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Destination Revealed: Post-Nesting Migrations of Hawksbill Turtles (*Eretmochelys imbricata*) from Moso Island, Republic of Vanuatu [1]

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Abstract— Hawksbill turtle (*Eretmochelys imbricata*) nesting populations and behaviors in the Republic of Vanuatu are poorly understood. In an effort to evaluate their internesting home range, post-nesting migration and foraging habitat home ranges, 7 post-nesting hawksbill turtles were satellite tagged at Moso Island, Republic of Vanuatu between January 2018 and January 2020. The mean internesting home ranges of two turtles was 0.8 km^2 proximal to their nesting beach indicating possible value in establishing a marine protected area along the north coast of Moso Island during the nesting season. The Great Barrier Reef, Australia and New Caledonia were the two major post-nesting destinations. Hawksbill turtles are legally protected by law in both countries. Foraging home ranges for 4 hawksbill turtles in New Caledonia and Aneityum Island, Vanuatu ranged from 1.7 to 28.9 km^2. It will be important to continue this study to better determine the total area of habitat utilization of the internesting hawksbills at Moso Island in order to facilitate the implementation of community-based conservation measures and to illuminate home range location and size.

Introduction

Hawksbill turtles (*Eretmochelys imbricata*) are critically endangered throughout most if not all of their range in the south-western Pacific Ocean (Mortimer & Donnelly 2008, Work et al. 2020). In this region, the resident population size and the number of nesting female hawksbills are poorly understood but the apparent trend is toward declining numbers in most areas. Reports indicate the Solomon Islands' largest hawksbill rookery is showing signs of recovery after the establishment of the Arnavon Community Marine Conservation Area (Hamilton et al. 2015, Hausheer 2017, Holland 2017, Vuto et al. 2019, Hamilton et al. 2021).

Nesting hawksbills in Vanuatu have been shown to come from forage grounds as far away as Northern Australia (Parmenter 1983, Miller et al. 1998, Bell et al. 1999, 2012, Read et al. 2015, Bustard, 2016). Siota (2015) lists two Vanuatu hawksbill recoveries from animals flipper tagged

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outside of the country. One, tagged near Lizard Island, Northern Great Barrier Reef (NGBR), Australia in 1997, was harvested in NW Espiritu Santo Island, Vanuatu in 2006 and the other was tagged in Samoa in 2007 and recovered in Vanua Lava, Vanuatu in 2007. One nesting hawksbill tagged at Bamboo Bay, Malekula Island, Vanuatu in 2009 was recovered stranded on the beach at Brooms Head, New South Wales, Australia in 2010. Mitochondrial DNA analysis demonstrated that there was a significant difference in allele frequency between feeding populations of Great Barrier Reef hawksbills and adjacent rookeries indicating that they came from distant breeding populations (Broderick et al. 1994). While it was once speculated that most hawksbills nest within a few hundred kilometers of their forage grounds, as is the case in Hawaii and the Seychelles, (Meylan 1999, Mortimer & Balazs 1999, Parker et al. 2009), we now know that there are instances where they travel more than 2000 km between nesting and forage areas (Van Dam et al. 2008, Hamilton et al. 2015, 2021). More recent satellite tracking of 29 nesting hawksbills in the Solomon Islands has shown that the NGBR is the home range/forage grounds for the majority of those tracked (Hamilton et al. 2021).

The Republic of Vanuatu, composed of 82 inhabited islands, has a resident population of hawksbills that is not well enumerated and a migratory population of adult hawksbills that nest on many of the islands in small numbers. Important documented nesting locations to date appear to be the Wiawi Village area (16.15° S, 167.23° E) and Bamboo Bay (16.42° S, 167.40° E), both on west Malekula Island, and Moso Island (17.53° S, 168.25° E) off Efate Island in Central Vanuatu. There are from 7 to 58 nests per year at each site (Siota 2015). Overall, Vanuatu is estimated to have approximately 300 hawksbills nesting annually (Mortimer & Donnelly 2008).

The Department of Environmental Protection and Conservation (DEPC) is now part of the Ministry of Climate Change Adaptation, Meteorology and Geo-Hazards, Environment, Energy and Disaster Management, Republic of Vanuatu. The DEPC has a wide range of initiatives to protect and conserve the environment and biodiversity in the archipelago through the Environmental Management and Conservation Act (EMCA) of 2003, but it is challenging to centrally manage the dispersed islands of an archipelago with unique cultural and environmental characteristics of the various islands of the Republic, and by the large area that needs to be covered and administered. There are fisheries regulations prohibiting the take of marine turtles except for permitted cultural uses, or keeping them in captivity unless permitted for research, tourism/education or head-start programs. Data are collected on turtle by-catch by the offshore tuna fishery through a Fisheries Observer Program. The Vanuatu National Environment Policy and Implementation Plan (2016-2030) (NEPIP) charges the DEPC to carry out the plans set forth in the document. Among those plans is the conservation of biological, ecosystem, genetic, human and cultural diversity which includes creating and managing conservation and protected areas.

In an effort to better understand the internesting movements, post-nesting migratory routes and home forage grounds of hawksbills that nest on Moso Island, Telonics^{tm} Argos and Iridium satellite tags were attached to seven post-nesting hawksbill turtles between January 2018 and January 2020. Here we present findings of internesting movements, post-nesting migration and home ranges of these turtles. This high-value information can help inform and direct national, international and traditional/community management efforts.

