 3 positions, Minimum Home Range could not be computed for six turtles arriving at five foraging area destinations as shown in Table 2. (Pānahāhā, Molokaʻi ; Lahaina, Maui; Johnston; Mākaha Point, Kauaʻi; and two turtles at Kahului Bay, Maui). Minimum Home Range estimates shown in Figure 10A-C for the three turtles departing from Laniakea, Oʻahu were 1.2 km^2 and 1.4 km^2 for the females and 0.2 km^2 for the male. The calculated Minimum Home Range values presented in Table 2 ranged from 0.1-20.4 km^2 with a mean of 7.2 ± 7.7 km^2; these areas encompassed 1-40% of Full Home Range areas. Full Home Range areas ranged from 0.1 - 175 km^2.

Discussion

Pathways from and to FFS:

The post-breeding migratory pathways taken by the turtles from FFS comprised two general routes (Figure 2). Fourteen of the turtles, including the two males, moved south of the island chain staying over deep oceanic waters until arriving in the MHI. In contrast, two turtles traveled a more direct track over the banks and reefs of Necker and Nihoa in the NWHI to approach the MHI. In both cases once the turtles reached the MHI, they traveled coastally until crossing the deep channels separating the islands. Usually only 1-2 days were spent moving along the coast, however, a few cases differed. Female 24192_98 spent 5 days traveling along the coastline of Molokaʻi before moving father east to Kahului, Maui. Female 24196_97 spent 15 days coastally on Kauaʻi, then 6 days transiting the northeast shoreline of Oʻahu, then 3 days along Molokaʻi before moving to her final foraging destination of Keaukaha, near Hilo on the island of Hawaiʻi. This turtle migrated 1721 km, the farthest linear distance away from FFS of the 17 turtles tracked. The female that migrated from FFS to Johnston traveled only 830 km in a nearly direct open-ocean pathway to the atoll.

The two GeoBar tags with experimental internal helix antennas deployed at FFS in 1998 on two females both yielded sufficient data for complete tracking to the MHI; one migrated to

Lahaina, Maui and the other to Kahului, Maui. However, less reliable and overall fewer LC positions were received for each track, hence the additional manufacturing of these tags was not pursued (Schroeder & Balazs 1999).

Considerable difficulty was experienced attaching the experimental electromagnetic head coils to the three females at FFS making it problematic how long they stayed in place after release. Female 24192_98 migrated from FFS to Kahului, Maui on a route that appeared similar to the other turtles. Female 25694_98 traveled from FFS to ʻEwa Beach, Oʻahu, again in a manner consistent with most other turtles tracked. These negative findings of any electromagnetic effect are in agreement with those of Papi et al. (2000) using magnets placed on nesting green turtles at Ascension Island. However, the third female with an attached head coil in our study showed substantial deviation in her pathway returning from FFS (Figures 2, 3C, Table 2, ID 24195_97). This turtle swam in a protracted counter-clockwise route on the high seas considerably south and east of the MHI before circling back north and west eventually arriving at Mākaha, Kauaʻi where transmissions ceased a few days later (Figure 2). This voyage lasted 94 days covering an amazing 3936 km. Since there was no discernible change in course for any of the three turtles during on/off periods of the artificial magnetic fields, evidence is lacking for any direct influence on the pathways they chose. The lengthy circular route of female 24195_97 may have involved a pelagic foraging excursion, similar to the natural behavior of some post-nesting green turtles in Japan (Hatase et al. 2006) and the Marshall Islands (Parker et al. 2015).

Three different migration routes were taken by the three turtles tracked from Laniakea, Oʻahu to FFS (Figure 4A-B). The male took the most direct path following the banks and reefs of the NWHI. In contrast, one of the females first moved to Kauaʻi following that island's southern coast before continuing to FFS on a route south of the NWHI over deep oceanic waters. The other female went considerably north of the NWHI traveling entirely over deep ocean before reaching FFS.

In an earlier study of green turtles at Laniakea (Rice & Balazs 2008) time-depth recorders placed on two males and a female demonstrated biphasic diving behavior during migrations to and from FFS. Shallow dives of 1-4 m occurred during the day and deep dives averaging 35-55 m happened at night. However, the female made several extreme dives to 135 m, and the males to depths of 100 m, setting a world record for known green turtle diving depths in the wild (Rice & Balazs 2008). Satellite tags were not used in the Rice & Balazs (2008) study so it wasn't possible to determine the routes taken and locations of individual dives for these three turtles. Visual sightings of etched numbers placed on the carapace were used to verify each turtles' presence from a distance at FFS and back again at Laniakea.

Notably, the ocean pathways taken by the turtles between FFS and the MHI were within the recently expanded Papahānaumokuākea Marine National Monument (Obama 2016) for at least 30% of their journeys, and entirely within the 200 nm Exclusive Economic Zone of the USA, except for portions of turtle 24195_97's circular pelagic route far off shore.

FORAGING AREA DESTINATIONS

Nine widely separated foraging areas shown in Figure 5 were identified in this study by satellite tracking adult green turtles linked to the colonial breeding site of FFS. Home ranges were delineated by MCPs, a methodology not previously employed with Hawaiian green turtles. Prior studies using acoustic telemetry of juvenile green turtles to estimate foraging range were carried out in Kāneʻohe Bay, Oʻahu (Brill et al. 1995), and at Kiholo Bay on the west coast of the island of Hawaiʻi (Laber & Waller 1994). Also, the spatial scope of inter-nesting marine habitat used by migrant turtles at FFS was estimated using radio telemetry (Dizon & Balazs 1982), but MCPs were not reported for these studies. Discrete home ranges using MCPs in the present study provide a powerful starting point for outlining zones of high conservation interest, considering the importance of breeding adults to the population.

