Demography of Sea Turtles in Biogeochemical Microzones within Kiholo Bay, Hawai'i Island

An informal report to Hui Aloha Kiholo, authored by Scott Henderson, February 2022

ABSTRACT

Sea turtles (honu, in Hawaiian) recruited steadily to high-nutrient estuarine environs of eastern Kiholo Bay (Hawai'i Island) from about 1980 to 2021. Over this period, the population size structure was relatively constant, but notably nearly all measurements of honu (N=1057) were less than 80 cm straight-line carapace length (SCL). Observations of inner bay turtles in early 2021 (N=266) indicate that, as compared to 1980-2018 data (N=776), percentage of juvenile honu increased three-fold, whereas percentage of largest size-class adults decreased almost two-fold, suggesting that recruitment of juveniles is occurring at a steady to slightly increasing level, and that larger honu are likely emigrating away from the bay as they approach 80 cm SCL size. A recent major decline in daytime presence of in-water and basking honu has occurred in the inner bay lagoon, whereas use of inner bay shoreline and inland ponds remained largely unchanged. Lessened lagoon use may be a response to steadily increasing numbers and size of lagoon honu leading to increased grazing of substrates to a point where it is no longer energy efficient for sub-adult to adult honu to forage in the lagoon. Decreased use of the lagoon where benthic algae is heavily depleted, emaciated condition of some honu in the bay, and increasing out-emigration of larger honu suggest that east Kiholo Bay has reached carrying capacity relative to numbers of turtles that can be sustained in healthy condition in the inner bay. It is not likely that decreased use of the lagoon by honu is attributable to predation or human activities.

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Introductory Statement

The purpose of this report is to present and compare results of past and recent demographic studies of sea turtles (including "green" and "hawksbill") species) in ecological microzones at eastern Kiholo Bay, and to examine how sub-population trends identified in those studies may be driven by local environmental conditions such as nutrition, wave energy, human influence and predation.

Section 1. History of green sea turtle monitoring at Kiholo Bay (Hawaii Island)

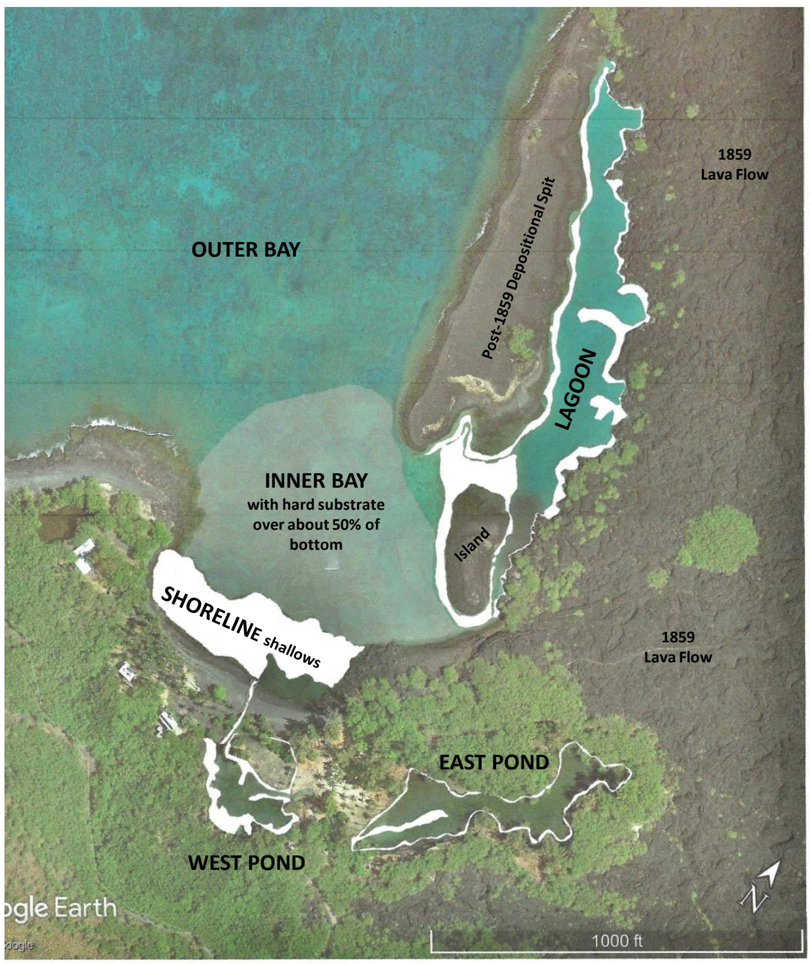
Sea turtles have existed in Kiholo Bay in low abundance since at least the early 1900's, and in the 1940s and 50s were periodically harvested in small numbers from the 'auwai (water channel) that connects the bay waters to the inland brackish water ponds (retired Pu'u wa'a wa'a ranch employee, personal communication, 2021). In the course of boating and diving activities during camping stays at Kiholo Bay in the mid-1960s, the author and family very rarely saw honu in the bay or lagoon waters. Turtles were also very rarely seen in Kapoho Bay (east Hawai'i Island) where the author's family owned a beach house in the 1950s and 1960s. Low abundance of turtles throughout most waters of the main Hawaiian Islands in the mid-1900s was attributed to high levels of harvest of turtles for food, especially as a novel menu item for local restaurants. Passage of protective regulations in the late 1970s made it illegal to take turtles, and subsequently their numbers have steadily increased throughout the islands in the 1980s and in the decades following.

In May of 1973, George Balazs (then of Hawaii Institute of Marine Biology) tagged and measured 15 turtles in Kiholo Bay with average carapace length of 49 cm (G. Balazs, 1973, unpublished data) and made follow-up visits for tagging and monitoring in 1980-81. In October 1987, a three-day turtle tagging expedition involved a group of Hawaii Preparatory Academy (HPA) students and instructors accompanied by G. Balazs (then of NOAA, Marine Turtle Research Program). The group captured and tagged six turtles during that trip, and three-day revisits over the next two years yielded captures of only seven to 10 turtles. By the late 1980s, 11 to 37 turtles were captured in the 5-acre (2 ha) Kiholo lagoon on each visit, and during the 1990s from 40 to 85 turtles were captured each time in the lagoon with equal or reduced capture effort (Balazs et al. 2000).

By 1998, a total of 313 green turtles and three juvenile hawksbill turtles had been captured and tagged within the Kiholo lagoon. Only four of those turtles have been recaptured elsewhere, all within 12 to 16 km (7.5 to 22 miles) distance from Kiholo. And only one tagged turtle captured at Kiholo over a 14.4-year period ending in 1990 was found to have been tagged elsewhere. That turtle had been tagged as a captive-bred day-old hatchling at Sea Life Park (Oahu island) and was recovered about 3 years later at Kiholo as a juvenile of about 35 cm SCL (G. Balazs,pers. com.,2021). Overall, these turtle tagging data provide strong evidence of extended residency of turtles inhabiting Kiholo Bay and other discrete coastal sites on the island of Hawai'I (ibid.).

Present day concentrations of turtles in Kiholo Bay are greatest in four distinctly different biogeochemical zones (Fig.1). The zones are situated in the eastern confines of Kiholo Bay where about 12.6 million gallons per day of very-low salinity ground-water flows into the bay from shorelines within the lagoon, inner bay and inland ponds (Fig.2). Typically, those spring waters contain relatively high levels of dissolved nitrogen, phosphorus and silica compounds, collectively providing a substantial source of basic nutrients that sustain steady growth of algal turf within nearshore low-salinity waters. An estimated 90 percent of turtles residing within the 536 acres (217 ha) of greater Kiholo Bay (bounded by Nawaikulua Point at south and Hou Point at north) spend most of their time feeding, resting and basking in the 20-acre (8 ha) area of the inner-most bay and inland ponds (Fig.1) where benthic algae preferred as food by turtles is concentrated (S. Henderson, personal observations, 1979-2021).

Figure 1. Kiholo Bay primary turtle use zones and areas comprised of in-place or wave-transported lava substrates (depicted in white or grey) that commonly sustain significant coverage of benthic algae . All white areas consist of greater than 90 percent hard bottom (primarily basaltic) substrate coverage. Areas not colored white within bounds of the lagoon and inland ponds consist of sand/silt substrates not conducive to macro-algae growth. Google Earth imagery.



HARD SUBSTRATE AREA: (WHITE)	**Lagoon & Island**	**2.10 acre**	**0.86 hectare**	**8,482meter sq**
	Shoreline shallows	**2.10 acre**	**0.85 hectare**	**8,478 meter sq**
	West Pond	**0 .44 acre**	**0.18 hectare**	**1,770 meter sq**
	East Pond	**0.37 acre**	**0.15 hectare**	**1,505 meter sq**
(GREY)	**Inner Bay w/50% hard substrate**	**8.10 acre**	**3.27 hectare**	**32,716 meter sq**

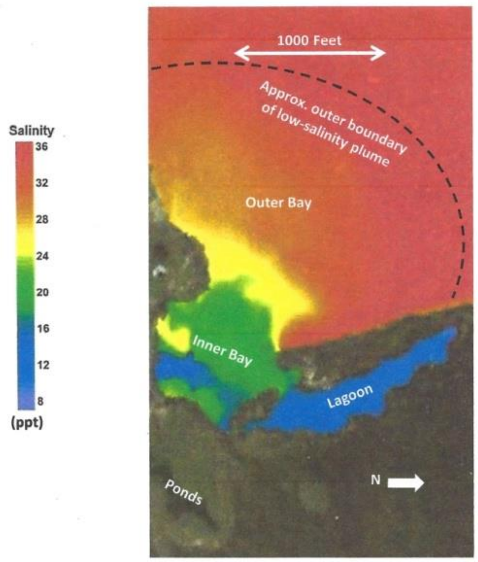


Figure 2. Surface-water salinity of Kiholo Bay on 10/23/2011. University of Hawaii, Hilo EPSCoR program image and data. Salinities of the inland ponds were not measured at this time. Labels and approximate boundary of low-salinity plume added by the author.

