

Habitat Use of the Anahulu River, Oahu, Hawaii, by Hawaiian Green Turtles (*Chelonia mydas*)

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INTRODUCTION:

The Hawaiian green turtle (*Chelonia mydas*) is a genetically distinct population that resides exclusively within the confines of the 2400 km long Hawaiian archipelago (Dutton et al. 2008; Frey et al. 2013). The species was listed as Threatened under the United States Endangered Species Act in 1978 and the population has steadily increased over the last 40 years at an estimated growth of 5.4% per year (Balazs, et al. 2015). Where once seeing a green turtle in the coastal waters of the main Hawaiian Islands was a rarity, today they are commonly seen and, indeed, turtle viewing is a very popular tourist activity.

The Hawaiian green turtle protection and concurrent population increase has meant that we find green turtles in areas and environments where they were not previously seen. An example of adaptive invasion of unusual habitats is found at Kiholo Bay on the Big island where green turtles migrate up a 75 m long shallow canal to enter old Hawaii brackish water fish ponds (loko i'a) to feed and rest (Lee et al., 2014). Another example is on Oahu where turtles pass through drainage channels/culverts to access tidal ponds where they feed and rest on the west shore of the island. On the north shore of Oahu is another habitat where green turtles utilize an area that is adjacent to their normal shoreline habitat, the Anahulu River near Hale'iwa Harbor, Hale'iwa, Hawaii (21.594017⁰ N, 158.103485⁰ W).

Over the years since protection was instituted and the population began to increase, green turtles have started using the 1.4 km riverine estuary of the Anahulu River, moving into and up the river, sometimes in large numbers. As high as 270 turtles have been counted entering over a 2-hour period (Clarke, et al, 2011). While we do have some estimation/count of green turtles entering and leaving the river, we do not know how often individual green turtles enter the river, patterns of entry or exit, nor how long they spend in the river. For this research, acoustic tags/receivers were used to study the use of this unusual habitat by 15 green turtles. Tags attached to the turtles allowed us to detect their presence and rough location within the confines of the 1.4 km of the Anahulu River that is available to them.

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THE STUDY AREA:

The Anahulu River drains the Anahulu River watershed of 44.1 Km² with a maximum elevation of 867 m (Parham et al., 2008). The watershed land use classifications are listed as approximately 70% conservation, 28% agricultural and 2% urban. Anahulu River is perennial with a total length of 103.9 km and is classified as a 3rd order stream. The lower estuarine portion of Anahulu Stream is 1.4 km in length and ranges in width from 20 m to 40 m with a total area of 4.4 hectares. The stream has a maximum depth of approximately 4 meters at high tide near the ocean entrance but further upstream the depth does not exceed 2 meters at high tide. The estuarine stream bottom is comprised of gravel and anoxic fine sediment with significant presence of H₂S in many areas (personal observation).

The Anahulu watershed and the lower reaches of the Anahulu estuary are subject to high rainfall events that cause excessive runoff over relatively short periods of time (one or two days). These events often result in flow volumes of 10 to 15 X 10³ cfs and gauge heights up to 4.5 m (Figure 1). During these periods the stream is characterized by very strong currents and heavy sediment loads (USGS, 2003).

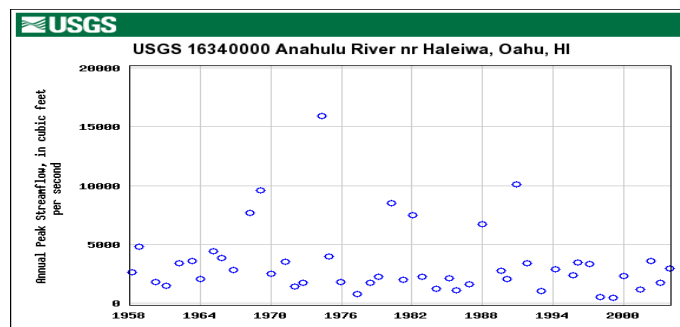


Figure 1. Peak flow events for Anahulu Stream (river) from 1958 to 2003.

The Anahulu stream empties into Waialua Bay adjacent to the Hale'iwa Boat Harbor and south of Hale'iwa Beach Park. The stream normally carries a heavy load of sediment and tannins from the watershed runoff and decaying organic matter. Visibility is usually no more than 1 meter and declines significantly during periods of high runoff. Outside of heavy freshwater runoff from the Anahulu watershed, the waters flow quietly and water levels are predominately influenced by tidal fluctuation. Tidal flux in Hawaii ranges from -0.05 m to 0.93 m. The entrance to Anahulu River shows an accumulation of sandy sediment which, depending on the runoff and ocean wave conditions, can be as narrow as 5 meters at low tide to as wide as 20 meters at high tide. The depth of the entrance at low tide can be less than .1 m. Correspondingly, at high

tide the depth would be approximately .5 to 1 m in depth. The lower 1.4 km of the river is an estuary with a salt water wedge extending up all the way to the point of the third bridge (21.593 N, 158.093 W) (Clarke et al., 2011).