Sixteen of the 17 turtles deployed with satellite tags at FFS migrated to their apparently intended end-point destinations at eight discrete locations in the MHI and one at the closest neighboring island to the Hawaiian Archipelago of Johnston Atoll. Johnston was known to the indigenous people of Hawai‘i as Kalama and the green turtle foraging aggregation at this site has been shown to be genetically part of the Hawaiian green turtle population (Balazs 1985, Dutton et al. 2008). Transmissions from one of the females (24197_98, Tables 1 and 2) ceased while still at sea but clearly heading in the direction of the MHI (Figure 3C). The failure of transmitters and satellite reception of signals can result from several causes, as studied and discussed by Parker et al. (2014). Death of a turtle due to natural predation and other factors is also a possibility.

The strong assumption can be made that the end-point destinations in our study are the approximate foraging areas of residency prior to the turtles' reproductive migrations to FFS. Green turtle site fixity to residential foraging pastures and proximal underwater resting areas has been well-documented in Hawai‘i (Bennett et al. 2002, Bennett & Keuper-Bennett 2008) and elsewhere globally (Hirth 1997). In fact, the turtle that migrated from FFS to Johnston had originally been flipper-tagged there 9 years previous during ocean-capture studies (Balazs 1985, 1994). Furthermore, female 4800_92 tracked to the Kāne‘ohe Bay foraging location had been flipper-tagged when found nesting at FFS during the 1989 season and then ocean-captured in Kāne‘ohe Bay during March 1992, just 5 months before being encountered again back on the beach at FFS where a satellite tag was attached.

Location data from three of the females in our study gave clear indication of periodic protracted occupancy at two separate Minimum Home Range areas (Figures 6B, 8A-B). Forage availability, perhaps seasonal in nature, may have been the motivating factor for these modest shifts in residency of 8-16 km.

Of the 16 turtles (14 females, 2 males) recorded making a complete migration from FFS to a foraging area, 15 (94%, 13 females, 2 males) involved the MHI to the southeast. O‘ahu and Maui accounted for six turtles each (40%) while Kaua‘i, Moloka‘i , and the east side of the island of Hawai‘i hosted only one (6.7%) turtle each. None of the satellite tagged turtles traveled to the geologically older remnant NWHI to the northwest of FFS (Figure 1). However, historical flipper tagging studies at FFS (Nurzia Humburg & Balazs 2014) showed that 15.7% of the breeding turtles, 26 of the 166 tag re-sightings away from FFS were at residential foraging sites in this remote and ancient segment of the Hawaiian chain. The overwhelming majority of flipper tag re-sightings were made in the MHI where coastal benthic habitats rich with marine vegetation and underwater refugia are expansive for green turtle residency and nutrition (Arthur & Balazs 2008, Russell & Balazs 2009). The re-sighting locations of flipper-tagged turtles breeding at FFS are therefore congruent with findings using satellite telemetry.

It is noteworthy that two of the turtles (4800_92 and 4801_92) satellite tagged nesting together on 6 August 1992 both departed FFS within 4 days of one another and both took similar oceanic routes to reach the same destination of Kāne‘ohe Bay, O‘ahu. The documentation of these movements constituted the first successful post-nesting satellite tracking for any green turtle globally (Balazs 1994), thereby heralding the beginning of a new technological era for expanded species research.

Two of the eight MHI foraging destinations revealed in this study (Mākaha, Kaua‘i and Pānahāhā, Moloka‘i) were not previously known; the other six, along with Johnston, and numerous other green turtle foraging sites in the MHI, had been previously identified by other means, including ocean surveys, flipper tagging, and knowledge gleaned from local fishers (Balazs 1980, Balazs et al. 1987, Brill et al. 1995, Balazs & Chaloupka 2004, Chaloupka & Balazs 2007, Chaloupka et al. 2009, Balazs et al. 2015).

Not surprisingly, two of the largest bays in the Hawaiian Islands, Kāne‘ohe (41 km^2), O‘ahu and Kahului (34 km^2), Maui, were the destination for more than half (60%) of the 15 turtles migrating to home foraging habitats in the MHI, thereby emphasizing the conservation importance

of these two residential areas for breeding adults in the Hawaiian green turtle population. Green turtles are known to occur in abundance at both locations, undoubtedly due to availability of desirable algal forage and benthic terrain providing ideal underwater refugia (Balazs et al. 1987, Brill et al. 1995, Russell & Balazs 2009). Additionally, the plume of warm water continually discharging from an electric generating plant built in 1947 on the shoreline of Kahului Bay supplies a thermal physiological advantage similar to turtles basking ashore (Whittow & Balazs 1982). Turtles, mainly adults, crowd together in the plume, usually at night and often in great numbers – ranging from approximately 20-200 (Balazs et al. 1987, G. Balazs & M. Rice personal observations). Temperatures within the plume are 28-30°C, whereas the surrounding ambient seawater ranges 24-27°C depending upon time of year. A greater understanding is needed of the contribution made to reproductive readiness and somatic growth from the thermal bonus for green turtles utilizing this unique ecological niche in Kahului Bay.

CONCLUSIONS

The geographically isolated and genetically discrete population of green turtles in the Hawaiian Islands is among the best and longest studied globally. Additionally, monitoring of nesting trends has demonstrated significant increases over the past four decades giving a vastly improved conservation status (Balazs et al. 2015, http://www.iucnredlist.org/details/16285718/0). Our present study brings together satellite tracking results conducted over the span of 22 years that elucidate breeding migration corridors and home ranges of foraging pastures, thereby contributing further to the overall body of knowledge for the Hawaiian green turtle. Our satellite tracking results also raise a number of intriguing and important questions and data gaps helping to point the way forward for future studies. Potential avenues of investigation include: tracking of breeding males and females to and from FFS using combined GPS/dive-recorder technology; tracking of cryptic green turtles breeding in the MHI and in the NWHI to the northwest of FFS to locate their home range foraging areas; careful examination of migratory pathways extending outside the protected zone of the Marine National Monument to identify possible threats; and conduction of systematic marine surveys of home range habitats identified in our study, especially the warm-water refugia present in Kahului Bay, Maui.

At this 45-year juncture of continuous research focused on the Hawaiian green turtle, the overall goal of conservation investigations should be adjusted to embrace more than the collection, archiving, and publishing of scientific findings. A new era should be initiated that encompasses cultural integration by and for the indigenous Hawaiian people that are themselves linked for millennia to their green turtles. Exactly how this will take place should be left to Hawaiians to decide.