Typical diet of honu at Kiholo consists primarily of algal turf comprised of various red algae (esp. *Pterocladiella* spp. and *Hypnea* spp.), and various green algae (esp. *Cladophora hemisphaeric*a and *Ulva* spp.) with small amounts of brown algae, cyanobacteria, and animal material (Harrington et al. 2002, Arthur and Balazs 2008). When continuously grazed by herbivorous organisms, these algae usually form close-cropped carpets with moss-like appearance that commonly extend from intertidal shallows to depths of 1.2 to 1.8 m (Fig.3).

Small numbers of honu began to enter the two inland ponds (*West* and *East Ponds* in Fig. 1) at Kiholo in the late-1980s to early-1990s via the 60 m-long by 2 to 3.5 m-wide channel (ʻauwai) that connects the ponds to the ocean. In year 2000, a study showed that the ponds were being used primarily as a resting area for turtles with more than 50 turtles transiting the ponds per day (Harrington et al. 2002). Investigations in 2013 used automated camera, radio frequency identification (RFID) and swimming transects to count and determine movement patterns of turtles and their use of the ponds and adjacent bay for resting and foraging (Rice et al. 2013). It was found that during a 24-hour period the maximum number of turtles that entered the ponds was 74 and the maximum number exiting the ponds was 67.

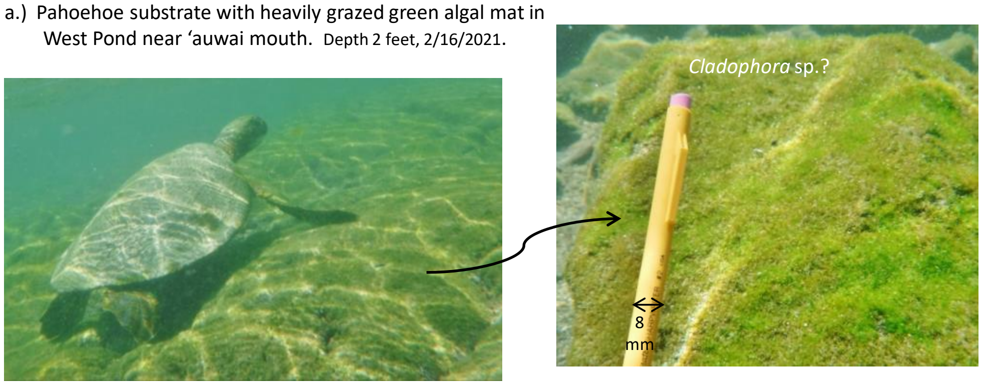
Tidal flow had a major influence on movement of turtles in and out of the ponds over a one-day average-range tidal cycle, with about 45 turtles leaving during dropping tide and 53 turtles entering during rising tide, and about 60 leaving and 50 entering during a typical low-range tidal cycle (ibid.). This tidal movement pattern is likely due to the fact that turtles can expend much less effort when swimming in the same direction as the strong tidal flow going in or out of the ponds through the narrow ʻauwai channel.

The 2013 investigations (of Rice et al.) attached radio frequency identification devices to 33 turtles of 49.5 cm average straight line carapace length (SCL) that were captured in or near the ʻauwai channel. Passage of these turtles in and out of the ponds was monitored with a radio signal sensing device at the ʻauwai channel for periods of 51 to 67 days, dependent on date of tagging. This monitoring showed that the 33 turtles were residing in the ponds for an average of 63.8 percent of time and were out of the ponds for average of 33.1 percent of time (ibid.).

Coincident with three of the 2013 visits to Kiholo Bay for RFID tagging, three snorkeling swimmers counted honu and noted their behavior (swimming, resting or feeding) while swimming the length of *West* and *East Ponds* and the connecting ʻauwai channel. Results of the three counts determined that average number of turtles in *West Pond* was eight and average number in *East Pond* was 15. About a third of turtles observed in both ponds were feeding. Basking turtles were seen only in *West Pond* on one day when five turtles had hauled out onto dry land. Total numbers of turtles recorded in *West* and *East Ponds* combined were 11, 17 and 21 for dates of 1/28/13, 2/28/13 and 9/28/13, respectively (ibid.).

Figure 3. Typical grazed algal mats in ponds and inner bay shallows.

a.) Pahoehoe substrate with heavily grazed green algal mat in West Pond near ʻauwai mouth. Depth 2 feet, 2/16/2021.



b.) Green algae (*Cladophora* sp.?) mats in intertidal shallows with high outflow of fresh spring water. 2/16/2021.

c.) Typical mixed species algal turf in near-shore shallows heavily grazed by fish, turtles & invertebrates. Depth 2 feet, 2/16/2021.

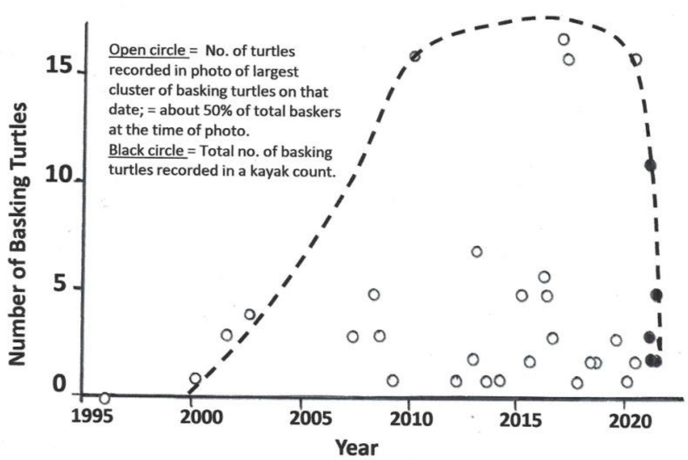
From 2013 to 2021, field staff of The Nature Conservancy (TNC, that owns and manages the inland ponds property) performed about monthly fish and honu censuses in *West Pond* and *East Pond* using a pair of snorkeling swimmers that transited the ponds in a spacing and route that provided good visual coverage of most of the upper water layer in the ponds. Unpublished count data shared by TNC showed that average number of honu seen in the ponds in the course of 21 surveys in 2013 and 2014 was in range of 18 to 21 individuals. Notably, those counts are very similar to counts of 11, 17 and 21 reported in 2013 surveys of the ponds (Rice et al. 2013). TNC average counts from 2014 through 2017 increased in nearly linear fashion to a high of about 58, and from 2018 through early 2021 were in a relatively narrow range of 42 to 53.

Numbers of honu occupying Kiholo Bay increased for at least three decades beginning in the early 1980s (S. Henderson, 1980-2021, personal observations; and several sources cited in Rice et al. 2013). In the early- to mid-1990s, observations in the course of HPA/NOAA monitoring visits as well as casual observations and photographs by the author showed that a few turtles began to come ashore during the day at Kiholo and rest in a "basking" mode, typically for periods of several hours. Initially turtle basking behavior at Kiholo occurred almost exclusively on shorelines of the *Lagoon*, but progressively expanded to other beach areas and inland ponds in environs of the inner bay (Fig.4). Photographs of some basking turtle clusters in the *Lagoon* over the last two decades in conjunction with recent kayak counts of turtles indicate that numbers of basking turtles peaked in about 2015 and have declined precipitously in very recent times (Fig.5).

Figure 4. Cluster of turtles basking at Kiholo mid-lagoon shore, 2/22/2011. S. Henderson photo.

Figure 5. General abundance of Kiholo lagoon basking turtles versus time. A proximal line plot of maximal number of baskers is shown as indication of temporal trend of lagoon basking.

S. Henderson, 1996-2021, unpublished data.



The data plot of Fig.5 does not include informal observations by visitors to the Kiholo Porteus family beach house made while kayaking in 2011 to 2015 when 30 to 55 basking honu were commonly counted on the *Lagoon* shores.

Anecdotal observations of turtle abundance and distribution made at frequency of two to four times per year from 1979 to late-2021 in inner Kiholo Bay by the author led to conjecture that abundance of in-water and basking turtles in the Kiholo *Lagoon* had declined considerably from late 2018 through late-2021. The most recent proximal enumerations of turtles in the *Lagoon* were from the 1990s when 40 to 85 turtles were captured in the *Lagoon* and the lagoon pass in the course of several tagging expeditions (M. Rice, May 23, 2021 personal communication).

Nearly all other quantitative data on past turtle abundance at Kiholo exists as formal counts performed only in the inland ponds (Rice et al. 2013; The Nature Conservancy, 2013-2021, unpublished data) and in the basking data of Fig.5. These past data sets provide general indication of past and present Kiholo Bay turtle abundance and use of the inland ponds, but cannot be used as reliable baselines for comparisons to temporal changes of turtle abundances outside of the inland ponds.

Section 2. Biogeochemical descriptions of primary turtle use zones within east Kiholo Bay.

(Most descriptive information in this section is based on unpublished observations by S. Henderson from 1980 to 2021).

Considerable differences exist in the present-day general oceanographic and algal coverage characteristics of immersed hard substrate areas within the primary turtle use zones of Kiholo Bay (Fig. 1 & Table 1). Within the total area of Kiholo inner bay, 78 percent of hard substrate that hosts growth of benthic algae (10.2 acres, 4. 1 ha) is found along shallows of the *Inner Bay* and *Shoreline* zones where algal turf coverage is generally low and high, respectively.