The Anahulu River has become an important tourist destination for kayaking and stand-up paddle boarding. Tourists rent equipment from a store on Hale'iwa Beach and paddle up the river to the end of the estuary. Often, there are 15-20 people on the river at mid-morning and early afternoon (personal observations).

The fauna of the lower Anahulu River is characterized by euryhaline species like mullet and various crustaceans, annelids, mollusks and poriferans. The benthic marine flora is very sparse because of the high sediment load/low light penetration and repeated scouring by high runoff events. The banks of the river are primarily lined with mangrove trees (*Bruguier sp.*) except where there are houses fronting the river. (Allen et al., 2000)

Of particular note is the presence of a fairly large number of green turtles (*Chelonia mydas*) in the "navigable" portion of the river. Turtles are observed moving in and out of the entrance of the river at all times of the day with an apparent increase in movement during the early morning and late evening periods. In order to develop a better understanding of the movements of the turtles into and out of the river and to where they go in the river, sonic monitoring stations were deployed and 15 hypersonic tags were attached to the carapace of 15 green turtles. The data presented here is the result of the sonic monitoring that occurred over a period of 16 months from October 2016 to February 2018. A severe runoff event in February 2017 destroyed and/or relocated several of our sonic receivers. Subsequent to February 2017, the study area was not totally covered by 5 receiver stations but station 1 remained active and functional throughout the study.

MATERIALS AND METHODS:

Turtle Capture and Tagging

(<http://akepa.hpa.edu/~mrice/turtle/Anahuluweb/images/ariver.html>)

On Oct. 16, 2016 a NOAA/HPA tagging team assembled at the mouth of the Anahulu River to capture green turtles (*Chelonia mydas*) and attach Vemcotm V13-1L 60 sec delay sonic transmitters (length 36m, diameter 13mm, weight in water 6g, Vemco, Bedford, Nova Scotia, Canada) to their carapace. The transmissions were at 69 kHz and were emitted randomly every 30 to 90 seconds as pulse trains of closely spaced pings which uniquely identify each turtle. The V13-1L have a nominal battery life of 845 days The sonic transmitters were attached to the third right or third left lateral scute of the turtle using the methods described by Balazs, et al. (1996).

Turtles were captured using a 50 m long, 35 cm mesh tangle net that was placed across the entrance to the Anahulu River. The capture team monitored the net continuously and, when a

turtle struck the net, it was quickly and safely brought to shore and placed in an animal carrier. Under a shaded canopy, captured turtles were measured and external Inconel tags (National Band and Tag Company, Newport, Kentucky) were applied to the left and right hind flippers (Balazs, 1999). The left or right 3rd lateral scute and surrounding area was dried and sanded prior to the attachment of a V13-1L acoustic transmitter (Figure 2). Once the attachment had thoroughly hardened, the turtle was safely and harmlessly released back into the river. The total time for the capture, tag attachment and release was approximately 1.5 hours (Table 1).

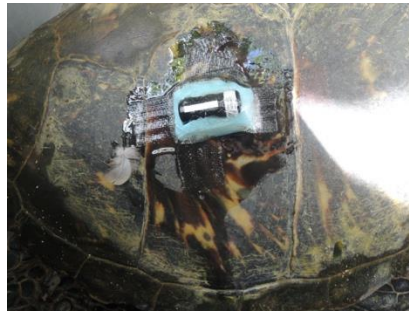


Figure 2. Attachment of Vemco V13-1L acoustic transmitter to the third lateral scute using a silicon elastomer base, fiberglass cloth and polyester resin. Note the one end of the tag was left uncovered so that sonic transmissions could occur.

The VR2W acoustic monitoring system (Vemco, Bedford, Nova Scotia, Canada) was used to monitor the acoustically tagged turtles. VR2W receivers were attached to 5/8" polypropylene rope using stainless steel hose clamps and heavy-duty zip ties and anchored using 3/8" chain attached to two 8" x 8" x 16" (~30 lbs. each) cinder blocks. The line was kept afloat using a commercial closed cell foam float. Signs were attached to the floats so that kayakers and paddle boarders would not move the devices. The receivers were placed in the center of the river halfway along each of the three straight stretches of the 1.4 km long Anahulu River estuary (Figure 3). Test runs were made up and down the river by boat with V13-1L acoustic transmitters to determine that the tags could be detected at all locations along the river. Our tests showed that there were no "blind" spots from the mouth to the very upper end of the river. An additional VR2W receiver ("OB") was placed outside of the river mouth at the entrance to the Hale'iwa small boat harbor (Figure 3). The OB receiver was attached directly to a fix weight on the bottom and was used to detect / confirm entry and exit of turtles into and out of the Anahulu River proper.