Acknowledgements

We extend our Appreciation and Aloha to the many colleagues of the NOAA Pacific Islands Fisheries Science Center, the Joint Institute of Marine and Atmospheric Research, the Hawaii Institute of Marine Biology, the US Fish and Wildlife Service, and the Department of Land and Natural Resources of the State of Hawai‘i, for 22 years of partnership in facilitating satellite tracking research of Hawaiian green turtles at French Frigate Shoals within the Hawaiian Islands National Wildlife Refuge and the Papahānaumokuākea Marine National Monument. Joanne Pettigrew, co-founder of the Show Turtles Aloha campaign and Mālama Na Honu organization, generously supplied her considerable expertise, time, and good cheer in support of tag deployments and re-sightings involving basking turtles at Laniakea on Oahu. The authors acknowledge with gratitude the numerous dedicated and professional field assistants that camped at remote French Frigate Shoals to gather data on nesting green turtles, especially Joe Spring, Irene Nurzia Humburg, Russ Miya, Tammy Summers, Yonat Swimmer, Susan Pultz, Kellie Takimoto and Julie Rocho; we

salute and honor their valuable contributions relevant to satellite tracking. We also thank Sea Life Park Hawai‘i's Steve Kaiser and Jeff Pawloski for past and present generosity and expertise in the benign use of their captive green turtle breeding colony for testing various aspects of tag attachment and other studies.

For their outstanding and consistent corporate service and technical assistance we thank Brenda Burger and Stan Tomkiewicz of Telonics Inc., and Seema Owens, Debbie Stakem and all staff of Argos CLS America. We thank Mike Salmon of Florida Atlantic University for the professional pleasure of learning from and working with him on the experimental electromagnetic coil project, thereby helping to point the way for future studies of this nature.

During the late 1960s, the first author was inspired by Linda Balazs to improve the deteriorating conservation status of Hawaiian green turtles due to over-harvesting for commercial purposes. That inspiration continues to the present in efforts to make others aware of the significant successes in population restoration (see http://www.iucnredlist.org/details/16285718/0).

The authors thank Nikki Atkins, Mike McCoy, Shandell Brunson, Stacy Hargrove and two anonymous reviewers for providing useful review comments on our paper.

This paper is dedicated to the memory of Dr. Archie Carr, a global inspiration to many who knew him either in person or through his magnificent writings both in scientific journals and popular literature. Years ago Dr. Carr recognized that earth-orbiting satellites would one day be used to unlock the mysteries of green turtle migrations and other hidden aspects of sea turtle life history. We are confident that Dr. Carr would now marvel at the Golden Age of sea turtle research that is upon us. The challenge is that we use the results of these technological wonders to the best advantage of sustainability for both sea turtles and the human cultures historically linked to them.

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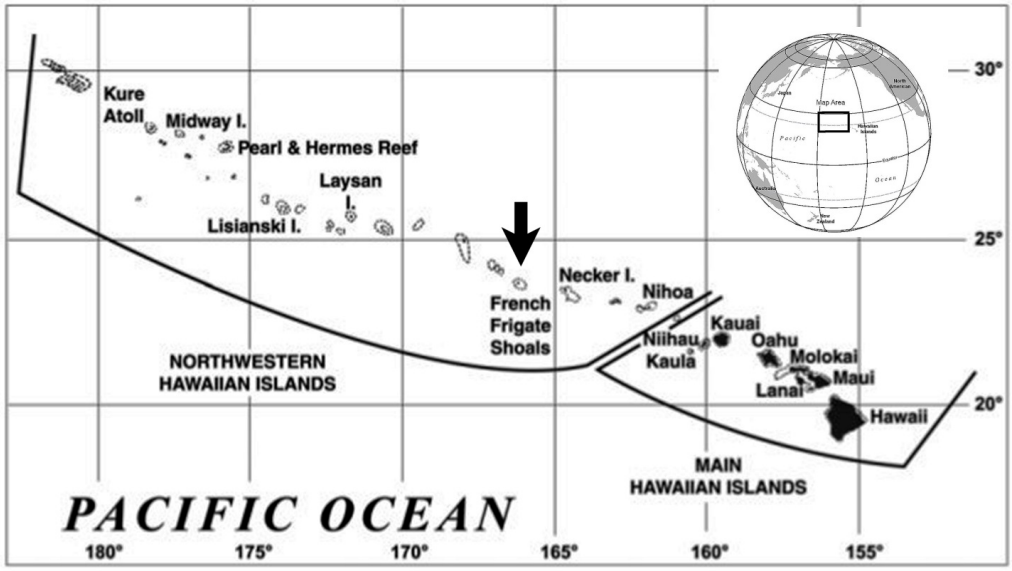

Figure 1. Hawaiian Archipelago located in an isolated region of the Central North Pacific. Colonial breeding by green turtles in abundance occurs at the mid-point location of French Frigate Shoals (Balazs et al 2015)