Freshwater flowing from springs along shorelines of eastern Kiholo Bay and ponds (Fig. 2) mixes with ocean seawater resulting in typical salinities of the upper surface layer (0.6-1.0 m depth) in ranges of 18-28 ppt (parts per thousand) for the *Inner Bay*, 6-28 ppt for the inner bay *Shoreline,* 4-25 ppt for the *Lagoon*, and 3-10 ppt for the inland *West* & *East Ponds* (Table 1). Tidal flushing brings oceanic water of high salinity into the bottom layers of the inner bay, lagoon and ponds at depths 0.6 to 3.0 m below surface, where typical salinities range from about 20 to 30 ppt.

Biota of the brackish high-nutrient environs in Kiholo Bay is comprised largely of algae and herbivorous grazing organisms. Corals are largely absent or sparse in areas where ambient salinities are less than about 24 ppt. Primary grazer populations are comprised of honu and a wide variety of mollusks (primarily neritid, littorinid, ceranthid and thiarid snails), urchins (primarily short-spine echinometrids), crabs (primarily grapsids), shrimp (primarily palaemonids) and fish (primarily acanthurids, labrids, kyphosids, mugilids, pomacentrids, scarids, zanclids and chaetodons).

The *Inner Bay* zone (as defined in Fig.1) has high exposure to wave energy and currents that rapidly mix fresh water plumes from springs with oceanic water. Water depths in this zone average about 1.5 m within a range of about 0.3 to 3.7 m. Bottom substrate is smooth to lightly-folded pahoehoe lava with a few small patches of sand, a small number of large *Porites* species coral heads and a few scattered small colonies of encrusting and branching corals. Large winter swells create surf of 0.6 to 2.2 m height that scours the inner bay bottom and moves sand and pebble sediments onto 220 m of beach along the southeast shoreline of Kiholo Bay.

Most exposed hard substrate in the *Inner Bay* zone is covered by low to moderate amounts of close-cropped algal turf composed of unidentified taxa of brown to greenish-colored intertwined filamentous, branching and crustose algae, as seen in Fig.3c. In the relatively high-salinity environs of the *Inner Bay* zone, low occurrence of algal turf is likely related to high water motion that rapidly mixes and dilutes nutrient-rich spring water plumes with low-nutrient sea water resulting in only "medium" levels of nutrient availability. High water motion, commonly encountered in this zone, probably substantially reduces algal turf coverage via sediment scouring of bottom substrates by surf action (Table 1). Additionally, moderate to high numbers of herbivorous fish and turtles visit and graze this zone and undoubtedly also contribute to low turf levels.

Table 1. Hard substrate planar area, surface salinity, dissolved nutrients level, algal turf coverage and wave energy for primary Kiholo turtle use zones.

	Planar Area (**acre**/hectare)	Upper Meter Salinity (ppt)	Estimated Dissolved Nutrients Levels	Algal Turf Coverage	Wave Energy Conditions
Lagoon, West Shore & island	**1.3**/0.55	4-25	med	low	low, calm
Lagoon, East Shore, 1859 Lava Flow	**0.8**/0.31	4-25	med	low	low, calm
Shoreline, Inner Bay	**2.1**/0.85	6-28	very high	high	med to high
Inner Bay, 50% Hard Substrate	**8.1**/3.27	18-28	med	low	high
West Pond	**0.44**/0.18	3-10	med to high	med to high	calm
East Pond	**0.37**/0.15	3-10	med to high	med to high	calm

Total planar area of hard substrate within the primary Kiholo turtle use zones = 13.1 acres (5.3 hectares)

A 180 m-long by 15 m-wide band of intertidal shallows along the southeast shoreline of the *Inner Bay* zone (*Shoreline* in Fig.1) receives a high volume of freshwater from numerous springs along the seaward base of the fringing beach. Even though water motion is medium to high along this exposed shoreline, dilution of nutrient-rich spring water is considerably lower than mixing and dilution that take place in the adjacent *Inner Bay* zone. Dilution of spring flow is reduced locally because prevailing onshore wind and wave surge action tend to push spring inflow toward the shoreline, thus retaining localized patches of high-nutrient water in place for longer periods of time, especially during periods of low tide. The entrapped nutrient-rich waters in this zone are more persistently available to benthic algae, and sustain relatively abundant algal turf (Table 1 & Fig.3b).

During calm water (low surf) conditions, moderate numbers of honu are commonly seen foraging over the overall area of the *Inner Bay* zone, but highest density of feeding honu in that zone usually consists of small individuals preferentially grazing at high-tide on green algal turf in the western half of the intertidal *Shoreline* band defined in Fig.1. The dominant species of green algae in these environs have been identified by various investigators as *Ulva flexuosa* and various species of *Cladophora* , including *C. catenata, C. hemisphaerica* and/or *C. laetevirens* (Harrington et al. 2002, Rice et al. 2013).

In addition to turtles, other herbivores that compete for algal resources in the *Shoreline* portion of the inner bay include substantial numbers of fish (primarily tangs, labrids, kyphosids, mugilids, pomacentrids and chaetodons), large numbers of mollusks (primarily cerithids, littorinids, neritids and thiiarids,), and low to moderate numbers of crabs, shrimp and short-spine echinometrid urchins. Large numbers of herbivorous fish are commonly seen browsing on high tide conditions in shoreline shallows immediately south of the ponds ʻauwai channel. Their abundance in this area appears to be favored by presence of irregular substrate consisting of overhanging lava ledges and blocks (Fig.3c) that provide protective cover from marauding predators such as jacks and barracuda. The very shallow intertidal topography of this zone reduces grazing pressure on benthic algae by reducing presence of herbivorous fish in the shallows during periods of low tide.

In contrast to the surf-roiled waters of the inner bay *Shoreline*, calm water conditions prevail in protected waters of the adjacent *Lagoon* (Fig.1). The interior west shore of the *Lagoon* consists almost entirely of surf-rounded basalt pebbles, cobbles and small boulders derived from wave erosion of the 1859 lava flow (Fig.4) and very small amounts of sandy sediment. Those erosional deposits make up all of the structure of a 430 m-long by 60 m-wide depositional spit creating a natural peninsula barrier on south side of the *Lagoon*, and the deposits slope steeply downward to the *Lagoon* floor. The 630 m-long eastern boundary of the *Lagoon* consists almost entirely of un-eroded terminal edge of the 1859 pahoehoe lava flow (Fig.5). A detached portion of the spit at south end of the lagoon forms a 110 m-long by 45 m-wide island composed of erosional deposits identical to those of the main spit.

Boulder and cobbles on shallows of the submerged *Lagoon* interior western slopes are largely covered with thin turf of filamentous algae, much of it greenish in color indicative of chlorophyte presence (Fig.4). With increasing water depth, those rock substrates are increasingly covered by chalky coatings of fine detritus and diatoms with decreasing amounts of algal turf. The submerged 1859 lava substrates on the eastern side of the *Lagoon* are covered with thin veneers of algal turf and detritus/diatom material similar to that of the western slopes. Algal turf declines to very low levels on all hard substrates as the northern extreme end of the *Lagoon* is approached and flushing with oceanic water is lowest.

Over the last four decades, substantial numbers of in-water and basking turtles have been observed and studied in the *Lagoon*, and about one-third of in-water turtles observed by the present author over that period were seen browsing on algal turf in shallows of the *Lagoon* and the adjacent island perimeter. The majority of the other two-thirds usually appeared to be in scanning mode swimming close to shore as if looking for good browsing spots. Small numbers of turtles intermittently surface over deeper waters of the *Lagoon*, presumably making bounce dives to browse pahoehoe lava structure protruding from soft bottom sediments.

Figure 4. Interior west shore of lagoon consisting of surf-eroded lava from 1859 flow. Grazed algal turf coats the submerged cobbles/boulders from intertidal to about 2 m depth.

Figure 5. Interior east shore of lagoon consisting of un-eroded 1859 pahoehoe lava. Algal turf is similar to that seen on submerged lava surfaces along the west shore (above).

G. Balazs observed that during night dives in the *Lagoon* the 1970 s through 2000s, his research crews usually saw and captured turtles that were asleep in underwater nooks, or occasionally resting on the silty bottom. Daytime observations rarely found honu in sleeping mode, instead turtles seen during the day were loitering or swimming slowly, but not actively feeding. When using nets to fence off the opening of the lagoon, crews caught all the turtles they needed within a few hours after sunset, noting that those honu were apparently coming into the lagoon to sleep after feeding in the bay. In the morning, an exodus of turtles occurred back out into the bay (G. Balazs, personal communication, 2020).

Interestingly, the hard substrate submerged slopes of the *Lagoon* extreme north end have an abundance of attached shell remnants of Hawaiian oysters (*Ostrea sandvicensis*) that have existed there for at least five decades (S. Henderson, 1980-2021, personal observations; Figs.6a & b). Oysters are filter feeders that rely heavily on plankton as primary food source. Mass die-off of the oysters in the *Lagoon* apparently occurred sometime before 1980, and this die-off event could have been caused by a drastic decline in their planktonic food. History of the physical and oceanographic setting of the *Lagoon* may have some relevance to possible past existence of rich planktonic communities in the lagoon. Prior to the period of 1957-1960, erosion and long-shore transport of material from the seaward face of the 1859 lava flow created the depositional spit (peninsula) that extended continuously from edge of the lava flow at north end of the existing peninsula to the south end of the existing island. At that time the enclosed *Lagoon* had only one narrow pass between the island and the shore (at extreme south end of the *Lagoon*), and all flow of water in and out of the lagoon flushed through this single 15 m-wide opening.