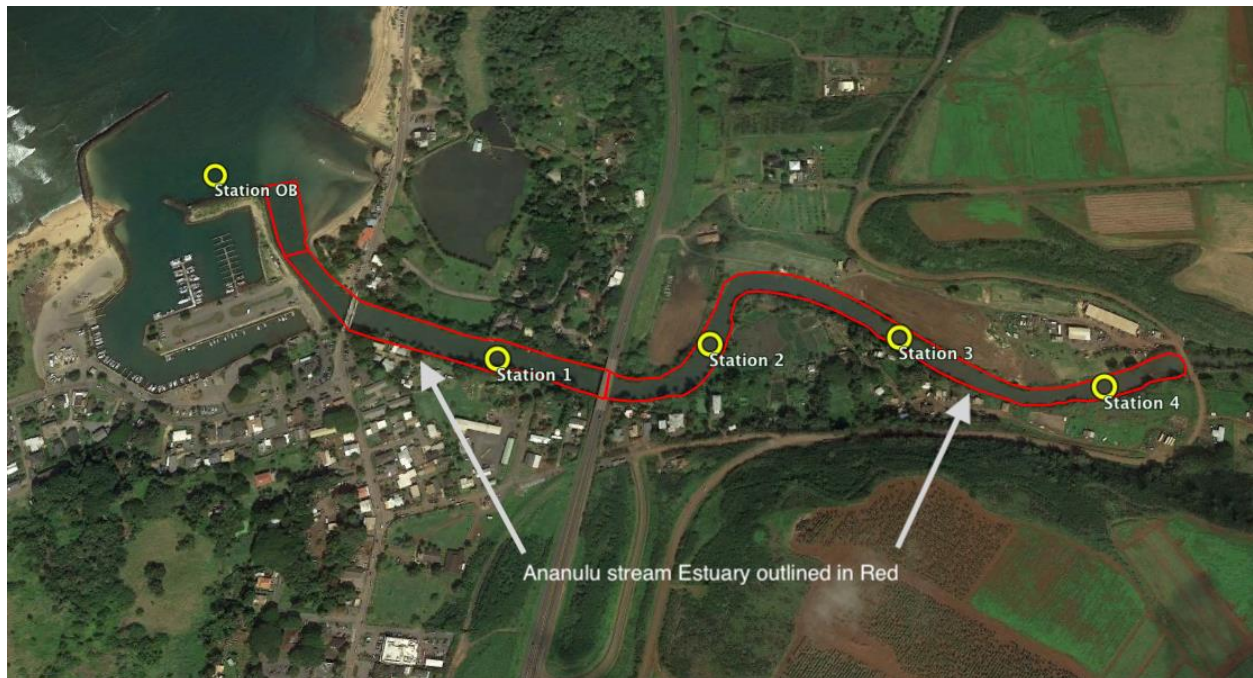


Figure 3. Anahulu stream estuary outlined in red. Vemco VR2 Receivers and HOBO salinity data logger stations are denoted by yellow circles.

Data from the VR2W receivers were downloaded by bringing the receivers into a boat and syncing with them using VUE Vemco™ software via bluetooth. Data files from each station were saved and added to a consolidated VUE database after each download. Detection data were analyzed with VUE, Excel, Access (SQL) and File Maker Pro software to determine presence and absence of turtles in the Anahulu River estuary.

RESULTS:

The Anahulu stream estuary can be characterized as a typical riverine estuary with a salt water wedge extending up 1.4 km to the point where the stream becomes shallow and the bottom is substantially above the high-high tide level. Salinity varies from 0 to 29 ‰ at one meter off of the bottom. The average salinity decreases from station 1 to station 4 (26 ‰ to 16 ‰). Perhaps of more importance to green turtles using the estuary as part of their habitat are the extreme runoff events where total flow volume can become very high (USGS National Water Information System, 2003)(>15,000 cubic feet/sec) almost certainly making the entire 1.4 km uninhabitable by turtles. These events are fairly short lived and the estuary returns to a low flow with a normal temperature and salinity regimen.