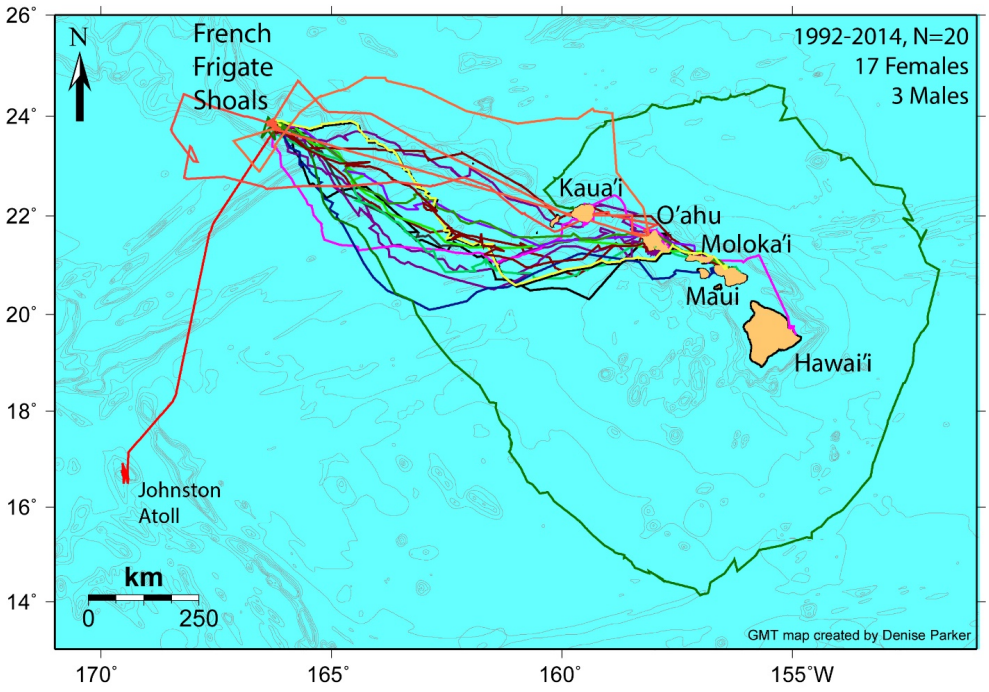

Figure 2. Composite view of the ocean pathways by the 20 green turtles tracked during their breeding migrations linked to the colonial nesting site of French Frigate Shoals. Turtles were randomly selected for satellite tagging between 1992-2014.

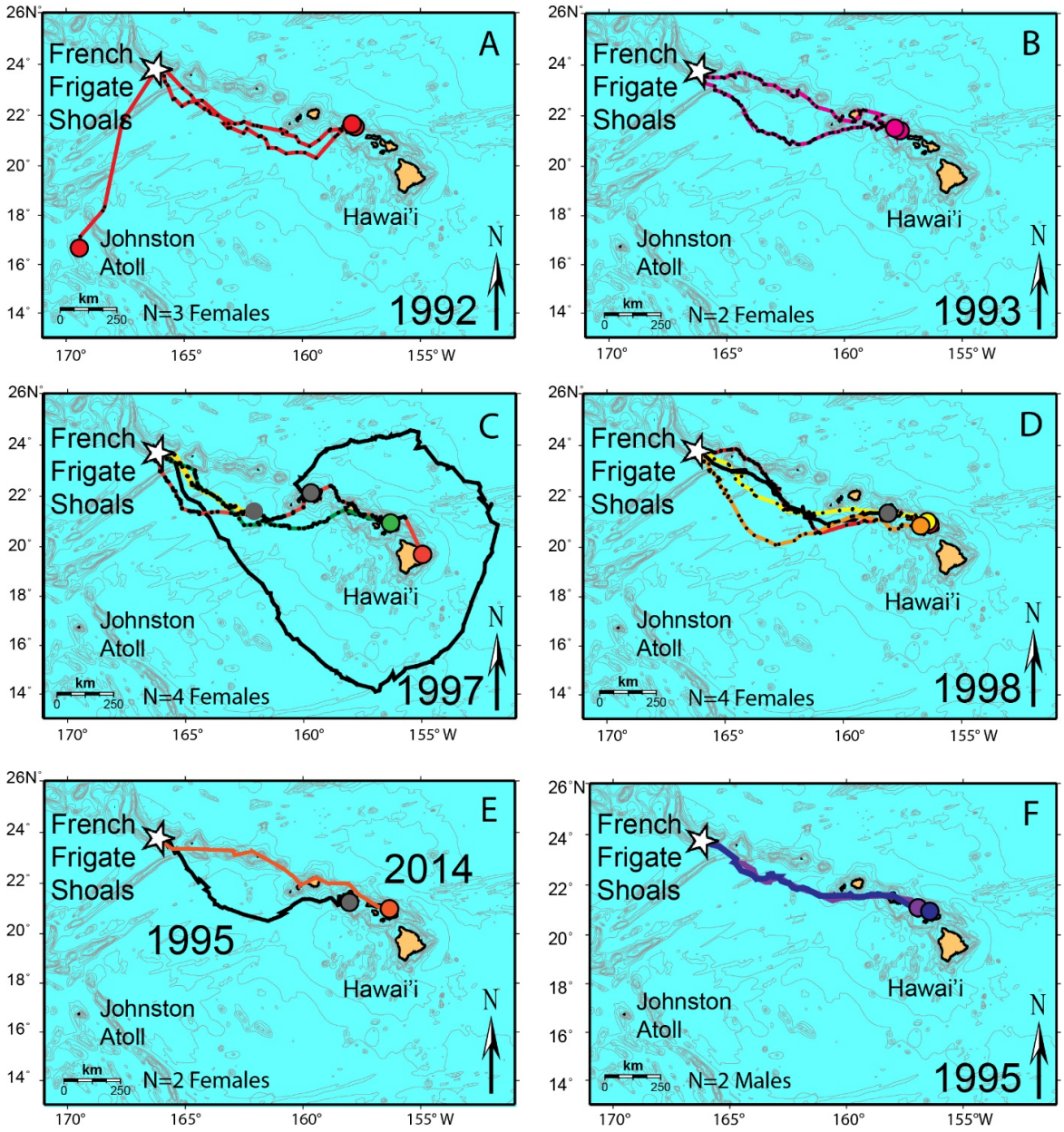

Figure 3A-F. Migration pathways from French Frigate Shoals breeding site for 15 females and 2 males. The release location is shown with an open star and final tracking position is indicated by a colored circle. Year of tracking is indicated on the map.