Figure 6a. (left) Lagoon cobble/boulder slope with attached remnant shells (yellowish colored) of Hawaiian oyster (*Ostrea sandvicensis*). At west shore of extreme back end of Lagoon, 0.9-2.5 m depth.

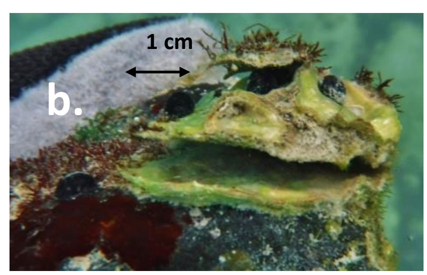


Figure 6b. (above right) Remnant oyster shell on cobble from slope at a. above. Tentatively identified turf algae on rock and shell from left to right are *Gelidium* sp, *Cladophora* sp, *Pterocladiella* sp, & *Hypnea* sp. Dark red crusts at lower left are *Peyssonnelia rubra*. Four black gastropods are *Nerita picea*.

When the *Lagoon* had only one relatively narrow pass, flushing of the *Lagoon* by sea water would have been relatively low, and residence time of water in the *Lagoon* would have been relatively long. Under low flushing conditions, spring-flow high-nutrient water would have been trapped in the *Lagoon* for extended residence time likely creating high-nutrient "chemostat" conditions conducive to maintenance of rich plankton blooms that could support an abundant filter-feeding oyster population.

Observations by past residents of the bay reported that surges of the 1957 and 1960 tsunamis eroded a new pass of 60 m width into midsection of the *Lagoon*. Greatly increased seawater influx through the new pass would have substantially diluted spring water in the *Lagoon*, causing a major increase in salinity and concomitant decline in dissolved nutrient concentrations in the *Lagoon*. A sudden large reduction in nutrient supply would likely have caused a die-off of *Lagoon* plankton and coincident die-off the oysters that were dependent on that plankton as a food source. Prior to the existence of the large pass at the *Lagoon*, high nutrient levels probably also favored abundant growth of benthic algae that would have served as food for many herbivorous organisms, including sea turtles.

Figure 7. *Left*. View looking up north axis of Kiholo lagoon.
***Right*. Green plankton-rich water at center of lagoon.**

Figure 8. *Left*. Plankton-rich water near the main Kiholo lagoon pass. Dark area is a large school of halalu (juvenile mackeral scad). *Right*. Halalu aggregating at top edge of the dense green phytoplankton horizon. Depth at center of image is about 1.5 m below surface.

As mentioned earlier in this report, honu numbers in Kiholo nearshore waters were very low in the first half of the 20th century due to over-harvesting. When there were only low numbers of turtles present in the Kiholo bay before 1957-1960, their grazing pressure on benthic algae in the *Inner Bay* and *Lagoon* would likely have been negligible in comparison to grazing levels by other herbivores, especially fish, urchins and gastropods. However, an abundance of benthic algae in the high-nutrient environs of the *Lagoon* could have been an attractant, luring increasing numbers of turtles to Kiholo inner bay, raising their population density in the bay to levels considerably higher than turtle densities in other lower-nutrient embayments along the west side of Hawai'i island.

The mid-century catastrophic increase in flushing of the *Lagoon* waters, that caused salinity increase and dissolved nutrients decrease with an accompanying crash of algal populations in the *Lagoon*, apparently also affected the life histories of coconut palms along interior shorelines of the *Lagoon*. **Appendix A** describes the history of the palms and lagoon water chemistry parameters that have affected the coconut palms and the marine and ground water environment in the *Lagoon*.

For at least the last 50 years, an obvious green- to brown-colored water layer has existed nearly continuously in the *Lagoon* at depths of about 1 to 2.5 m immediately below the halocline that separates the surface and bottom water layers (Figs.7 & 8). The top of this colored layer is consistently located at the base of the cold low-salinity water layer that floats on the surface of the denser underlying high-salinity water. The saline layer derives its color from elevated biomass of large-cell-size phytoplankton sustained by dissolved nutrients absorbed from the overlying groundwater discharge water layer (Adolf et al. 2019, Rice and Jim 2020).

Tidal inflow of dense seawater from the ocean generally intrudes close to the *Lagoon* floor with low levels of mixing and disturbance of the low-salinity layer above it. Tidal outflow of the dense bottom layer is generally much slower than outflow of the surface layer. Combined forces of wind and tide usually drive surface water out of the *Lagoon* very quickly, probably within a day or less, allowing very little growth of phytoplankton before that surface water is flushed into the open bay and diluted with oceanic water. On the other hand, accumulation of phytoplankton in the bottom (high salinity) layer is enhanced by its relatively longer residence time of three to 11 days. Persistent stratification of the *Lagoon* waters favors long-term stability and lessened dilution of the resident bottom-layer phytoplankton that have typical growth rates of one to two divisions per day (Adolf et al. 2019).

The end result of these combined factors is that groundwater-derived surface water in the *Lagoon* is generally cool (less than 72 deg F) and very clear with very low abundance of phytoplankton, whereas the *Lagoon* water deeper than about one meter is generally warm (greater than 72 deg F) and turbid with high levels of phytoplankton. Nutrient-laden surface water that flows out of the *Lagoon* mixes with bay water where it moderately enhances phytoplankton biomass (ibid), and undoubtedly is also consumed in part by benthic algae. Density of algal turf coverage in the *Lagoon* is generally low (Table 1). Presence of the abundant, persistent and stable phytoplankton population in the *Lagoon* undoubtedly consumes a significant portion of dissolved nutrients present in the lagoon, and likely reduces the nutrient supply available for benthic algae. However, moderate to high numbers of herbivorous honu, fish and molluscs inhabit the *Lagoon*, and their constant grazing activity is likely also a significant factor in continuous thinning of algal turf in the *Lagoon*.

The nearly land-locked environs of *West Pond* and *East Pond* (Fig.1) are largely protected from wind and wave action, and both ponds receive high volumes of high-nutrient ground water that floats on the surface of more saline underlying water that intrudes tidally from the bay. All tidal flow in and out of the ponds passes first through a 2 to 3.7 m-wide by 60 m-long channel (‘auwai) into *West Pond*, and thence through a 3.5 to 12 m-wide by 70 m-long channel into *East Pond*. The channel depths are shallow, in range of 0.1 to 1 m dependent on tidal state.

Figure 9. Clear low-salinity water horizon floating on underlying higher-salinity phytoplankton-rich water in East Pond.

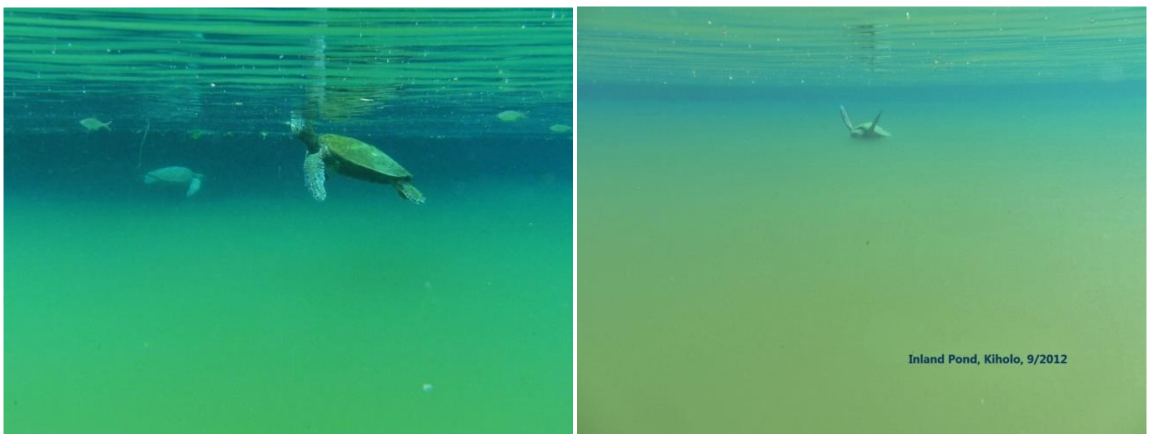
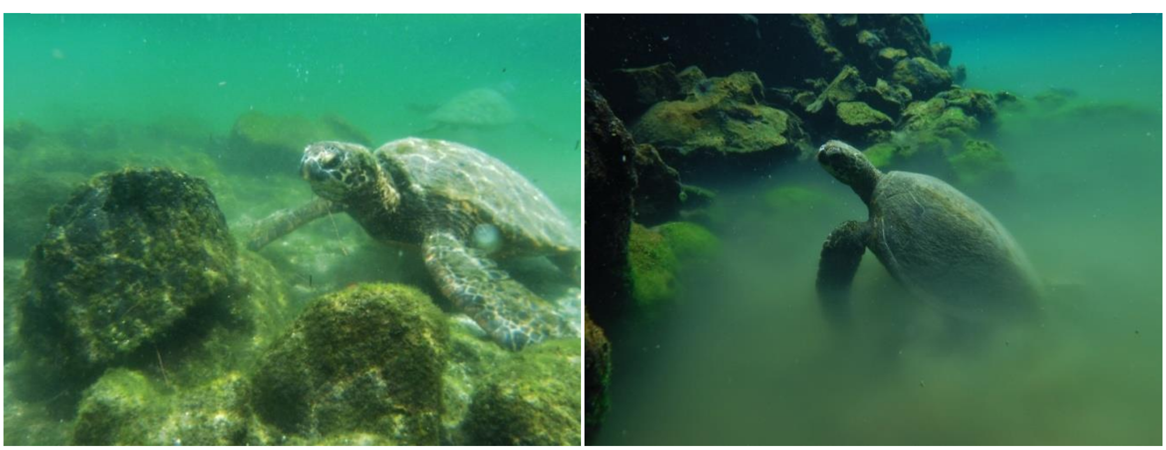


Figure 10. Algal turf being grazed by turtles in West Pond (left) and East Pond (right).