From February 2017 to February 2018 there were several flash flood events that we were able to capture on a HOBO water level data logger (HOBO water level logger U20L-01, Onset

Computer Corp.). Figure 4 shows one such extreme runoff event that occurred on 2/28/17. The rest of the water level values are reflective of the mixed diurnal tides characteristic of the Anahulu stream estuary. Temperature and water level statistics during this same period (Figure 4) are shown in Table 3. The high water levels and low temperature values are the result of these extreme run off events. Average temperature variations over time are small and may be more directly linked to seasonal variation.

Table 1. Information regarding sonic tagged turtles and detection information from VR2W receivers in the Anahulu River from 10/25/2016 to 2/13/2018.

TURTLE ID NUMBER	SCL (CM)	Wt (KG)	Date Tagged	Transmitter	Date First Detected	Date Last Detected	Total Detections	Detection Span (days)
407D27655D	79.5	72.0	10/25/16	A69-1601-55417	10/25/16	2/13/18	36640	476
4527306808	60.7	28.5	10/26/16	A69-1601-55414	10/26/16	2/7/18	39429	469
Z313	89.8	106.3	10/27/16	A69-1601-55410	10/27/16	7/29/17	25951	275
4627552B61	57.5	24.6	10/26/16	A69-1601-55421	10/26/16	6/14/17	43040	231
8999	79.1	64.0	10/26/16	A69-1601-55415	10/26/16	6/11/17	22657	228
45234C786B	78.8	63.6	10/26/16	A69-1601-55407	10/26/16	6/9/17	75434	226
8995	72.4	50.4	10/26/16	A69-1601-55408	10/26/16	5/7/17	23881	193
45241D0E17	51.3	22.0	10/25/16	A69-1601-55420	10/26/16	1/22/17	9566	88
4524705807	56.9	25.0	10/26/16	A69-1601-55409	10/26/16	1/22/17	13662	88
45254C1248	69.6	43.8	10/26/16	A69-1601-55412	10/26/16	1/19/17	14079	85
45266A206E	85.6	98.6	10/25/16	A69-1601-55419	10/25/16	1/15/17	8469	82
45255A7C5D	84.7	84.7	10/26/16	A69-1601-55413	10/26/16	1/8/17	3039	74
8997	64.7	39.6	10/26/16	A69-1601-55416	10/26/16	12/28/16	6905	63
Z306	66.1	44.0	10/27/16	A69-1601-55411	10/27/16	12/26/16	5779	60
4526682A7B	72.1	54.1	10/25/16	A69-1601-55418	10/25/16	12/10/16	6493	46

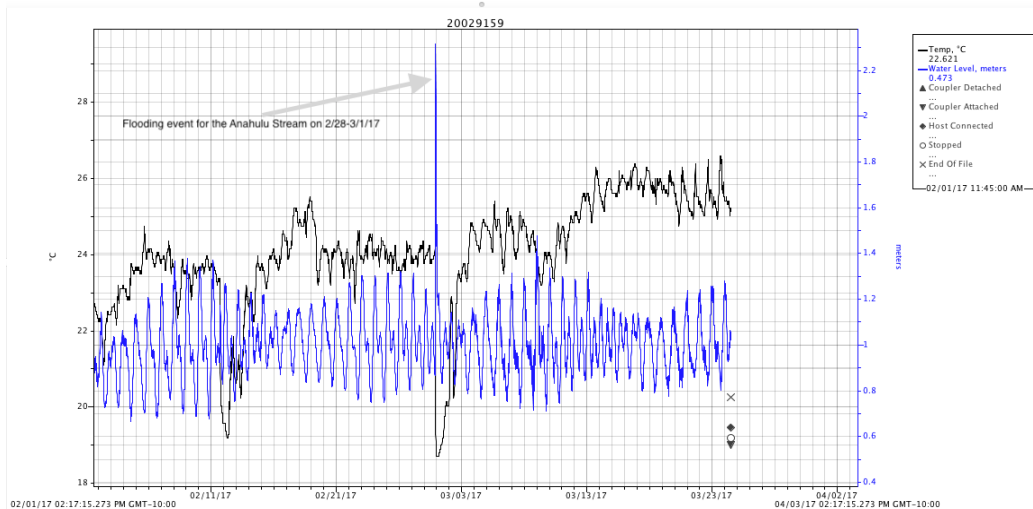


Figure 4. Temperature and water level data for Anahulu stream between 2/1/17 and 3/24/17. The extreme runoff event occurred on 2/28/17 after high rainfall in the watershed area and resulted in a typical high-volume flow for a short period of time.

Table 2. Temperature and water level statistics for three data logging periods using the HOBO Water level logger (U20L-01). These three periods cover 377 days.