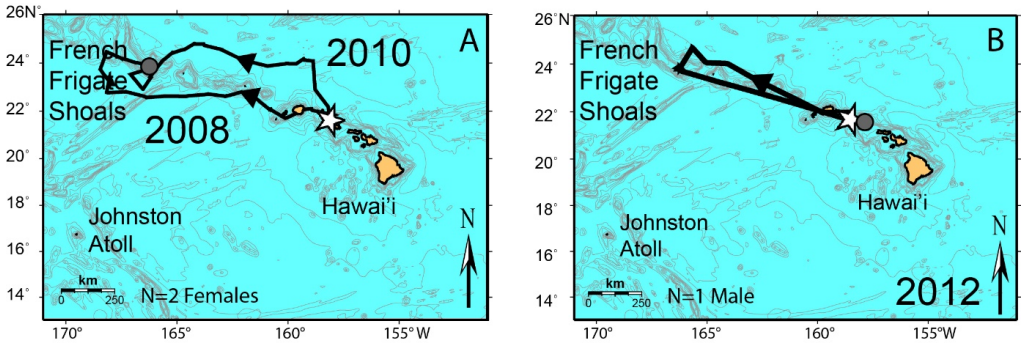

Figure 4A-B. Migration pathways from the Laniakea, O'ahu foraging site to French Frigate Shoals for two females and one male. The male tracking documented a round-trip migration with the return to Laniakea followed by a move to Kāne'ohe Bay, O'ahu. Year of tracking is indicated on the map.

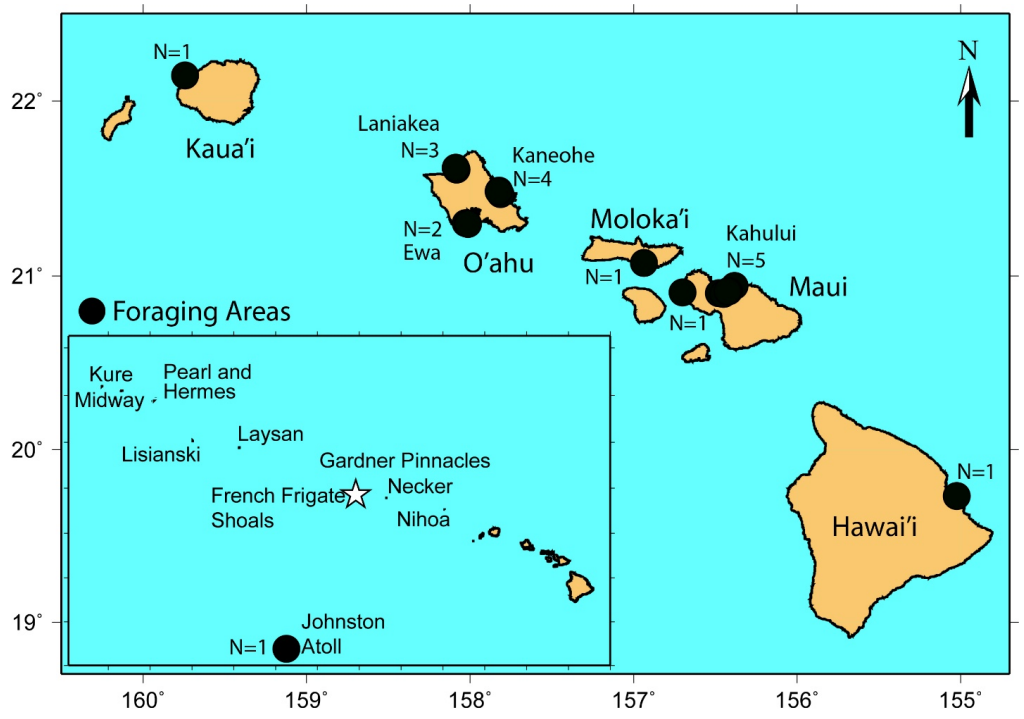

Figure 5. Foraging areas destinations/origins for 19 of the 20 green turtles tracked from 1992-2014. Transmissions from one turtle stopped midway between French Frigate Shoals and the Main Hawaiian Islands.