Materials and Methods

Nesting beaches on the northwest coast of Moso Island, Vanuatu (17.52° S, 168.24° E), were monitored during the night between 1/10/2018 and 1/13/2018, 1/8/2019 and 1/11/2019 and 1/7/2020 and 1/12/2020 to locate nesting hawksbills. Teams of two or three people walked the beaches every two hours commencing after sunset to look for ascending turtle tracks. Red lights were used to minimize the possibility of disrupting turtle behavior. If tracks were observed and a nesting turtle was found, the turtle was allowed to complete nesting and begin moving back to the water before being safely and harmlessly restrained on the nesting beach using a plywood box container (in accordance

with stipulations in Marine Resource Scientific Research Permit number VAN 001-RES-18 provided by the Vanuatu Fisheries Department and Bioprospecting Permit VAN-ENV-03419 issued by the Department of Environmental Protection and Conservation). Once safely restrained, curved carapace length (CCL) and curved carapace width (CCW) measurements were recorded. Flipper tags, if present, were recorded and, if tags were not present, titanium flipper tags (Secretariat of the Pacific Regional Environment Program (SPREP), PO Box 240 Apia, Samoa) were applied to the left and right front flipper (Table 1). Each turtle was given a name by one of the Moso Island villagers as a way to "personalize" the study.

Argos satellite-linked transmitters, TAM 2640 (placed on 4 turtles) made by Telonics, Inc. (Mesa, Arizona, USA) or Telonics TGW-4370-4 Iridium GPS tags (placed on 3 turtles) were safely and securely attached to the second or third central scute using UV activated polyester resin and fiberglass cloth following the procedures described by Balazs et al. (1996). The percentage increase in drag resulting from the attached transmitter was <5% as calculated from the cross-sectional area and based on the shape of tag (Jones et al. 2013). After the satellite tags were attached and the polyester resin hardened sufficiently (approximately 1.5 hours after capture) the post-nesting females were released. All turtles moved directly back to the ocean after release.

The TAM 2640 tags were programmed with a duty cycle of 6 hours on and 24 hours off to promote increased battery life. Argos satellites relayed location data to ground stations and locations were calculated by measuring the Doppler shift of the transmitter signals. Location data were made available through CLS America (https://Argos-system.clsamerica.com). Argos location accuracy is defined by Argos as follows (LC = location code): LC 3 better than 250 m radius, LC 2 better than 500 m radius, LC 1 better than 1500 m radius and LC 0 over 1500 m radius. There is no assigned accuracy value for LC A and LC B. Despite having no assigned value for accuracy, Argos Location Classes A and B were used in the track calculations and were rejected only if they (1) showed the animal on land, (2) gave a speed of travel over 5 km/h, or (3) the position demonstrated a turn of greater than 90 degrees from the previous direction over a 24-hour period (Parker et al. 2009, Luschi et al 1998).

Telonics SeaTrkr-4370-4 Iridium GPS tags communicate directly with Iridium Satellites and utilize Telonics QFP (Quick Fix Positioning) through the use of Telonics Data Converter software (TDC). The SeaTrkr tags take GPS positions every hour with an accuracy of 9-12 m with all QFP positions reported through email and analyzed by the TDC (Tomkiewicz et al. 2010, Figgener et al. In prep). The TDC software labels any questionable positions as unresolved or uncertain. All unresolved and uncertain positions were removed from the data set. Argos doppler data were uploaded to Movebank (Kranstauber et al. 2011, Wikelski et al. 2018) (https://movebank.org) and tracks were calculated using the Douglas Argos filter (Douglas et al. 2012) to limit the number of implausible locations based on user specified parameters. The same data were also uploaded to ZoaTrack (Dwyer et al. 2015) (https://zoatrack.org) and tracks were calculated using the Argos Kalman filter. Because most locations were of the LC A or B class, it was impossible to calculate rate of movement except in a general sense for total distance and total time of travel. The date of departure from the nesting area until the date of arrival at forage grounds or the date of the last location was used to calculate the total time of travel. Distance traveled was determined by linking the accepted location data with straight line measurements to arrive at a total distance traveled. Average rate of travel (km/h) was calculated using the total distance traveled (km) and total time of travel (h). The values thus obtained are only rough estimates of the true rate of travel because of the low accuracy LCs. The data from the TDC output was uploaded to ZoaTrack and plotted (Dwyer 2015). Spatial and temporal Zoatrack analysis modules were utilized to analyze track distances, rates of travel, areas of utilization and diel rates of movement in home ranges.

Home range was calculated for 4 of the 7 turtles using ZoaTrack's Spatial Analysis to compute a fixed kernel density area (termed the Kernel Utilization Distribution, KUD) at the 95% and 50% level (Calenge 2006).

Results

Destination Great Barrier Reef

Lucy (164957) was captured on January 9, 2018 and a Telonics TAM 2640 Argos satellite tag was attached. She departed Moso Island on 1/26/2018 approximately 17 days after tag attachment and, most likely, after nesting one more time (Witzell 1983, Dobbs et al. 1999). She traveled in a west-southwest direction, skirting around the northern tip of Grande Terre, New Caledonia before crossing the Coral Sea to Australia's Great Barrier Reef (Fig. 1a). The final position was received on 3/22/2018 approximately 7 km from Collins Island in the Broad Sound Islands National Park, Australia. The total distance traveled was 2073 km in 55 days at an average speed of 1.6 km/h (Table 1).

Teslaba (164949) was captured on January 12, 2018 and a Telonics TAM 2640 Argos satellite tag was attached (Table 1). She did not provide any locations until 2/12/2018, one month after tag deployment on 1/12/2018. The reason for this delay is unknown. On 2/12/2018, when we first received a location transmission, Teslaba was 145 km WNW of Moso Island. Back tracking at the calculated rate of travel (1.9 km/h) indicates that she probably left Moso Island on 2/09/2018. This date seems very plausible as it would allow two more nesting events to occur at 14 day intervals. The last recorded position for Teslaba was on 3/29/2018 when she was roughly 226 km east of Cape Melville National Park Australia (Fig. 1a). She traveled 2259 km in 50 days at an average speed of 1.9 km/h. The track ended before she reached her forage grounds but it is likely her destination was the Northern Great Barrier Reef area of Australia.