The narrowest constricting point in the channels is at a mid-length point on the seaward-most channel where the channel is 7.1 m wide with a depth of about 0.7 m at 0.6 m tide height. Flow constriction in the channels reduces total tidal water volume exchange causing water levels in the ponds to never reach total equilibrium with those in the ocean, and highest and lowest water levels in the ponds are attenuated by about 25 percent relative to open bay levels (S. Henderson, 2012, unpublished data of Kiholo Hind Pond Survey).

On incoming tides, relatively dense bay water of high salinity flows into the basal water layers of the ponds. On dropping tides, outgoing flow is largely low-salinity floating spring water that is skimmed into the shallow channels that connect to the bay waters. The waters of *West Pond* and *East Pond* are distinctly stratified with a well-defined 0.3 to 1.0 m layer of cold (less than 72 deg F) fresh water floating on top of a denser underlying layer of warm salt water. Well developed and persistent phytoplankton blooms commonly exist throughout the ponds at base of the halocline in the near-surface reaches of the high-salinity layers in the ponds, especially in *East Pond* (Fig.9). Rich phytoplankton growth occurring in water horizons just below halocline base in the ponds is similar to the setting in sub-halocline waters of the *Lagoon*, as described earlier.

Phytoplankton horizons in the *Lagoon* and *West and East Ponds* are usually green in color, but can grade seasonally into hues of yellow to brown to bronze. These color changes likely relate to seasonal changes in dominance of phytoplankton taxa such as chlorophytes, diatoms, cyanobacteria, dinoflagellates, euglenophytes, cryptophytes, chrysophytes and haptophytes. Temporal abundance of these taxa would be expected to change in response to varying levels of insolation, salinity, temperature, dissolved nutrients and trace elements.

Substantial amounts of dissolved nutrients are likely consumed by phytoplankton in the inland ponds, but nutrient levels are apparently sufficient to sustain medium to high algal turf coverage in those environs (Fig.10 and Table 1), even under high grazing pressure by turtles, fish, crustaceans and mollusks. Particularly high levels of benthic green algae are found on hard substrates in *West Pond* immediately adjacent to the inland mouth of the ʻauwai channel where bay water inflow impinges (Figs.3a & 10). Benthic algae in *East Pond* are also dominated by green algae, but algal turf in *East Pond* is generally not as robust as turf in *West Pond* (Fig.10).

In the deepest basin of *East Pond* at depths of 1.2 to 2.1 m, fine sediments cover most of the bottom and grade vertically from sand to silt to mulm. The mulm layer is generally 0.3 to 1 m thick and consists of a loosely-compacted fluffy mix of cyanobacteria, diatoms and organic debris (Fig.11). This layer is commonly browsed by a variety of herbivorous and omivorous fish such as mullet, goatfish and aholehole. The lightly-compacted lower base of the mulm is commonly inhabited by burrowing infauna such as gobies, crabs, shrimp, microcrustaceans, and sipunculid and enteropneustid worms (Fig.11).

Turtles frequently bury themselves into the mulm layer resting with only their upper head protruding from the soft sediment. It is not known why they exhibit this burrowing behavior, but they could be attracted to the warmth of the mulm layer that is almost continuosly emmersed in dense warm (greater than 72 deg F) seawater. Burial may also help clean their carapaces by denying fouling growth access to sunlight and oxygen. Additionally, turtles have infrequently been observed “scouting” over the top of the mulmlayers, then diving down into the layer and emerging above the layer with an apparent mouthful of sediment followed by gular pumping that pushes water and sediment out of the perimeter of the turtle’s beak. Conjecture is that this could be a means of harvesting infaunal invertebrates and algal mats from the soft sediments (Rice et al. 2013, S. Henderson, 2010-2020, personal observations). Average water depths in *West Pond* are considerably less than those of *East Pond*, and fine granular sediment deposits are generally thin with thin overlying mulm layers. Over the last three decades, the author has not observed any sediment burrowing or feeding behavior by turtles in fine sediments in *East Pond*.

Figure 11. (Left) Silty sand substrate with thin layer of mulm in 0.75 m water depth at north end of East Pond. Fish at far left are Hawaiian shrimp gobies (*Psilogobius mainlandi*) near burrows that they share with snapping shrimp (Alpheid sp.**). Plumes of silt/mulm are caused by gobies and shrimp darting into the larger burrows in the sediment. An abundance of infauna burrows are visible over the sediment surface.**

(Below) Turtle rising from mulm/silt layer that it had been resting in at 2 m depth in East Pond.

Sediments on the floor of the *Lagoon* are composed primarily of calcareous sandy muds with a thin top-layer of low-organic mulm. Observations of turtle behavior in environs of the *Lagoon* floor are lacking because underwater visibility is extremely low due to persistance of dense phytoplankton and fine sediment turbidity generated by tidal flushing of the basal seawater layer.

<u>Section 3. Environmental factors that may affect demographics, health and mortality of Kiholo turtles.</u>

Large sharks are potential predators of turtles, and sightings of large tiger sharks in inner Kiholo Bay have slowly increased over the last three decades. High ocean temperatures in summer and fall initiate instinctual drive in blacktip reef sharks and hammerhead sharks to migrate to some Hawaiian estuarine bays and nearshore areas to pup and mate (Clarke 1971). A 2013 study concluded that about one-quarter of mature female tiger sharks migrate from French Frigate Shoals to nearshore areas of the main Hawaiian Islands (likely including west Hawai’i) during late summer and early fall potentially to give birth and mate (Papastamatiou et al. 2013). Increased year-round numbers of sharks in the main islands are possibly attributable to steadily increasing ocean temperatures in the western and central Pacific occurring since 1970, and may also be due to cessation of contracted hooking and culling of sharks that occurred in years past for protection of humans from shark attacks.

Visitors to beach properties at Kiholo have witnessed at least 20 incidents of shark/turtle interaction in the inner bay over the last 40 years, and over that period about five dead shark-mutilated turtles have been found within the bay (S. Henderson, 1980-2021, personal observations). Nearly all of the attack sightings have taken place in the *Inner Bay* zone (Fig.1), most commonly in water depths of one to 2.5 m, and large tiger sharks are rarely if ever seen in depths less than one meter. Notably, turtles of relatively small size (37-55 cm SCL) preferentially forage in the intertidal shallows fronting the beaches of the *Shoreline* zone (Table 2), likely because their small size and nimble nature allows them to effectively graze the turf-rich shallows. Feeding in the nearshore extreme shallows also likely provides the small turtles considerable protection from prowling tiger sharks that are wary of swimming into intertidal depths.

Through much of 2020, large schools of halalu (juvenile bigeye scad) aggregated in Kiholo *Inner Bay* and *Lagoon* for an abnormally long period of time (greater than 8 months), and on several occasions large tiger sharks and other shark species were seen preying on the halalu schools just outside the main lagoon pass (S. Henderson, A. Hanano & L. Hind, 2020, personal observations). It is not known if any of the sharks attracted to the *Inner Bay* by presence of halalu schools may also have preyed on honu.

Over the last 50 years, year-round presence of tiger sharks in Hawai'i nearshore waters (including Kiholo Bay) has been increasing, possibly driven by steadily increasing oceanic water temperatures around the Hawaiian Islands caused by large-scale climate change effects (S. Henderson, 2000-2021, personal observations). If this suggested trend is indeed true, then the population of tiger sharks loitering year-round in the main Hawaiian Islands may continue to increase as oceanic water temperatures continue to climb. Increasing year-round tiger shark numbers around the main islands could lead to increased competition for food, and consequentially, increased shark predation on turtles in areas such as Kiholo Bay. Increased presence of large sharks in Kiholo Bay could cause small turtles to move from deeper waters in the *Inner Bay* zone into refuges of nearshore shallows and the inland ponds. Such a shift could apply more foraging pressure on the limited food supplies in the nearshore areas with possible resultant declines in growth rates and body condition of nearshore-dwelling turtles.

Observations reported above note that turtle/shark interactions in the inner bay occur at frequency of about 20 per 40 years, and that over the same time period about five shark-bitten dead and mutilated turtles were found. Those reports, however do not take into account that many attacks on turtles are unseen and that some predatory attacks may result in the entire turtle being ingested by the shark. Based on likelihood that those numbers actually largely underestimate the true numbers of shark attacks and resulting turtle mortality, it is conservatively estimated by the author that two to four turtles may now be taken annually by shark predation at Kiholo.

Hawaiian monk seals have experienced increased abundance in the main Hawaiian Islands (MHI) over the last several decades, and in 2013-2015 the estimated number of monk seals in the MHI was about 270. That number was about 21 percent of the estimated total number of monk seals (1,308) present at that time in the entire Hawaiian archipelago (Baker et al. 2016). Over the last decade, monk seal sightings at Kiholo Bay have occurred at a rate of about one to 10 per year (A. Hanano & S. Henderson, 2000-2021, personal observations). Typically, a single monk seal basks for a day or two primarily on beaches of the western bay. On one occasion in February 2016, a pair of monk seals loitered and basked together along shores of the *Lagoon*, island and inner bay beaches, and in February 2012 a single monk seal hauled out on the island and inner bay beaches.