Time Period	Max/Min Temp (C ⁰)	Max/Min Water level (m)	Avg temp (C ⁰)	Avg. water level (m)
2/1/17-3/24/17	26.6/18.71	2.3/0.7	24.04	1.0
3/24/17-9/01/17	29.9/21.0	1.6/0.6	26.6	1.1
9/01/17-2/13/18	29.0/19.4	1.6/0.5	24.8	1.0

Salinity values in the Anahulu stream estuary exhibit a typical salt water wedge that extends up the full 1.4 km of the lower portion we consider estuarine. Salinity/temperature loggers were placed at each of the 4 stations (Figure 3) at a distance of .5 meter off of the bottom. Data from two of the data loggers during the 2/28/17 flood event are shown in Table 3. The flood washed away stations 1 and 3 and they were never recovered. There were several events of freshwater run off that pushed the salt water wedge out of the estuary for short periods of time with a concomitant lowering of temperature. Once the event was over, the salt water wedge would reestablish itself within a couple of days. Figure 5 is from station 4, nearest to the upper end of the estuary and shows the most impact from fresh water runoff and the lowest salinity values.

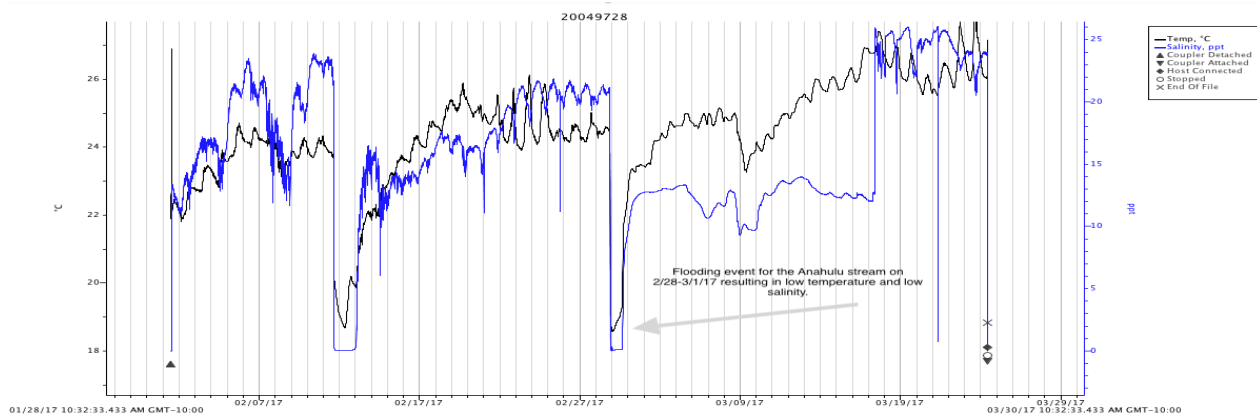


Figure 5. Salinity and temperature data from Station #4 from 2/1/17 to 3/24/17. This period encompasses water level values in Figure 4 above.

Table 3. Salinity and temperature statistics for salinity loggers at stations 2 and 4. Stations 1 and 3 were lost during the flood of 2/28/17.

Time Period	Station Number	Max/Min Temp (C ⁰)	Avg temp (C ⁰) ± SD	Max/Min Salinity (o/00)	Avg. Salinity (o/00) ± SD
2/1/17-3/24/17	2	27.6/18.8	24.4 (±1.3)	27.1/0.0	21.5(±5.0)
2/1/17-3/24/17	4	28.3/18.6	24.4 (±1.63)	26.1/0.0	16.2 (±5.7)

All 15 sonic tagged turtles were detected multiple times in the Anahulu river. The longest period of detection was for turtle 417 (16 months) and the shortest was for 411 and 416 (2 months). The average length of detection was 6 months (Table 1). On a monthly basis the 15 tagged turtles spent a varying percentage of their time in the river. Table 4 shows the monthly percent presence when detected for each of the 15 tagged turtles, mean percent presence by turtle and mean percent presence by month (Table 4). The mean percent of time spent in the river by detection of individual turtles on a monthly basis ranged from 0.07% to 56.3%. The mean percent presence over time of individual turtles in the river is shown in Figure 6.

Table 4. Compilation of percent presence as indicated by sonic detections in the Anahulu River of each of 15 sonic tagged turtles by turtle and by month. February 2017 was an extreme flood event and all data was lost for that month and is not considered in the calculations.