Pansiko (164950) was captured on January 12, 2020 and a Telonics TAM 2640 Argos satellite tag was attached (Table 1). Pansiko departed the Moso Island nesting area on 1/13/20, one day after tagging. She traveled in a westerly direction past the northern end of New Caledonia and into the Coral Sea. The last recorded location for Pansiko was on 2/25/20 when she was positioned approximately 360 km east of the Australian coastline and in line with an earlier track taken by Lucy (164947) (Fig. 1a). She traveled 1708 km in 43 days at an average speed of 1.7 km/h. Transmissions ended short of the Australian coast but it seems likely that she was headed for the Southern Great Barrier Reef area of Australia.

Destination New Caledonia and Vanuatu

Three of the remaining four post-nesting hawksbills equipped with satellite tags traveled from Moso Island to New Caledonia and one traveled from Moso Island to Aneityum Island, the southernmost inhabited island in the Vanuatu archipelago.

Ethana (164948) was captured post-nesting on 1/9/2018 and a Telonics TAM 2640 Argos satellite tag was attached (Table 1). She had metal tags in each of her front flippers. Tags R35177 and R35178 were applied by Tassiriki Village members on December 13, 2006 on Moso Island. Notes at the time of tagging, indicate that she did not lay eggs. Her CCL was 87.5 cm in 2006 and 2018 showing no growth in 12 years (Table 1).

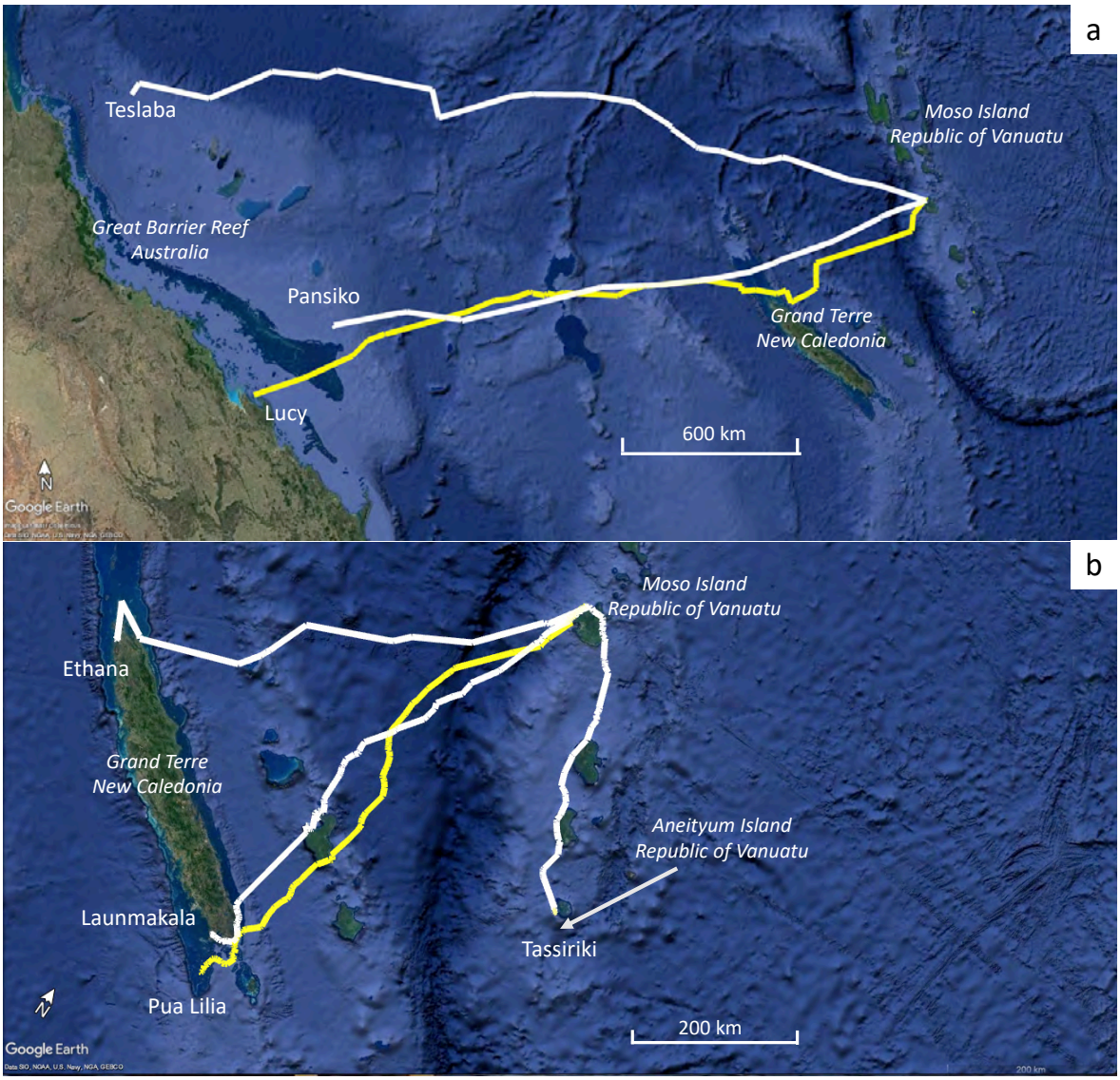

Figure 1. a. Post-nesting migration of Lucy (164957-yellow line), Teslaba (164949) and Pansiko (164950) from Moso Island, Republic of Vanuatu to the region of the Great Barrier Reef, Queensland, Australia. b. Post-nesting migration of Ethana (164948), Launmakala (713459), Pua Lilia (704626A-yellow line) and Tassiriki (713458) from Moso Island, Republic of Vanuatu to New Caledonia and Aneityum Island, Republic of Vanuatu.