In the 1980s, necropsy reports on several dead turtles found at Kure Atoll concluded that the turtles were likely killed by predatory action of monk seals (G. Balazs, 2021, personal communication). From 2009 through 2017, USGS-Biological Resources Division, Honolulu autopsied several injured or dead turtles from waters around Oahu and Kauai Islands and attributed the turtles' trauma to possible interactions with monk seals. There have also been several eye-witness accounts (including YouTube videos) of monk seals chasing, grabbing and biting turtles at Maui and Hawai'i island locations. In March 2021, a monk seal was observed vigorously interacting with turtles at Kukio Bay, Hawai'i Island (located about 6.5 km south of Kiholo Bay) and that event was thought to be linked to five dead or dying turtles that were found on the beaches at Kukio Bay. Those turtles had injuries that may have been inflicted by monk seals and sharks such as macerated, lacerated or missing appendages, puncture wounds to head and eyes, and collapsed lungs likely caused by forced submergence. It is not known if such encounters are also occurring at Kiholo Bay, but over the last decade monk seal visits to the bay have been relatively rare, and therefore likelihood of trauma being inflicted on Kiholo honu by monk seals at present seems slight and likely not a significant cause of turtle mortality at Kiholo Bay.

In the period of 1988-1995, nine turtle carcasses were recovered from Kiholo *Inner Bay*, and their cause of death was thought to be entanglement in gillnets (Balazs et al. 2000). In 1997, Kiholo Bay was designated a fisheries management area where gill nets are banned, and since then there have been no documented deaths of turtles at Kiholo caused by interaction with fishing gear such as nets and hook-line rigs. However, infrequent illegal use of gill nets, usually at night at the lagoon pass, does still take place and could cause take of about one turtle per annum.

Swimming and foraging turtles at Kiholo Bay that encounter swimming or wading humans at close range (less than 3 m) commonly exhibit a startled evasive response and swim away quickly seeking deeper waters. Basking turtles, however, do not appear to be as readily startled by close human proximity, probably because they are at varying levels of resting torpor with reduced neurological and physiological function causing lessened awareness. Turtles that are out of water in basking mode on Hawaiian shores have no known significant predators, and therefore have no need to be at high levels of alertness to escape capture. On the other hand, in-water turtles in Kiholo Bay are prone to predation by large sharks, and as such would be expected to have a well developed flight response to large moving shapes that can be mistaken as sharks. The flight response so commonly seen in Kiholo in-water turtles has very likely evolved as a means of avoiding predation by sharks, but not as a specific need to avoid humans.

Another potential source of stress in the Kiholo turtle population is interaction with human visitors and watercraft in the eastern bay. Numbers of visitors that walk, wade, swim, snorkel, surf, windsurf, spearfish, pole fish, throw net, boat and kayak the shorelines and waters of the bay has increased almost exponentially over the last three decades. Many of the visitors are tourists that come to Kiholo specifically to see turtles, largely by walking, wading and snorkeling in the *Inner Bay*, *Shoreline* and *Lagoon* zones. Commonly at mid-day, the number of people present on land and in water in the *Inner Bay* and *Lagoon* can exceed 100, with maximal total person visits estimated at about 500 per day. About 80 percent of the users are typically engaged in sunbathing, swimming, snorkeling and turtle watching activities, largely in the lagoon. Fishers, surfers and kayakers usually comprise the remaining 20 percent of users (S. Henderson, 1990-2021, personal observations).

Persons that come in close proximity (within 3 m or less) of in-water or basking turtles can often startle the turtles and cause them to cease activities such as foraging or basking. In some cases people will touch or grab turtles, causing further trauma and disrupting their normal feeding and resting behavior patterns. There are no known studies that have examined effects of "hazing" of turtles on their short-term and long-term behavior in bay environments like Kiholo. Of interest in this regard was that a very steep decline in numbers of *Lagoon* basking turtles took place in time frame of about 2015 to 2020 (pgs.5 & 6, above) when visitor numbers to the bay were peaking at very high numbers. However, during the initial peak of the COVID-19 virus pandemic the vehicle access gate to Kiholo Bay was closed to unauthorized visitors for about seven months (April-October 2020) causing daily lagoon visitor numbers to plummet from several hundred in January 2020 to only three to 30 in mid-September 2020 (S. Henderson, personal observations). Interestingly, numbers of basking turtles on all shores in the *Lagoon* and *Inner bay* remained at extremely low levels through the entire seven months of very low visitor presence in those areas. Since turtle basking did not significantly increase or "rebound" in the *Lagoon* during the period of exclusion of most visitors, it appears likely that high daily numbers visitors and recreational users of the lagoon were not directly responsible for decreases in presence of basking and in-water turtles. In opinion of the author, interactions of Kiholo turtles with walking, wading, and swimming visitors likely have no significant effects on behavior and mortality in the Kiholo turtle population.

Most slow-moving watercraft such as kayaks, canoes and paddle boards do not present an impact or injury hazard to near-surface honu unless they are accelerated by wave-riding, i.e. surfing. The rounded contours of hulls of most paddle or hand propelled watercraft would generally slide or bounce off of the armored integument of sea turtles, even at typical surf-propelled speeds of 16 to 32 km/hour (10 to 20 miles/hour. However, typical surfing craft such as surfboards and paddleboards are equipped with one or more stabilizing skegs (fixed vertical fins) that protrude 8 to 20 cm below the craft underside. Skegs have fairly sharp leading edges, and when moving at surfing speeds can seriously wound surface-swimming animals like honu.

Newly developed water sport technologies like kite surfing, surf foiling, wing foiling and stand-up paddle board foiling have created new classes of fast-moving watercraft that are not entirely dependent on surf energy for propulsion. Foil craft obtain lift and forward motion from a submerged wing-like "foil" attached to a "mast" which is attached to the bottom of the craft. The profile of the leading edge of the foil/mast assembly is shaped like a "T" with the foot of the T attached to the craft. Leading edges of the mast and foil usually taper to sharp edges for hydrodynamic efficiency. Foil craft can attain speeds of 16 to 40 km/hour (10 to 25 miles/hour) or more presenting a potential hazard to near-surface swimming animals that can be lacerated or otherwise wounded by the sharp edges of the submerged mast foil structures.

Use of various types of foil craft and kite-propelled craft in Kiholo Bay has increased markedly over the last two decades, and on a typical windy weekend day 15 or more kite and foil craft can be seen cruising the bay, often passing at high speed through the *Inner Bay* surf zone and the *Lagoon* where there is high density of feeding, swimming and breathing turtles. Increasing frequency of use of the bay by these high-speed water craft is increasing likelihood that turtles will be injured by encounters with the sub-surface skegs and foils of the various fast-moving craft. At present, the author estimates that one to two turtles per annum could be killed by encounters with high-speed sailing water craft.

On a daily basis, about two to four conventional powered boats driven by sub-surface propellers pass through ocean waters of outer Kiholo Bay, usually in depths greater than 10 meters in support of tourist-oriented whale and dolphin watching and SCUBA diving expeditions. These boats usually transit at speeds of 8 to 40 km/hour (5 to 20 miles/hour) and often spend 50 percent of more of their time anchored or drifting. Honu are very rarely seen near-surface in deep water areas outside Kiholo, and as such would very rarely experience damaging encounters with power boats in those areas. However, power boats are seen infrequently transiting Kiholo *Inner Bay* and *Lagoon* at depths less than 10 meters at frequency of about 1 to 2 times per week and speeds of 8 to 40 km/hour (5 to 25 miles/hour) (S. Henderson, 1990-2021, personal observations). It is estimated that encounters with propeller-driven boats at Kiholo Bay may cause death of one honu per two years.

Fibropapillomatosis (FP) is a tumor-causing disease that is prevalent in some Hawaiian green sea turtle sub-populations, and it has become more widespread and severe since its discovery in 1928. However, there is only one record of FP occurrence in the Kiholo Bay turtle population (G. Balazs,personal communication, 2021). Low occurrence of FP in Kiholo turtles may possibly be due to relatively low-nitrogen/alanine content of the algal turf that they ingest (Balazs and Chaloupka 2004, Colbourne 2017). As Kiholo turtles have very high site fidelity through nearly all of their sub-adult to early-adult life history, their feeding habits and nitrogen uptake are not likely to change significantly while resident at Kiholo Bay. Therefore, unless there is a major increase in abundance of high-nitrogen taxa of macro-algae in the bay, there is presently no reason to expect that FP will become established in the Kiholo honu population, and today the disease presents no major threat to that population.

Over the last 50 years, there have been no precise determinations of total number of turtles in the Kiholo Bay population. As mentioned earlier in this report, there have been numerous one-time enumerations of turtles within small zones of the eastern bay such as the lagoon and the inland ponds, but those data are fragmentary and ancillary to primary studies that focused on tagging, tracking, basking and behavior. Without reliable total population numbers collected periodically over the years it has not been possible to determine if the Kiholo population is increasing or decreasing in recent years.

From accountings earlier in this section, the estimated combined effects of the six potential environmental stressors at Kiholo Bay could result in estimated mortality of four to eight turtles per annum. If it is assumed that the total number of turtles in the bay over the last decade has actually been about two-fold greater than the total highest number of turtles recorded in Balazs and Rice monitoring events up to year 2000 in the *Inner bay*, *Lagoon* and *Inland Ponds* (about 130, from studies examined above), then it follows that in year 2000 the total number of turtles in the Kiholo population may have been about 260. Applying death rates of four to seven turtles per annum to a starting population of 260 individuals, annual mortality would be 1.6 to 2.8 percent. If those death rates remain fairly constant over a 10 year period and if recruitment replenishment equaled out-emigration, then the initial population could be reduced by 16 to 28 percent (40 to 70 turtles) over 10 years. In actuality, the Kiholo Bay turtle population appears to have been essentially stable or slowly increasing over the last decade, suggesting that if the estimated mortality rates above are indeed accurate, then recruitment has increased and/or out-emigration has decreased over the same period.