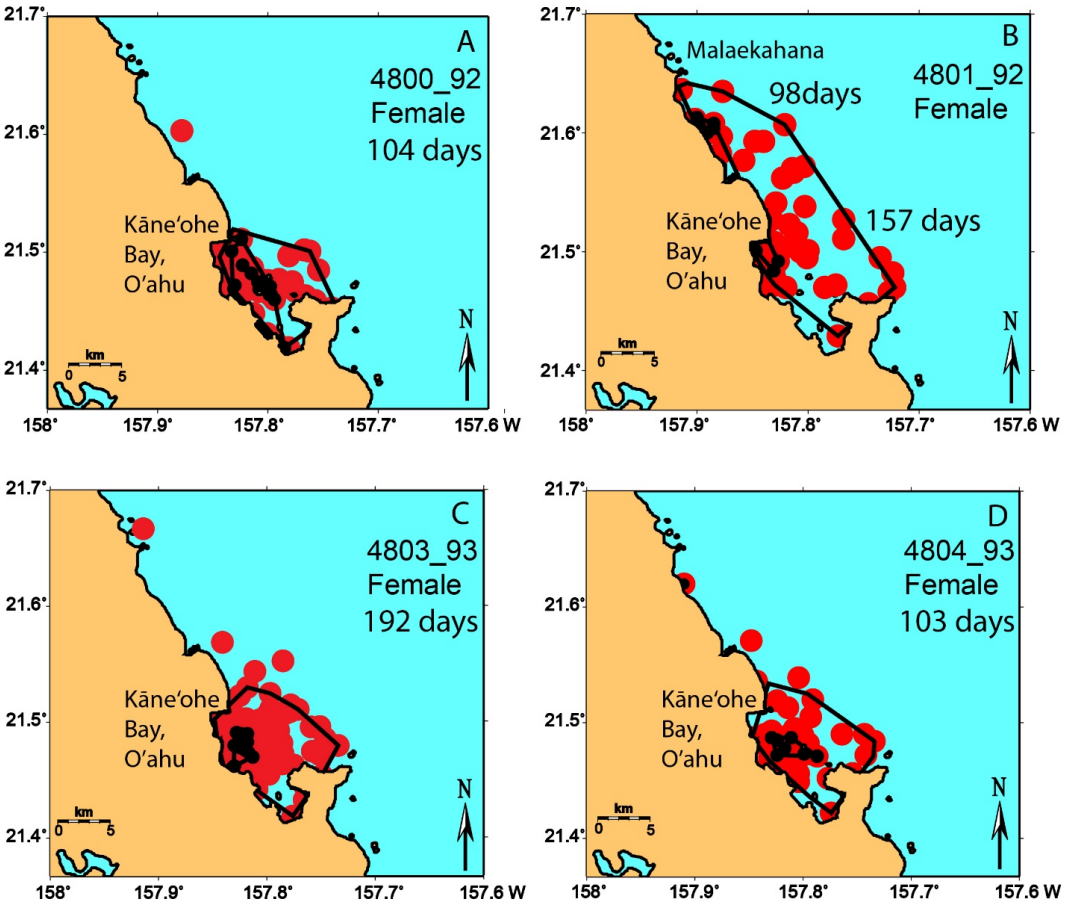

Figure 6A-D. Home ranges for four female green turtles that migrated to Kāne‘ohe , O‘ahu from French Frigate Shoals. Large colored circles indicate 1 km radius around each position. Black circles indicate positions with LC 1, 2 or 3 data. Black lines outline the Minimum Convex Polygons for Minimum Home Range and Full Home Range areas. Two Minimum Home Ranges are indicated for female 4801_92 in Figure 6B.

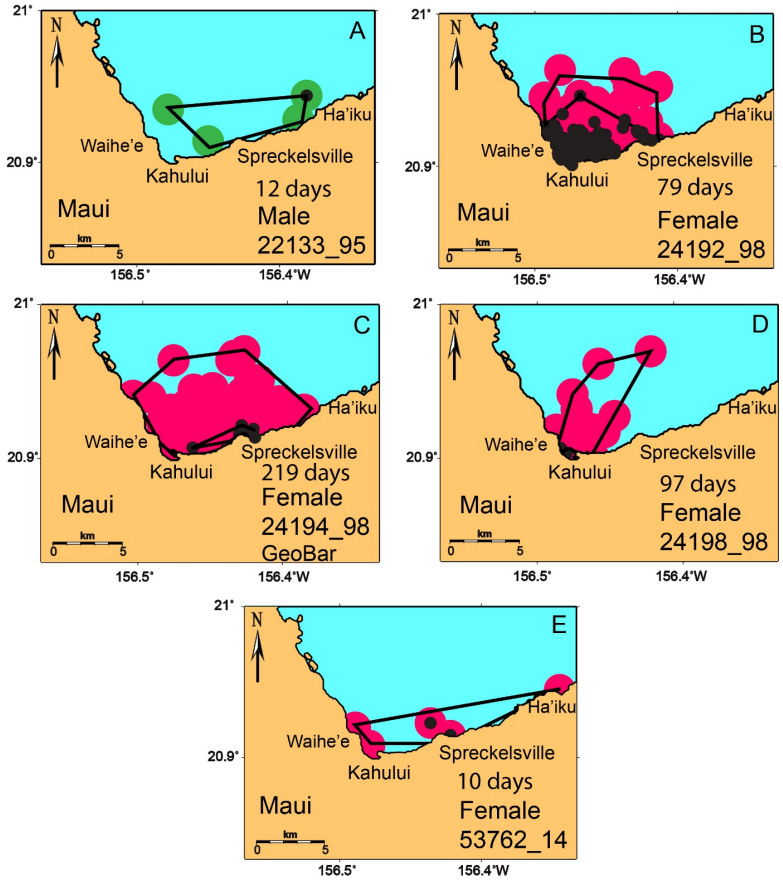

Figure 7 A-E. Home ranges for four females and one male green turtle that migrated to Kahului, Maui from French Frigate Shoals. Large colored circles indicate 1 km radius around each position. Black circles indicate positions with LC 1, 2 or 3 data. Black lines outline the Minimum Convex Polygons for Minimum Home Range and Full Home Range areas.

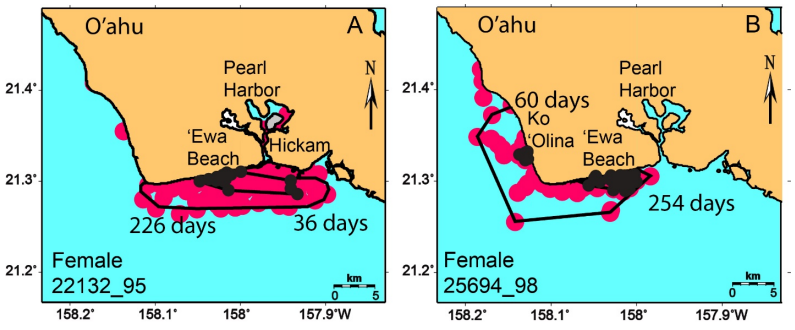

Figure 8 A-B. Home range for two female green turtles that migrated to ‘Ewa Beach, O‘ahu from French Frigate Shoals. Large colored circles indicate 1 km radius around each position. Black circles indicate positions with LC 1, 2 or 3 data. Black lines outline the Minimum Convex Polygons for Minimum Home Range and Full Home Range areas. Both ‘Ewa turtles occupied two Minimum Home Range areas.