Table 1. Tagging information, transmitter life, migration time, distance, speed and transmitter life for seven post-nesting satellite tracked hawksbill turtles. LFF = left front flipper, RFF = right front flipper. CCL & CCW = Curved Carapace Length & Width Respectively

Tag # & Turtle Name	Tag Type	No. of days Transmitting	Date Captured	Date Released	Release Location	CCL CCW (cm)	Flipper Tags	Postnesting Migration to Forage Grounds				
								Departure to Forage Grounds	Arrival at Forage Ground	No. of Days Migrating	Travel Distance (km)	Speed (km/h)
164957 "Lucy"	Telonics TAM 2640	71	1/9/18	1/9/18	17.5221^0 S 168.2347^{0}E	CCL = 88.0 CCW = 81.0	LFF-R56249 RFF-R56250	1/26/18		55	2073	1.6
164949 "Teslaba"	Telonics TAM 2640	78	1/12/18	1/12/18	17.5221^0 S 168.2397^0 E	CCL = 89.0 CCW = 80.0	LFF-R56248 RFF-R56247	2/09/18		50	2259	1.9
164950 "Pansiko"	Telonics TAM 2640	44	1/12/20	1/12/20	17.5205^{0}S 168.2589^0 E	CCL = 100.0 CCW = 95.0	LFF-R40763 RFF-R40764	1/13/20		43	1708	1.7
164948 "Ethana"	Telonics TAM 2640	256	1/9/18	1/10/18	17.5197^0 S 168.2461^0 E	CCL = 87.5 CCW = ?	LFF-R35190, LFF- R35177, RFF-R35189, RFF-R35178	1/26/18	2/7/18	12	536	1.9
704626A "Pua Lilia"	Telonics SeaTrks 4370-4	699	1/9/19	1/10/19	17.5221^0 S 168.2399^0 E	CCL = 94.0 CCW = 87.2	No Tags Applied	3/07/19	3/28/19	21	689	1.4
713459 "Launmakala"	Telonics SeaTrks 4370-4	626	1/7/20	1/7/20	17.5221^0 S 168.2404^0 E	CCL = 87.0 CCW = 77.0	LFF-R49320 RFF-R49321	1/11/20	2/2/20	22	599	1.1
713458 "Tassiriki"	Telonics SeaTrks 4370-4	518	1/8/20	1/9/20	17.5221^0 S 168.2396^0 E	CCL = 94.5 CCW = 85.5	LFF-R40015 RFF- R40016	2/8/20	2/20/20	11	378	1.4

Ethana's trip to her foraging ground is organized into two segments due to ARGOS tag inaccuracies during the second leg of her trip. Ethana departed Moso Island on 1/26/2018 15 days after satellite tag attachment, suggesting she nested one more time. Upon departing the island, she traveled in a west south-west direction toward the northern tip of New Caledonia reaching its northeast coast on 2/7/2018. During this phase of her trip, she traveled at an average speed of 1.9 km/h for a total distance of 536 km (Fig. 1b, Table 1). Between 2/8/2018 and 2/17/2018 Ethana traveled north, around the northern tip of New Caledonia and then south down the coast to Nehoue Bay (20.34° S, 164.13° E) where she took up residence on 2/17/2018 (Fig. 1b). The total distance for this portion of the track was approximately 107 km and took 10 days. The total travel distance and time from Moso Island to Nehoue Bay, New Caledonia was estimated to be 643 km and 22 days. Because of position inaccuracies during the second segment, overall average speed was calculated using data from the first segment only. She was tracked for 234 days in Nehoue Bay. Ethana's 95% home range KUD was 28.9 km^2 and the 50% home range KUD was 5.7 km^2 (Fig. 2a, b).

Pua Lilia (704626A) was captured post-nesting on January 9, 2019 and a Telonics SeaTrkr Iridium GPS satellite tag was attached (Table 1). She was released on January 10, 2019 and remained in the vicinity of the nesting grounds until her departure on March 7, 2019 (Table 1). Positional data (Fig. 3b) indicates she nested an additional 4 timesafter release on 1/10/19 (1/23/19, 2/6/19, 2/20/19 and 3/6/19) at 14 day internesting intervals. Her internesting movements showed a maximum travel distance of 2.4 km from the middle of the nesting area. The 95% KUD area was 1.2 km^2 and the 50% KUD area was 0.04 km^2 (Fig. 3a). Her activity level during the internesting period was very low with increased swimming activity about 2 days before and after nesting (Fig. 3b) (Bell & Parmenter 2008).

On March 7, 2019, Pua Lilia departed Moso Island, headed around the north-east side of Efate Island and moved into open waters to the south south-west. She passed along the southern tip of Lifou, Loyalty Islands, Province of New Caledonia and past the southern tip of Grand Terre, New Caledonia arriving at her home forage grounds on March 28, 2019 after traveling 689 km in 21 days at an average speed of 1.4 km/h (Fig. 1b, Table 1). Her tag continued transmitting from her home range until 12/10/2020 (624 days). Pua Lilia's 95% home range KUD was 7.4 km^2 and the 50% home range KUD was 2.0 km^2 (Fig. 2c, d).

Launmakala (713459) was first detected nesting on January 7, 2020. A Telonics SeaTrkr Iridium GPS satellite tag was attached (Table 1). She was safely released on January 7, 2020. Launmakala spent 4 days post-tagging in the waters near the nesting beaches prior to departing Moso Island on January 11, 2020. Her path of travel took her along the northwest side of Moso Island, around the west coast of Lelepa Island, along the eastern shores of Efate and, on January 14, 2020, she left the shores of Efate and headed southwest toward the Loyalty Islands (Fig. 1b). On January 22, 2020, she arrived at the northern shore of Lifou Island. She spent 6 days traveling along the west coast of Lifou Island before departing in a southerly direction on January 28, 2020. Two days later, she arrived on the southeastern shore of Grand Terre, New Caledonia. She traveled south along the shoreline, rounding the tip of southern New Caledonia, swimming westerly and crossed the mouth of Prony Bay into the Canal Woodin. After traveling for 22 days, she ended her journey along the southern shore about 1 km west of the Phare du Canal de Woodin (Woodin Lighthouse) on February 2, 2020 (Fig. 1b). Launmakala had traveled 599 km over those 22 days at an average speed of 1.1 km/h (Table 1). Launmakala's 95% home range KUD was 1.7 km^2 and the 50% home range KUD was 0.2 km^2 (Fig. 2e, f).