Turtle Number	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	Mean % presence in river/month	N	Standard Deviation	max	min
November, 2016	36.1	19.2	14.6	17.8	9.6	26.9	4.0	28.9	21.8	8.1	22.2	31.1	12.1	27.4	47.9	21.8	15	11.04	48	4
December, 2016	47.2	16.8	27.7	15.6	14.5	12.0	0.0	9.8	15.3	12.9	24.6	28.7	10.1	10.8	38.3	18.9	15	12.25	47	0
January, 2017	50.7	21.4	11.8	13.5		0.7	6.3	15.7	11.5		4.2		16.7	26.7	38.0	18.1	12	14.45	51	1
February, 2017																				
March, 2017	52.9	12.0		18.7				56.3	43.9		35.3				22.3	34.5	7	17.37	56	12
April, 2017	47.1	17.8		11.0				29.3	11.9		5.3				11.3	19.1	7	14.49	47	5
May, 2017	43.3	5.9		6.9				26.5	24.9		5.9				9.1	17.5	7	14.44	43	6
June, 2017	44.4			6.4				12.9	40.2		10.0				44.4	22.8	6	18.04	44	6
July, 2017				3.5				33.1			10.8				33.1	15.8	4	15.39	33	4
August, 2017								1.1			6.7				6.7	3.9	3	3.26	7	1
September, 2017								13.2			6.7					9.9	2		13	7
October, 2017								8.6			20.7					14.7	2		21	9
November, 2017								11.5			8.6					10.1	2		12	9
December, 2017								9.5			5.2					7.4	2		10	5
January, 2018								5.3			6.9					6.1	2		7	5
February, 2018											24.2					24.0	1			
Mean % presence by turtle	46.0	15.5	18.0	11.7	12.0	13.2	3.4	18.7	24.2	10.5	13.2	29.9	12.9	21.6	27.9					

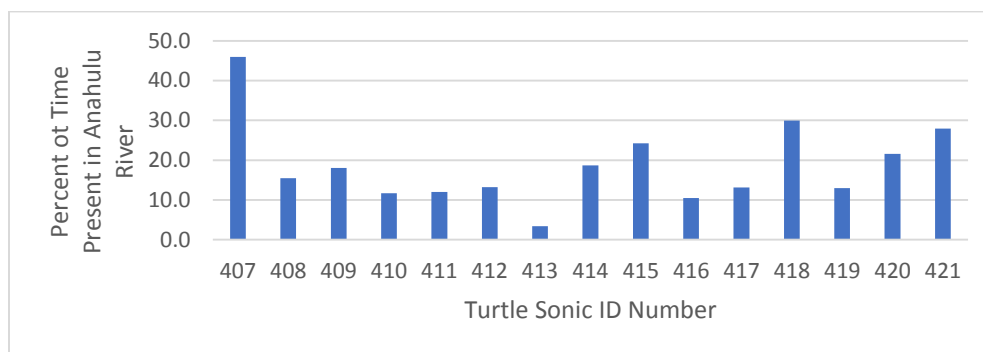


Figure 6 The mean percent presence of individual turtles in the river during the period over which each was detected.

Because of the turbidity of the water, there were no visual observations of our tagged turtles and it was impossible to know their exact location in the river when they were detected by the VR2W receivers. Based on our earlier testing we knew that a sonic tag would not be detected by more than one receiver at a time so when a particular receiver (Station 1 for example) detected a tag/turtle we knew that the turtle was in that stretch of water which was a total of .6 km long. Station 2 covered .2 km, Station 3 covered .4 Km, Station 4 covered .2 km and Station 5 covered .05 km (see Figure 3). Figure 7 shows the number of detections for each turtle at the 5 receiver stations and Figure 8 combines the data from all turtles to give the number of detections at each station. The information on where turtles preferred to be in the river is based on the number of detections at each station understanding that this is only a rough estimate of where they were located. Based on the information shown in Figures 7 and 8, Stations 1 and 2 received the majority of detections with the number of detections dropping off rapidly at Stations 3-5. As might be expected, our sonic tagged turtles spent the majority of

their time in the lower part of the river with detections there accounting for over 81% of all detections.