Section 4. Recent monitoring of sea turtle behavior, size & abundance at four microzones of eastern Kiholo Bay. Casual observations have noted an obvious decline in numbers of in-water and basking *Lagoon* turtles over period of late-2018 through late-2021 (S. Henderson, 2015-2021, personal observations). However, there are no known causes for these declines, and only a limited amount of data exists for comparative purposes on past abundance and distribution of turtles in Kiholo Bay.

As an initial step toward understanding the present and future abundance and habits of turtles in the lagoon and inner bay, a monitoring program was initiated by the author in early 2021 to perform periodic transect counts of swimming and basking turtles and to simultaneously estimate straight-line carapace lengths (SCL) of those individuals. A single observer collected data over predetermined kayak, swimming or walking paths (transects) at *Lagoon*, *Shoreline*, *West Pond* and *East Pond* zones. Intent was that these transect data could be used for comparison with past and future observations and as a present-day measure of turtle abundances and habits in zones of the inner bay most densely populated by turtles. To enable this monitoring effort, turtle transect routes were defined for the *Lagoon*, *Shoreline*, *West Pond* and *East Pond* as seen in Fig.12 (below).

An initial transects monitoring series was conducted on 14 different days in February through July, 2021. Resultant data are presented in Table 2 with average numbers and straight-line carapace lengths of in-water and basking turtles shown for each zone. For all four zones combined, the sum of all average numbers (SAN) of in-water and basking turtles was 52. The SAN of turtles in *West Pond* and *East Pond* combined was 31.5, which is 63 percent of the SAN of all turtles counted in all four zones combined, demonstrating that over this monitoring period a majority of turtles present on transects in the inner bay of Kiholo preferred the inland pond environs during daylight hours. SAN of all in-water and basking turtles (52) observed over the total area transected (11 ac.) yields an average density of 4.7 turtles per observed acre.

Only 11.6 percent (31) of the total number of turtles (266) observed in all transect counts combined were larger than 60 cm SLC. The largest size turtle was a female of 77.2 cm SCL that was seen repeatedly basking on western shore of the *Lagoon* peninsula (Table 2). Turtles seen along the surge-exposed western shoreline of the *Lagoon* island were invariably intensely grazing on boulder shallows, and 51 percent of those turtles were in size range of 50 to 76 cm SCL. The *Shoreline* zone in-water turtles were smallest in average size (42.3 cm SLC, Table 2), and were commonly seen browsing on algal turf on hard substrate very close to shore in intertidal shallows, usually at higher tide levels.

During rising to high tide conditions in the *West Pond* just inland of the ‘auwai mouth, clusters of turtles were commonly observed grazing on green algal mat on pahoehoe lava shallows (Fig. 3a). Mixed sizes of turtles present in *East Pond* were usually seen browsing or searching on hard substrate areas, with highest feeding activity focused on green algal turf in shallow water of 0.3 to 1.0 m depth (Fig. 10).

Figure 12. Turtle transect monitoring paths at Lagoon, Shoreline, West Pond and East Pond locales at east Kiholo Bay.

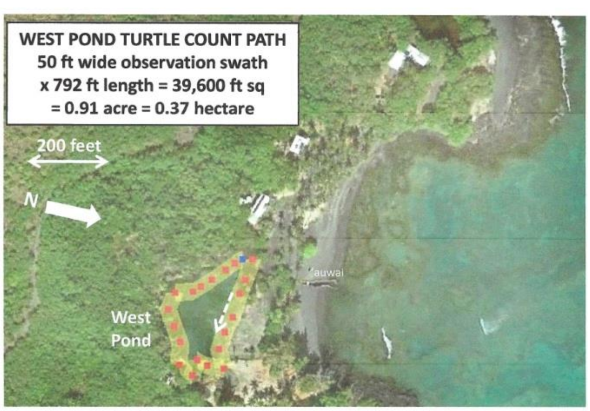


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Table 2. Average and minimum/maximum numbers and size (estimated straight-line carapace [SLC] length, in cm) of in-water and basking turtles observed on February, March, May, June & July 2021 transects at four zones in Kiholo Bay. Ct = number of counts performed, N = total number of turtles for all counts performed**.**

	Average No. of Turtles per Count		Max./Min. No. of Turtles per Count	Average SLC (cm) per Count	Max./Min. SLC (cm) for All Counts
Lagoon, **In-Water** 12 Ct	**4.3**	N=51	**7/1**	**48.3**	**61/28**
Lagoon, **Basking** 12 Ct	**3.9**	N=47	**11/1**	**54.4**	**77/37**
Shoreline, **In-Water** 7 Ct	**12.0**	N=84	**23/5**	**42.3**	**60/28**
Shoreline, **Basking** 7 Ct	**0.3**	N=2	**2/0**	**41.0**	**49/33**
West Pond, **In-Water** 3 Ct	**21.0**	N=63	**33/14**	**45.7**	**65/33**
West Pond, **Basking** 3 Ct	**0**	N=0	----	----	----
East Pond, **In-Water** 2 Ct	**10.5**	N=21	**15/6**	**45.6**	**69/33**
East Pond, **Basking** 2 Ct	**0**	N=0	----	----	----

Notably, the average number of in-water turtles observed in the *Lagoon* (4.3) is very low as compared to numbers in the other three count areas (Table 2). Additionally, the average number of basking turtles in the *Lagoon* (3.9) is very small compared to peak numbers of baskers seen in time frame of 2015 through 2021 (Fig. 5 & observations reported in pages 7 & 8). Casual kayak observations made by the author in the *Lagoon* environs on about nine daytime occasions in August and September 2021, counted only three to five basking turtles and three to six in-water turtles, showing a continued recent trend of very low daytime use of the *Lagoon* by turtles.

In-water sleeping and resting behavior of turtles at Kiholo Bay has only been documented as non-quantitative observations made in association with tagging operations in eastern Kiholo Bay. In the late 1990s, 40 to 85 turtles were captured in vicinity of the lagoon during tagging missions (Balazs et al. 2000), and 42 turtles transiting the inland ponds were netted and tagged (Harrington et al 2002). Authors of both of these studies noted that the turtles in the lagoon and ponds were commonly observed resting, feeding or basking during the daytime and often found sleeping in the same environs during nighttime. Since the time of these studies, there have been no nighttime observations performed in the lagoon, so it is not known if turtles presently use the lagoon for night resting.

Section 5. Comparisons of 2021 monitoring results with previous observations and studies.
As documented earlier in this report, numbers of in-water turtles in the *Lagoon* steadily increased from about 15 in 1973, to range of 11 to 37 in 1987-89, and to maximal numbers of 40 to 85 in the 1990s. In experience of the author, over the last two decades numbers of in-water turtles seen in the *Lagoon* have gradually declined to levels that were less than half of those in the 1990s. Turtles began to bask on *Lagoon* shores in the early 1990s, with numbers of *Lagoon* basking turtles peaking in range of 30 to 55 in 2013-2015. Twelve counts performed in the *Lagoon* in February to July of 2021 yielded count averages of only 4.3 in-water turtles and only 3.9 basking turtles. Collectively, these count numbers indicate that major decreases in numbers of daytime in-water and basking turtles have occurred in the *Lagoon* over the last four to six years.

In 2013, it was determined that about 33 turtles resided in the inland ponds, spending about 64 percent of their time in the ponds. Average numbers of in-water turtles counted in monthly tallies in *West Pond* and *East Pond* increased from 38 in 2015 to 48 in 2020 (The Nature Conservancy, 2013-2021, unpublished data). In early 2019, about 30 to 35 turtles were using the inland ponds (M. Rice, personal communication, 2021). Daytime counts of early 2021 documented in this report yielded an average number of turtles in the ponds of 31.5 (Table 2). Overall data of these four sources indicate that numbers of turtles observed in the ponds over the last six years have remained in a relatively narrow range (of 31 to 48), with most of the variability in ponds turtle numbers probably caused by diurnal movement of turtles in and out of the ponds.

Basking turtles are rarely seen in *West Pond* and *East Pond*, and typical sightings are usually of only a single individual at a time and have never reported more than four basking honu (Rice et al. 2013; S. Henderson & TNC staff, 1990 to 2021, personal observations). No basking turtles were seen in the inland ponds in the 2021 counts performed by the author. The numbers of turtles observed basking in the inland ponds are too few for any meaningful trends to be identified in that regard. Use of the *Shoreline* zone for basking is also very low, as only two basking turtles were seen in 2021 counts, both on the same day. Prior to 2021, there have been no formal counts of in-water or basking turtles in the *Shoreline* zone, so the recent data is useable only as baseline data for comparison to future counts.

For the 266 turtles (in-water and basking) enumerated in Kiholo Bay and the inland ponds during the February to July 2021 surveys, average SCL was 46.6cm, and average SCL of in-water and basking turtles were 45 cm (219V) and 53.9 cm (49V), respectively. SCLs of the 2021 counted turtles ranged from 28.0 to 77.2 cm. In a May 1973 visit to Kiholo Bay, G. Balazs captured, tagged and measured 15 turtles of

49.2 cm average SCL in a size range of 37.3-66.0 cm (unpublished data). SCL measurements of 313 Kiholo turtles tagged from 1980 to 1995 fell within a range of 33.2 to 71.5 cm (Balazs et al. 2000).