Tassiriki (713458) was first detected on January 8, 2020 and a Telonics SeaTrkr Iridium satellite tag was attached (Table 1). She was released on January 9, 2020 (Table 1). Tassiriki remained in the nesting beach area for four subsequent weeks and likely nested two more times before departing to the south of Efate Island (Fig. 3d). She successfully nested prior to capture on 1/8/20 and position data indicates that she came ashore very near the 1/8/20 nest site to nest again on 1/24/20 (16 days later). After that, she remained in the vicinity and appears to have nested again on 2/7/20 (14 days

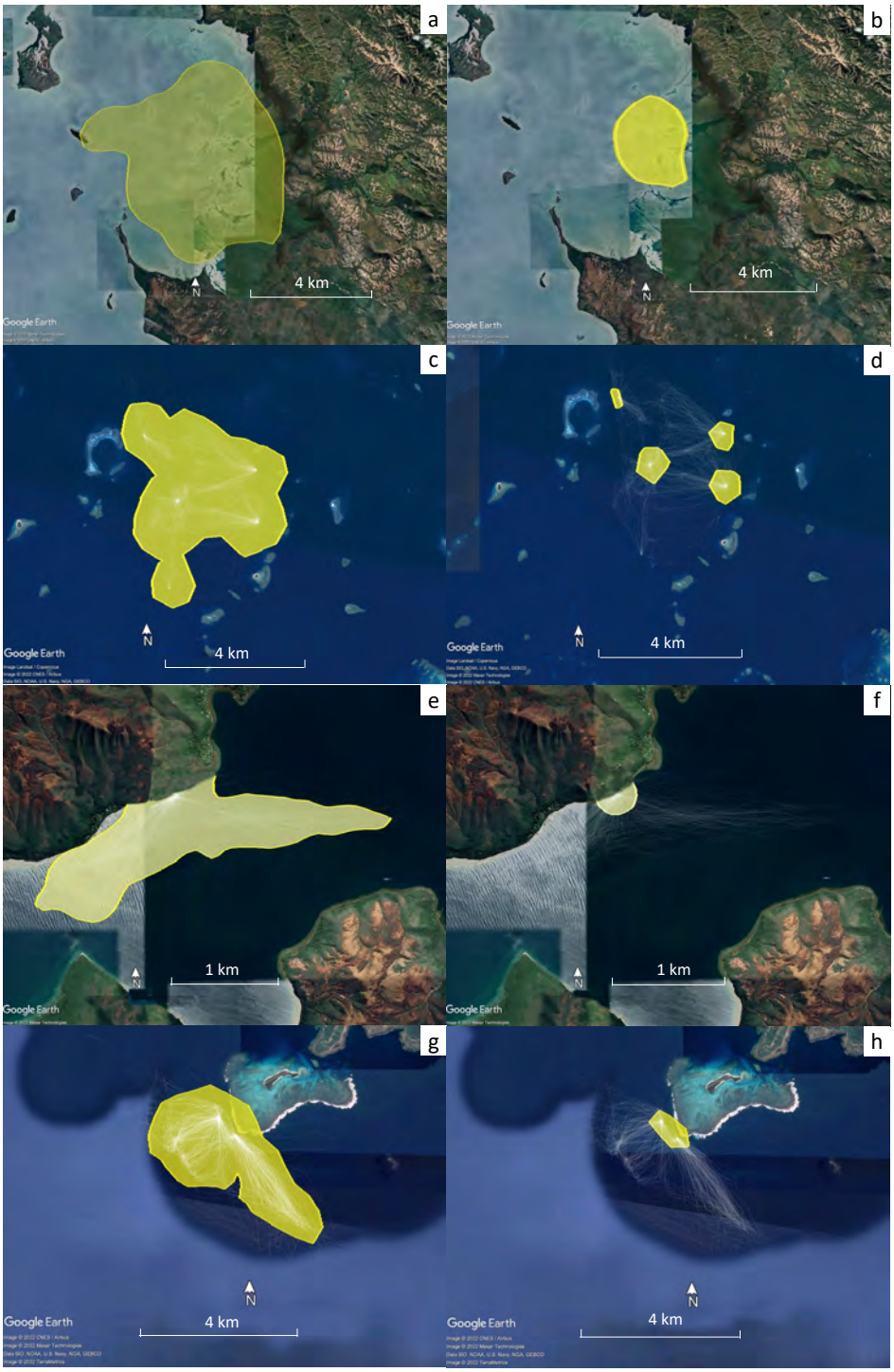

Figure 2. Home range calculations for four post-nesting hawksbills tagged on Moso Island, Republic of Vanuatu using the kernel utilization distribution (KUD) estimator. a. 95% KUD = 28.9 km^2 and b. 50% KUD = 5.7 km^2 for Ethana (164948). c. 95% KUD = 7.4 km^2 and d. 50% KUD = 2.0 km^2 for Pua Lilia (704626A). e. 95% KUD = 1.7 km^2 f. 50% KUD = 0.2 km^2 for Launmakala (713459). g. 95% KUD = 7.4 km^2 and h. 50% KUD = 0.6 km^2 for Tassiriki (713458).

later) approximately 100 m to the west of the 1/8/20 nest. All three nests were within 100 m of each other. The 95% KUD for her internesting movements was 0.3 km^2 and the 50% KUD was 0.009 km^2 (Fig. 3c).