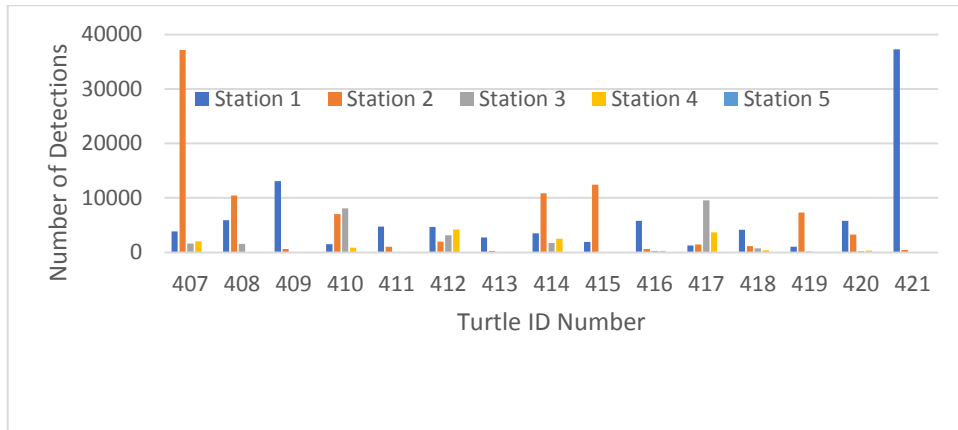


Figure 7. Number of detections received at each station (1 through 5) for each sonic tagged turtle.

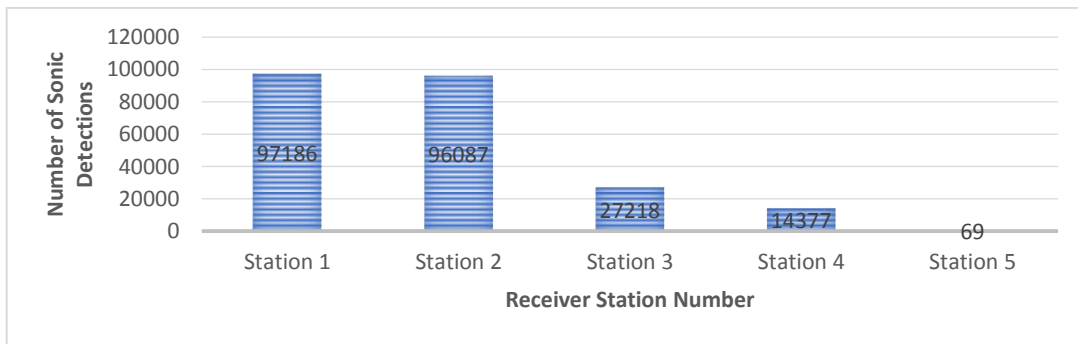


Figure 8. Combined detections for all turtles at each of the 5 receiver stations over the period of the study.

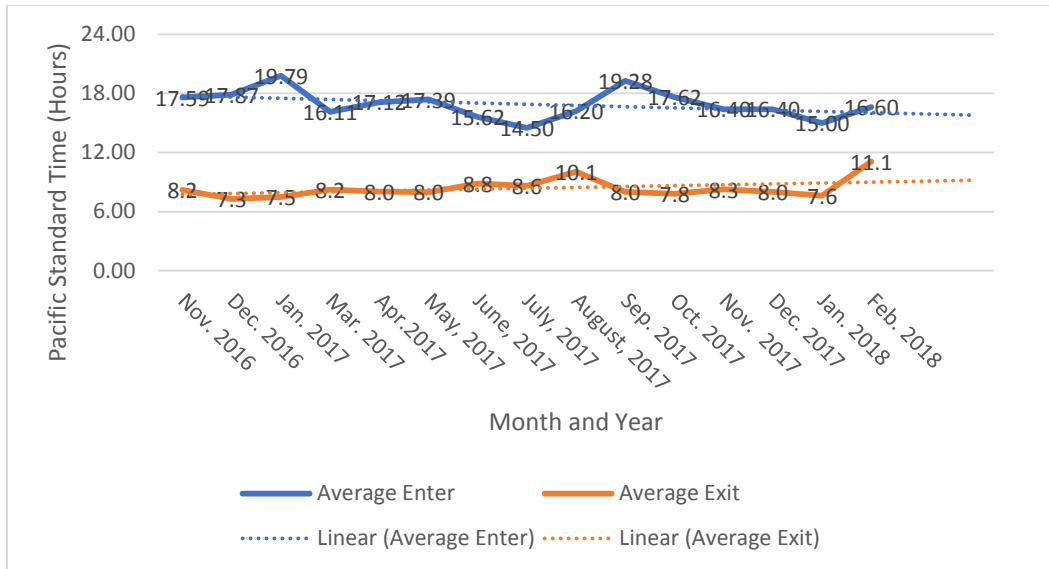


Figure 9. Mean monthly times of entry into and exit out of the Anahulu River of 15 sonic tagged turtles from November 2016 to February 2018.

As was outlined by Clarke et al (2011) there is a clear diel migratory behavior for green turtles that spend time in the Anahulu River. Our data confirmed this and shows that the mean time of exit by our sonic tagged turtles from the Anahulu River to the ocean was 0822 h and the mean time of entry was 1654 h. Turtles were detected entering and leaving in small numbers at all times of the day and night when the entry channel was open and accessible. Figure 9 shows the monthly mean times of entry and exit of sonic tagged turtles while Figure 10 shows that some of our sonic tagged turtles were present at all times of the diurnal cycle with a definite crepuscular rhythm.