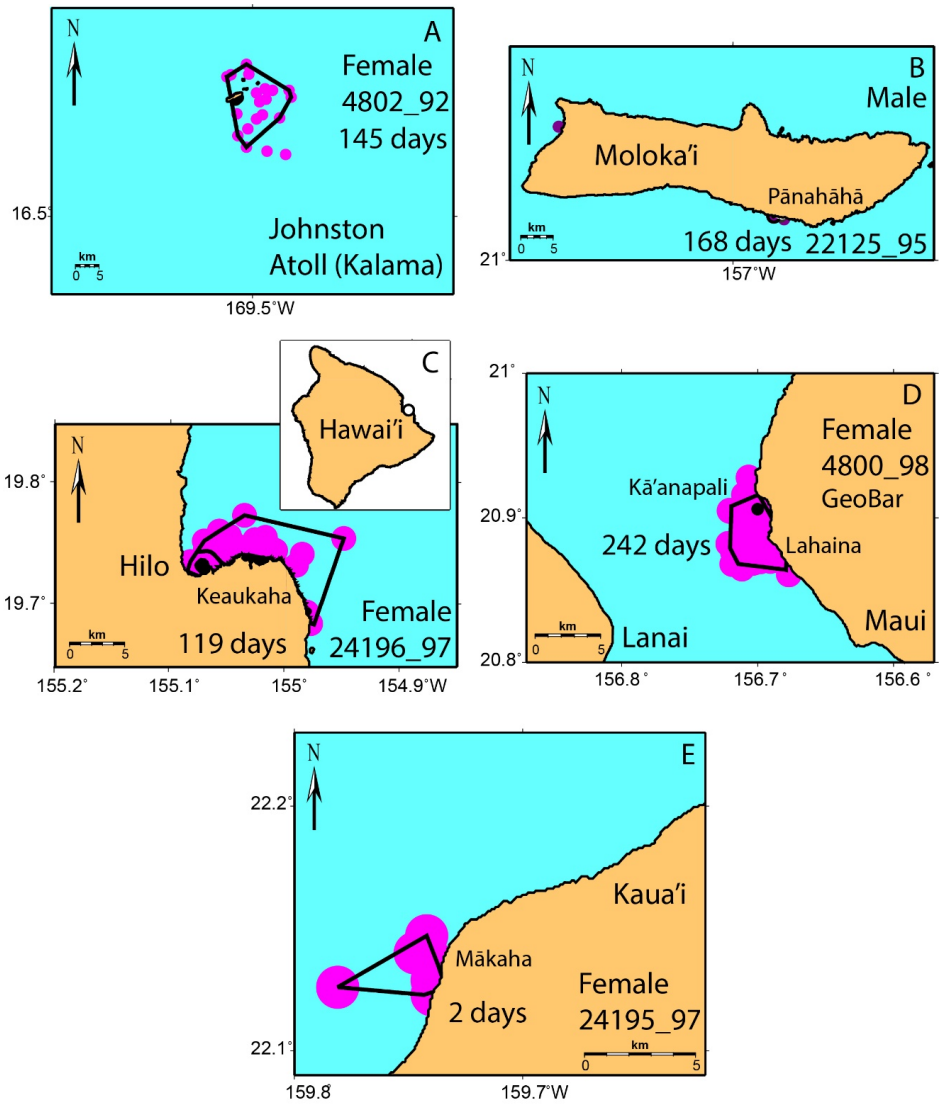

Figure 9 A-E. Home ranges for four females and one male green turtle that migrated from French Frigate Shoals to five other neritic foraging areas. Large colored circles indicate 1 km radius around each position. Black circles indicate positions with LC 1, 2 or 3 data. Black lines outline the Minimum Convex Polygons for Minimum Home Range and Full Home Range areas.

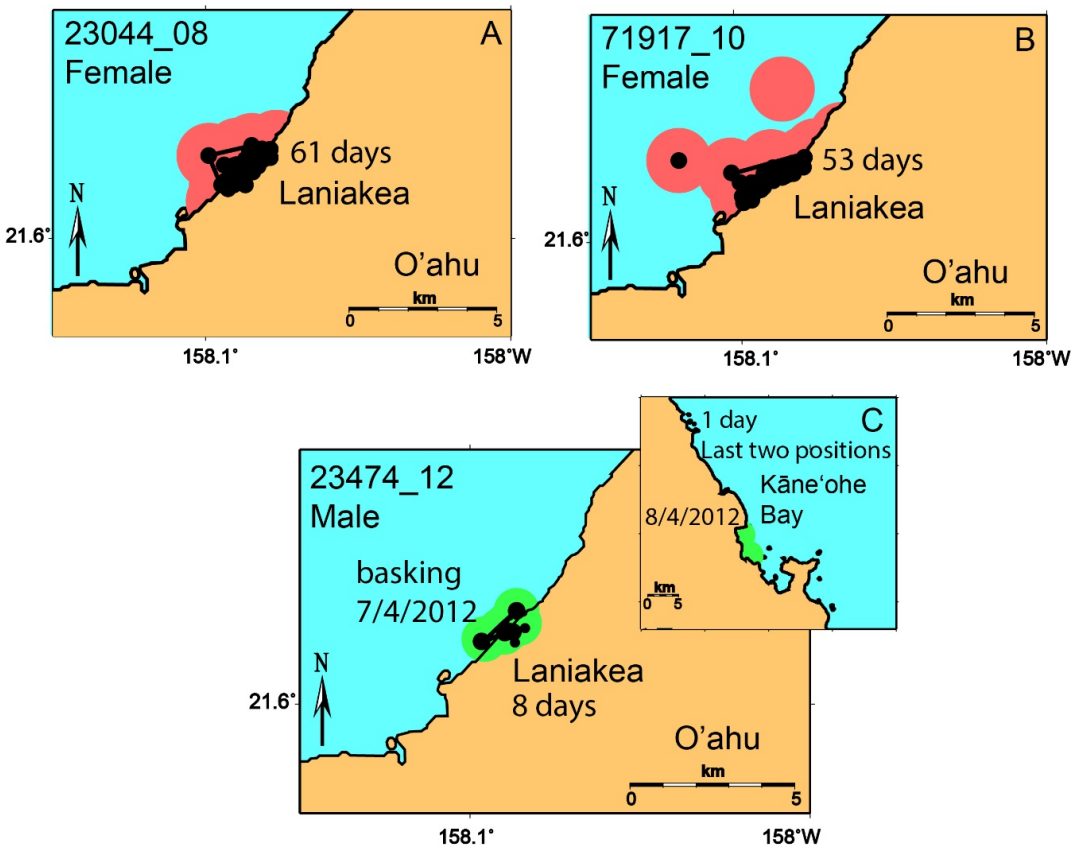

Figure 10 A-C. Home ranges for two females and one male green turtle at the Laniakea, O'ahu foraging area prior to their migration to French Frigate Shoals. Large colored circles indicate 1 km radius around each position. Black circles indicate positions with LC 1, 2 or 3 data. Black lines outline the Minimum Convex Polygons for Minimum Home Range areas. Male 23474 moved to Kāne'ohe Bay after initially returning to Laniakea.