Tassiriki departed Moso Island on February 8, 2020 and traveled east along the coast of Efate before departing into open water at the eastern most point of the island. Her track was south-southeast to Erromango Island which she skirted on the west side. She crossed the 37 km channel to Tanna Island and skirted along the west coast of that island before swimming across the remaining 64 km to Aneityum Island. Tassiriki arrived at her home forage grounds (20.26° S, 166.76° E) on February 20, 2020 after traveling for 11 days at an average speed of 1.4 km/h covering a total distance of 378 km (Fig. 1b, Table 1). Tassiriki was tracked in her home forage grounds for 507 days and the 95% KUD was 7.4 km^2 and the 50% KUD was 0.6 km^2 (Fig. 2g, h).

Launmakala and Tassiriki showed a distinct diel movement pattern in their home ranges indicating that they were resting at night and active (foraging) during the day. Fig. 4 shows examples of the distance traveled between location fixes for each of the turtles. The regions of the graph where the distance between fixes is at or near zero indicates that the turtle is not moving with the inference being that it is resting. The portions of the graph showing distances between fixes above zero indicates active movement (foraging, swimming). Pua Lilia had periods of similar behavior but also showed increased activity at night.

Discussion

Great Barrier Reef Turtles

The three post-nesting hawksbills that traveled toward the GBR, their suspected home foraging grounds, traveled in excess of 1700 km during their homeward migration (Table 1). The path taken by Teslaba (Fig. 1a) was by a northerly route which may have carried her into the North Vanuatu Jet where she could take advantage of the westerly flow (Choukroun et al. 2010). Her calculated speed of travel was 1.9 km/h.

Lucy and Pansiko traveled a more southerly route moving west south-west across the northern tip of New Caledonia, passing between Chesterfield Islands and Bellona Reef and onward toward the Great Barrier Reef. This area of the Coral Sea is marked by less directed currents and more counter-clockwise eddies. The mean rate of travel for Lucy and Pansiko was 1.6 km/h .

All three GBR bound turtles traveled a relatively direct route at a higher average rate of speed in contrast to the other 4 turtles that traveled shorter distances. The post-nesting migratory paths across the Coral Sea indicate the turtles were crossing busy shipping lanes (https://www.marinevesseltraffic.com/CORAL-SEA/ship-traffic-tracker), one near the north-west end of New Caledonia and the other near the east coast of Australia. Once they reached the GBR, where they are listed as critically endangered by the IUCN and vulnerable by the Australian Environment Protection and Biodiversity Conservation Act 1999 and the Queensland Nature Conservation (Wildlife) Regulation 1994, they should be relatively safe from human impacts.

The duration of satellite transmissions for all three GBR bound turtles was short and we are not certain what their ultimate destination was within the GBR. Why the Telonics™ TAM 2046 tags failed so early in the migrations is uncertain although antenna or other physical damage is a distinct possibility (Parker et al. 2014, Hart et al. 2021).

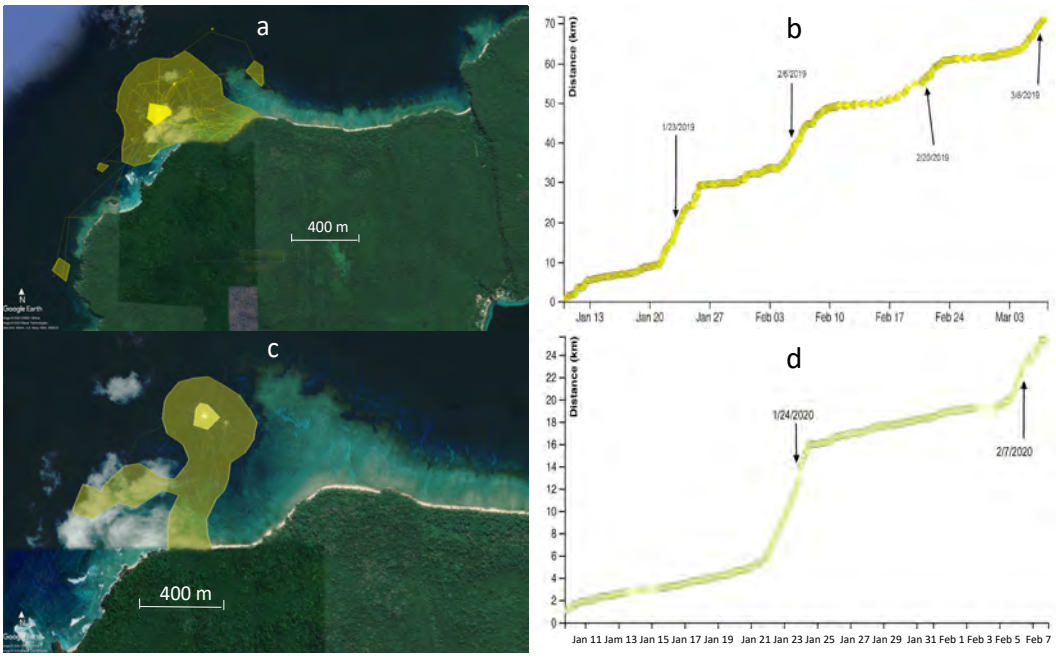

Figure 3. a. Internesting movements of Pua Lilia (704626A) between January 10, 2019 and March 7, 2019 off Moso Island, Republic of Vanuatu. The 95% KUD (light yellow) = 1.2 km^2 and the 50% KUD (dark yellow) = 0.04 km^2. b. The sum of the minimum distance moved between consecutive location fixes for Pua Lilia. The increased slope of the distances indicates increased swimming activity and correlates in each case with the time before and after the suspected nesting dates. c. Internesting tracks and KUD for Tassiriki (713458) from January 8, 2020 to February 8, 2020. The 95% KUD (light yellow) = 0.3 km^2 and the 50% KUD (dark yellow) of 0.009 km^2. d. The sum of the minimum distance moved between consecutive location fixes for Tassiriki. The increased slope of the distance traveled indicates increased swimming activity and correlates in each case with the time before and after the suspected nesting dates.