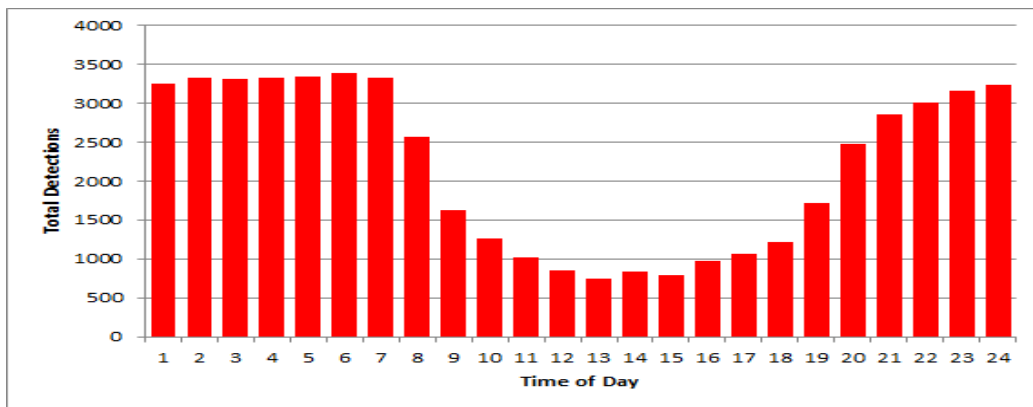


Figure 10. Detections at Station 1 from October 25, 2016 to February 15, 2018 showing that all 15 turtles were detected at all times of the day with a definite diel nocturnal preference.

DISCUSSION:

The Anahulu River Estuary represents a unique and unusual habitat for Hawaiian green turtles. Juvenile, sub-adult and adult green turtles move in and out of the river on a regular basis at all hours of the day. It has been shown that the movement of turtles out of the river environment is most active during the morning hours when turtles move out to feed in their more customary marine habitats. It appears that many green turtles that exit the bay in the morning will return to enter the bay in the early to late afternoon hours and spend the night in the river. This type of diurnal migration is also seen at other sites in Hawaii that involve migration into estuarine environments (personal observation). We also see such a migration at night in ocean waters where turtles come into shallow waters to lay quiescent during the night (unpublished data). Both of these types of diel migratory behavior probably provide similar advantages to green turtles. There is little to no forage material in the Anahulu River estuary and it is surmised that the turtles move into that environment because it is a safe location away from predatory tiger sharks and it is a very low energy environment requiring less energy expenditure. There may also be some unknown advantage of parasite removal to turtles being in low salinity water for hours at a time.

The number of sonic detections at the 5 stations shows that over 80% percent were from stations 1 and 2. This is the widest and longest portion of the river and seems to be the preferred resting habitat. Some turtles did travel all the way up to station 5 and a few of them preferred the area of stations 3 and 4. Because of the very low water clarity, exactly where in the river turtles rest is unknown. There are a couple of places where they can be observed resting out of the water on the muddy banks during low tide. During these times, a sonic tagged turtle would not have been detected since the signal does not cross the air-water boundary effectively. This would have lowered the number of detections. There was only one instance where a sonic tagged turtle was observed basking so this was not probably a common occurrence and its effect on the number of detections would have been minimal.

We found that the 15 turtles on which we deployed sonic tags were very regular visitors to the river for the first 4 months. After the February 28, 2016 flood event when several of our sonic receivers were displaced or lost, the number of turtles detected dropped from 12 to 7. The reason for this decline is unknown. It is possible that some of the turtles shed their tags, the environment changed after the flood and became less inviting to the turtles, some turtles may have died or moved to other areas, or they may have shifted to a different resting area. While there is not much we could have done to protect our equipment from the flood, I believe that a more secure attachment for the tags might have increased monitoring time for the turtles.

The Anahulu River is a tourist attraction for paddle boarders and kayakers who paddle up the river for recreation and they are thrilled to see turtles when they surface. This activity has not been observed to have any adverse effects on the turtles that move into and out of the river. The heaviest tourist traffic occurs at mid-day and the heaviest turtle traffic tends to occur in the early morning and evening. We observed tourists transiting the entrance to the river at the same time as turtles and the turtles did not react in any observable way to their presence.

Tourists do not appear to contribute to the debris load in the river although it may be that non-reef safe sunscreens might add to the pollution level in the river.

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