Table 1. 1992-2014 Satellite tagging specifics, turtle size, sex, and dates and locations of release. SCL = straight carapace length, CCL = curved carapace length. FFS = French Frigate Shoals.

Argos ID_YR	Satellite Tag model	Other tags	Duty cycle (hrs on/off)	Carapace length (cm)	Sex	Release date	Release location
4800_92	ST-3	H142, W491	6/6	87.0 SCL	F	6 Aug 1992	East Is, FFS
4801_92	ST-3	A858, F509	6/6	85.0 SCL	F	6 Aug 1992	East Is, FFS
4802_92	ST-3	7560, F157	10/50	91.0 SCL	F	1 Aug 1992	East Is, FFS
4803_93	ST-3	U273	6/6	90.1 SCL	F	30 Aug 1993	East Is, FFS
4804_93	ST-3	U204	6/6	90.4 SCL	F	25 Aug 1993	East Is, FFS
22125_95	ST-3	-	6/6	86.0 SCL	M	7 Jun 1995	East Is, FFS
22132_95	ST-3	A769	6/6	98.0 SCL	F	7 Jun 1995	East Is, FFS
22133_95	ST-3	6038	6/6	87.0 SCL	M	23 Sep 1995	East Is, FFS
24195_97	ST-14	Coil, A734	3/3	94.0 SCL	F	7 Sep 1997	East Is, FFS
24196_97	ST-14	6T	3/3	81.8 SCL	F	8 Sep 1997	East Is, FFS
24197_98	ST-14	746T	3/3	95.0 SCL	F	9 Sep 1997	East Is, FFS
24198_98	ST-14	15T	3/3	87.5 SCL	F	10 Sep 1997	East Is, FFS
24192_98	ST-14	Coil	6/6	99.7 CCL	F	2 Sep 1998	East Is, FFS
24194_98	GeoBar-14	-	9/3	101.5 CCL	F	2 Sep 1998	Tern Is, FFS
25694_98	ST-14	Coil	9/3	101.6 CCL	F	3 Sep 1998	East Is, FFS
4800_98	GeoBar-14	-	9/3	97.8 CCL	F	3 Sep 1998	East Is, FFS
53762_14	TAM-2639	4C3C602F5C	6/24	87.8 SCL	F	15 Aug 2014	East Is, FFS
23044_08	ST-24	413E195E1C	6/24	87.5 SCL	F	6 Feb 2008	Laniakea, O‘ahu
71917_10	TAM-2619	4233400066	6/24	87.0 SCL	F	5 Mar 2010	Laniakea, O‘ahu
23474_12	TAM-4410	442E084F24	6/48	80.3 SCL	M	2 Mar 2012	Laniakea, O‘ahu

Table 2. 1992-2014 Summary of satellite tracking, foraging pasture locations and their estimated home ranges. Missing data are specified by a hyphen. FFS = French Frigate Shoals.

Turtle ID	Days before leaving	Travel time (days)	Days at Final Location	Travel Distance (km)	Rate of Travel (km/hr)	Final Location	Total Days Transmitting	Minimum Home Range LC 1, 2, 3 data (km^2)	Full Home Range (km^2)
4800_92	10	26	104	1130	1.8	Kāne‘ohe, O‘ahu 21.5N, 157.8W	140	20.4	65.8
4801_92	6	26	255	1260	2.0	Kāne‘ohe, O‘ahu 21.5N, 157.8W	287	11.0	175.0
4802_92	38	16	145	830	2.2	Johnston Atoll 16.7N, 169.5W	199	-	138.6
4803_93	7	24	192	1180	2.0	Kāne‘ohe, O‘ahu 21.5N, 157.8W	223	4.1	80.9
4804_93	8	25	103	1100	1.8	Kāne‘ohe, O‘ahu 21.5N, 157.8W	136	4.8	77.5
22125_95	4	29	168	1050	1.5	Pānahāhā, Moloka‘i 21.0N, 156.9W	201	-	0.1
22132_95	3	22	262	1050	2.0	‘Ewa, O‘ahu 21.3N, 158.0W	287	19.4	56.6
22133_95	12	30	12	1200	1.7	Kahului, Maui 20.9N, 156.5W	54	-	22.2
24195_97	17	94	2	3936	1.7	Mākaha, Kaua‘i 22.1N, 159.7W	113	-	6.5
24196_97	91	59	119	1721	1.2	Keaukaha, Hawai‘i 19.7N, 155.0W	269	0.8	57.3
24197_98	16	11	-	541	2.0	Unknown	27	-	-
24198_98	5	38	97	1297	1.4	Kahului, Maui 20.9N, 156.5W	140	0.1	23.6
24192_98	9	32	79	1351	1.7	Kahului, Maui 20.9N, 156.5W	120	17.6	43.8
24194_98	18	25	219	1166	1.9	Kahului, Maui 20.9N, 156.5W	262	2.2	63.2
25694_98	7	16	314	997	2.5	‘Ewa, O‘ahu 21.3N, 158.0W	337	10.2	113.0
4800_98	17	30	242	1279	1.8	Lahaina, Maui 20.9N, 156.7W	289	-	16.9
53762_14	2	24	10	1125	1.9	Kahului, Maui 20.9N, 156.5W	34	-	21.6
23044_08	61	28	40	1615	2.4	FFS 23.7N, 166.1W	129	1.2 (Laniakea; 21.6N, 158.1W)	-
71917_10	53	28	72	1461	2.2	FFS 23.7N, 166.1W	153	1.4 (Laniakea; 21.6N, 158.1W)	-
23474_12	8	34	52 at FFS, 61 to O‘ahu	2039	2.5	Kāne‘ohe, O‘ahu 21.5N, 157.8W	155	0.2 (Laniakea; 21.6N, 158.1W)	-

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