New Caledonia and Vanuatu Turtles

Internesting Home Range

Two of the seven satellite tagged turtles (Pua Lilia and Tassiriki) had sufficient accurate data to enable calculation of internesting KUD. The internesting 95% KUD for the turtles was 1.2 km^2 and 0.3 km^2 for Pua Lilia and Tassiriki, respectively (Fig. 3a,c). These values for Moso Island hawksbills are in the same range as those reported around Barbados (Walcott et al. 2012). This is in contrast to internesting areas of between 13 and 31 km^2 for East Pacific hawksbills (Gaos et al. 2012). In the Dominican Republic, internesting home ranges from 21 to 64 km^2 were reported (Revuelta et al. 2015). In the US Virgin Islands, Hart et al. (2019) reported internesting home ranges from 9 to 525 km^2. Undoubtedly, habitat variability and methodology have an influence on home range calculations and size but it is important to note that the two turtles for which there are home range tracks and KUD calculations remained very close to shore, in shallow water and in a very small area during their entire time we were able to track them. This has positive implications for community efforts to protect nesting hawksbill turtles during the nesting season.

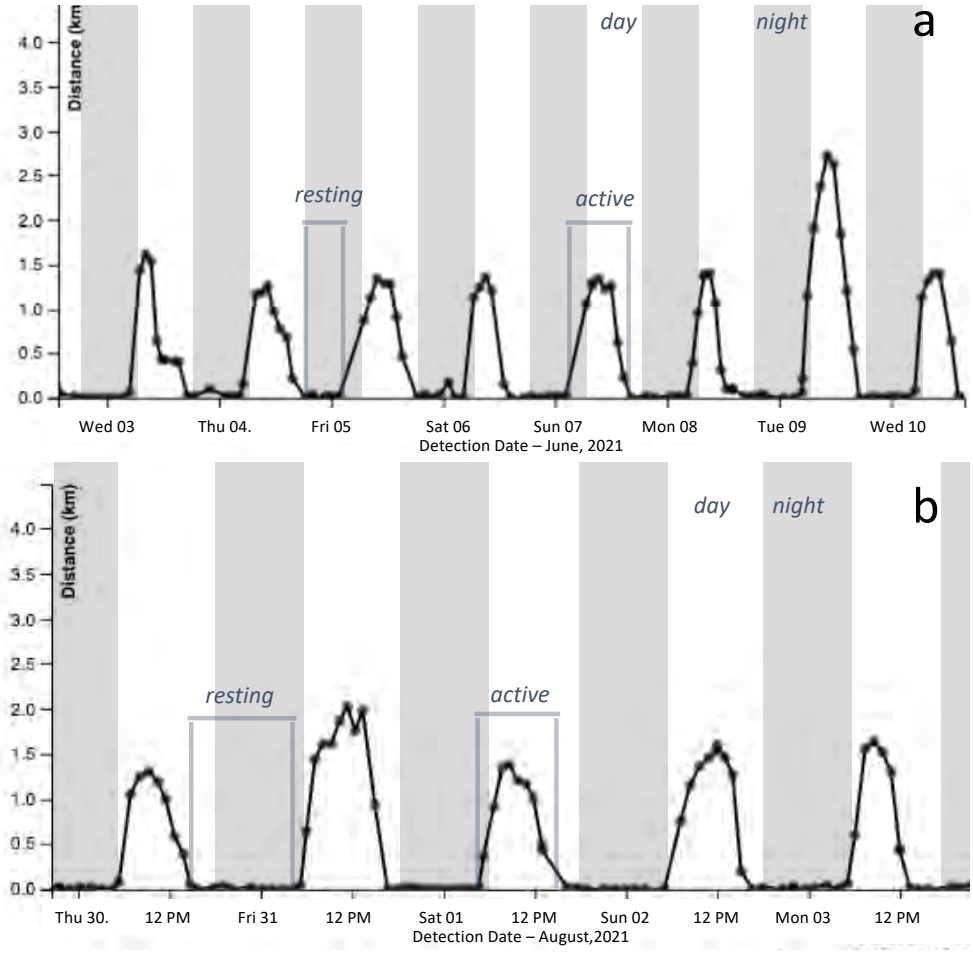

Figure 4. a. Example of typical diel movement of Launmakala in her forage grounds showing period of near zero nocturnal movement indicating resting behavior and periods of positive diurnal movement indicating swimming and foraging behavior. b. Example of typical diel movement of Tassiriki in her forage grounds showing periods of near zero nocturnal movement indicating resting behavior and periods of positive diurnal movement indicating swimming and foraging behavior.

Post-Nesting Migrations

Three of the 7 tagged post-nesting hawksbills migrated from Moso Island to New Caledonia. Ethana (carrying a TAM 2640 Argos tag) gave very intermittent, low accuracy locations and it was impossible to discern her precise track. It is estimated that she moved fairly quickly (1.9 km/h) from Moso Island to the east shore of northern New Caledonia and then slowed down and moved along the New Caledonian coastline toward her home range in Nehoue Bay (Fig. 1b). Her relatively high rate of travel could have been aided by the prevailing currents (Southern Fiji Jet and Southern Vanuatu Jet currents).

Pua Lilia and Launmakala traveled at average speeds of 1.4 km/h and 1.1 km/h respectively. Both intersected the Loyalty Islands and slowed down as they meandered along the north and south coastline of Lifou Island for a period of nearly 8 days (Launmakala – 0.5 km/h) and 2 days (Pua Lilia

– 0.6 km/h). In open water (Efate to Lifou and Lifou to Grand Terre, New Caledonia) their travel speeds ranged from 1.6 to 2.2 km/h.

Tassiriki is the only one of the 7 satellite tagged hawksbills that remained in the Vanuatu Archipelago. As with Ethana, Launmakala and Pua Lilia, Tassiriki traveled along the shorelines of Efate, Erromango and Tanna Islands (Fig. 1b) at a slower speed than she did when crossing open water (mean of 0.85 km/h in coastal waters and 2.0 km/h in the open ocean). Her overall average speed was 1.4 km/h. The meandering nature of these tracks in coastal areas may indicate that the turtles were resting and/or feeding during their time in shallow waters.

Forage Home Ranges

Four of the 7 turtles transmitted long enough to establish definitive home ranges (Fig. 2a-h). Ethana provided relatively inaccurate position classes and, as a result, may have an inflated home range (95% KUD = 28.9 km^2) compared to the other three (Pua Lilia, Launmakala and Tassiriki) that were outfitted with Telonics SeaTrks 4370-4 GPS tags which provide much higher position resolution (average 95% KUD home range area of these three was 5.5 km^2). Other regions of the world report larger home range areas for hawksbills (Hart et al. 2012, Hawkes et al. 2012). The relatively small home ranges of these three turtles again have implications for conservation and protection at the forage grounds for hawksbills in New Caledonia and Vanuatu (Shimada et al. 2020). The very large Natural Park of the Coral Sea created in 2014 by the Government of New Caledonia, offers protection for those hawksbills that traveled to New Caledonia in a way similar to the protection offered through Australia's GBR Marine Park and other associated acts. It is also the case that turtles consumed under a traditional take permit in New Caledonia are only green turtles (*Chelonia mydas*) (Richard Farman, personal communication, February 11, 2020).

CONSERVATION CONSIDERATIONS

The government of the Republic of Vanuatu has passed legislation banning the take or trade of leatherback turtles (*Dermochelys coriacea)* due to concerns regarding the status of this species (Fisheries Act No. 55 of 2005). This Act also prohibits interference with any nesting turtle or disturbing turtle nests including taking, selling or purchasing turtle eggs. It also made it illegal to use any weapon to capture, kill or destroy any turtle species as traditionally they are caught by hand. Fisheries regulations were passed in 2009 that closed earlier loop-holes and basically made the killing of any sea turtle illegal, as well as prohibiting holding any marine turtle in captivity (unless under permit) while allowing a provision for traditional harvest of turtles through application to the Department of Fisheries. These legal instruments were in addition to earlier work to involve traditional leaders, clans and families in the protection of sea turtles subsequent to the SPREP sponsored "Year of the Turtle" in 1995. This educational effort led to the formation of a turtle monitoring network in Vanuatu (now called Vanua-tai) (Petro 2002) to encourage monitoring and conservation at the community level. This is highly significant for management purposes given the difficulties in enforcing central government regulations throughout an archipelago, as well as traditional marine tenure rights held in Vanuatu that allows reef custodians to control access and harvesting activities on their reefs. It should also be noted that marine turtles are highly valued by most of the cultural groups found within Vanuatu and they had a number of traditional strategies to manage them (Hickey 2007). In 2015 a Vanuatu National Action Plan of Sea Turtles (NPOA Turtle) was completed as a policy document that seeks to further protect, conserve and manage sea turtles in Vanuatu's waters and also applies to all other jurisdictions where Vanuatu flag fishing vessels operate (Vanuatu Fisheries Department, 2015). All these efforts have helped strengthen turtle management but there is still an unknown amount of harvesting of foraging and nesting hawksbills and the gathering of eggs from nesting hawksbills (as well as other turtle species). The efforts to improve conservation are continuing as the Vanua-tai network expands to more islands, north and south of Efate, resulting in more community

awareness about turtle management and placing of taboos on the harvest of eggs and turtles (Johannes & Hickey 2004).

Successful conservation and management of such a highly migratory species is very difficult without a framework of international cooperation and effort. It is important to know where post-nesting hawksbills migrate to in order to initiate contact with governmental agencies, non-governmental organization and local communities to begin the necessary negotiations to insure appropriate and effective management of the species (Hawkes et al. 2012).

While the Republic of Vanuatu has enacted legal protections for marine turtles, enforcement remains an issue. Given the remoteness of some areas of the archipelago, enforcement will be an issue for the foreseeable future until positive community involvement through networks like the Vanua-tai and traditional governance is strengthened at the community level to facilitate decentralized conservation efforts (Vuki et al. 2000, Miller et al. 2020). To further strengthen the management of sea turtles in Vanuatu, the government of Vanuatu, with the support of SPREP, is currently coordinating a review of the management and conservation of turtles in Vanuatu amongst key stakeholders.

In the case of nesting hawksbills on Moso Island, our data indicate that it might be feasible and effective to establish local taboo areas under the traditional leaders of Moso to protect them during their time in Moso Island waters. It would also be very useful to re-invigorate the Vanua-tai network on Moso, which has waned over the last decade, so as to assist in monitoring turtle nesting activities, and compliance with existing legislation. One or two of the Vanua-tai members could also be trained by the Fisheries Department and appointed as Community-based Authorized Officers (CBAO) to work within the two communities on Moso island towards this goal. The CBAO may assist by investigating any breaches of the fisheries legislation and follow this up with the Vanuatu Fisheries Department. The internesting KUD is very small so a relatively small traditionally closed area might effectively encompass the entire internesting area.

It will be very important to continue to gather data on internesting home ranges with more satellite tag deployments for Moso Island nesting hawksbills in order to further establish the necessary size and potential efficacy of such a closed area to seasonally protect nesters and their nests. Additional tag deployments would also provide useful data on foraging areas as well as migration routes that are also highly relevant to improving turtle population management.

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