Section 6. Summary of past and recent observations of turtles and their food sources at Kiholo Bay. Total numbers of turtles within the greater area of east Kiholo Bay increased steadily from the late 1970s to about year 2000 with an estimated peak population of about 260 turtles. All turtles inhabiting Kiholo have been of immature size/age range (28 to77 cm). Tagging studies have shown that the turtles at Kiholo Bay have high site fidelity (Balazs et al. 2000), and there have been very few documented instances of turtles migrating to and from sites away from the bay.

Typical diet of green sea turtles at Kiholo consists of algal turfs comprised of red and green algae with small amounts of brown algae, cyanobacteria, and animal material. Most algal turf found on substrates in all microzones of east Kiholo Bay and inland ponds is very closely cropped, showing signs of intense continuous grazing by fish, mollusks, echinoderms and turtles. Fully developed macroalgae thalli are almost never seen on any substrates in inner Kiholo Bay, presumably because of intense grazing. Overall, this closely trimmed condition of substrates in the inner bay and inland ponds has existed continuously for at least the last 40 years (S. Henderson, 1980-2021, personal observations).

Turtles began entering and feeding in *West Pond* and *East Pond* in the late 1980s, and over the last two decades about 40 to 70 turtles have been using the ponds, primarily for feeding and resting. In *West Pond*, small honu graze heavily on algal turf, predominantly filamentous turf-forming chlorophytes, growing on extensive shallow pahoehoe outcroppings near strongly-mixed inflow and outflow of water near mouth of the ʻauwai. Larger turtles graze on mixed algal turf in *East Pond*, and some turtles rest and possibly feed infrequently on invertebrates in the warm bottom mulm layer of the pond.

The resident turtle population in the *Lagoon* peaked around 2013 to 2015 as indicated by informal counts of 30 to 55 basking turtles. Most basking by turtles in Kiholo Bay takes place on shores of the *Lagoon*. Turtles are less frequently seen grazing in the *Lagoon*, as compared to other inner bay zones, i.e. the *Shoreline*, *West Pond* and *East Pond* zones. Algal turf on hard substrates in the *Lagoon* is relatively sparse with low abundance of chlorophytes, and is very heavily grazed by fish and mollusks, and to lesser degree by honu.

Textural characteristics of hard substrates can affect grazing access of turtles to benthic algae. Large exposed areas of smooth basalt surfaces allow a wide variety of small to large herbivores to graze algal growth. However, rock and coralline surfaces with fractured, porous and folded surfaces (high rugosity) can hide algal turf in recesses where large animals like turtles cannot effectively browse. In the *Lagoon*, the entire 1.3 acres (0.5 ha) area of hard substrate along the west shore consists of rounded boulders and cobbles with substantial amounts of narrow interstitial spaces between them where algal turf commonly grows, but only small organisms like crustaceans and gastropod mollusks can forage. Additionally, the convex contours of the rounded boulders and cobbles are much more difficult for large-beaked animals like turtles to effectively graze as opposed to large flat surfaces formed by fracturing along lava flow edges. Therefore, most of the west shore broken hard substrate of the *Lagoon* is not favorable for effective grazing by turtles, whereas most of the east shore which is comprised of flatter lava surfaces is more conducive to grazing.

Consistent numbers of small turtles have frequented the inner bay *Shoreline* shallows for at least the last three decades intensely grazing abundant algal turf growing on relatively smooth pahoehoe surfaces. Entrapment of high-nutrient spring water along the shoreline sustains high biomass of algal turf, much of it consisting of green algae species preferred as food by turtles.

Section 7. Relationship of food availability to turtle abundance, size, and feeding and basking behaviors within Kiholo Bay microzones.

The most dramatic recent change in abundance of turtles in Kiholo Bay occurred in the *Lagoon* where in-water and basking turtle numbers declined to extremely low numbers (Tables 2 & 3). It appears that about 50+ turtles that resided in the *Lagoon* over the last decade are no longer there, at least not during daylight hours. The *Lagoon* contains about 2 acres (0.8 ha) of hard substrate with low algal turf prevalence sustained by medium dissolved nutrient levels yielding a nutriment (food availability) index of 4.2 (Table 3). That index is lower than the values calculated for the other three Kiholo Bay zones (Table 3), leading to conjecture that low food availability may have caused *Lagoon* turtles to move elsewhere to forage. Kiholo turtles have historically shown high site fidelity (Balazs et al. 2000) so a

Table 3. Present day estimated conditions of substrate (A), algal turf (B), dissolved nutrient levels (C) and recent turtle abundances in four primary use areas of Kiholo Bay. Also shown is "nutriment index" for each use area calculated as a product of (A) X (B) X (C) to provide approximate relative measures of amounts of benthic algae (turf) food that may be available in the four areas.

	Hard Substrate in Acres **(A)**	Algal Turf Prevalence **(B)**	Relative Dissolved Nutrients Level (Proximity to Submerged Ground Water Sources) **(C)**	Nutriment Index **(A)** X **(B)** X **(C)**	Average No. of In-Water/Basking Turtles in 2021 Counts
LAGOON	2.1	Low (1)	Med (2)	**4.2**	4.3/3.9
INLAND PONDS	0.8	Med to High (2.5)	Med to High (2.5)	**5.0**	31.5/0
INNER BAY	8.1	Low (1)	Low to Med (1.5)	**12.1**	No Data
SHORELINE	2.1	Med (2)	High (3)	**12.6**	12.0/0.3

preliminary assumption is that the food-deprived lagoon turtles might have moved to a more productive foraging site within the confines of Kiholo Bay.

However, there does not appear to have been a recent significant increase in turtles using the *West Pond*, *East Pond* and *Shoreline* zones, at least not enough to account for the 50 or so turtles that have abandoned the *Lagoon*. On the other hand, the *Lagoon* turtles may simply have moved into the immediately adjacent 8 acres (3.2 ha) of the *Inner Bay* zone, where the nutriment index of 12.1 is relatively high (Table 3). Turtles have never been formally enumerated in this zone as it is within surf zone where in-water visibility is often limited, so there are no rigorous past or present data on turtle abundance and use in that zone. However, casual observations of turtles made within this zone in the course of numerous kayaking traverses over the last three decades indicate that abundance of turtles in the inner bay has not increased, but instead has declined considerably over about the last five years (S. Henderson, 1990-2021, personal observations).

For about four decades after 1980, juvenile and sub-adult turtles, generally of 28 to 77 cm SCL, have steadily recruited to and resided at Kiholo Bay and have grown at slow rates of 1-2 cm carapace length per year (Balazs et al. 2000, Rice & Jim 2020). From 1998 through 2018, 776 measurements made at Kiholo, that included both initially-tagged and later-recaptured turtles, found that none of those turtles were greater than 80 cm SCL. Additionally, nearly all 569 turtle SCL measurements at four other west Hawai'i island coastal sites over the same period were also less than 80 cm in SCL. Note that these measurements were made on turtles at time that they were tagged, but also on tagged turtles that were re-captured at various times after tagging.

In comparison, about three percent of 174 turtles monitored in time-frame of 1998 through 2018 on east coast of the island at Kapoho Bay were larger than 80 cm SCL (Rice & Jim 2020). Observations of turtle populations throughout the main Hawaiian Islands for many decades have shown that the east (windward) coasts of the islands invariably host turtles that are considerably larger in size than those seen on west (leeward) coasts. Some marine researchers theorize that larger turtles migrate to and permanently reside on the windward coasts because those environs harbor more abundant and diverse growth of macro-algae that the turtles feed on to sustain their increasing energy needs that come with increasing body mass (Rice and Jim 2020, Balazs and Chaloupka 2004, Wabnitz et al. 2010).

Large numbers of turtles exceeding 80 cm in SCL are commonly seen foraging on rich growth of macroalgae in surge zones along the eastern coasts (Hamakua, Puna and Ka'u) of Hawai'i Island and on seaward surfaces of the Hilo breakwall. Additionally, mixed sizes of turtles venture into intertidal brackish shallows in many eastern coast estuarine environs to graze on several species of grass such as seashore paspalum (*Paspalum* vaginatum), California grass (*Urochloa* mutica), honohono grass (*Commelina diffusa*), sedges (*Cyperus* spp) and rushes (*Jancus* spp) (S. Henderson, 1990-2021, personal observations).

Over the last 50 years, the author has observed that algal turf in Kiholo *Lagoon* and *Inner Bay* has been sparse and very close-cropped with virtually no full-growth macroalgae visible. This close-cropped state has been continuously maintained over the long-term, apparently by intense grazing pressure by a wide variety of abundant mollusks, short-spine urchins, crabs, herbivorous fish and, more recently, by turtles. Honu have steadily increased in numbers at Kiholo Bay since protected by Federal law in 1978, and by a 1995 State designation of Kiholo Bay as an area where gill-netting is prohibited. These protective actions undoubtedly contributed significantly to Kiholo turtle population increases, and the gill-net ban also substantially reduced take and increased abundance of herbivorous fish such as tangs, parrotfish, nenue and mullet in the bay. Overall, increased abundance of and turtles and herbivores fish have likely led to substantial increases in grazing of benthic algae in the bay.

Steady increases in herbivore abundance in conjunction with the historic paucity of macro-algae in the inner bay raises the possibility that primary production (benthic algal growth) in the bay may no longer be able to sustain the Kiholo turtles in a healthy condition, i.e. the Kiholo Bay turtle population may have reached carrying capacity, possibly by the mid-1990s (Balasz and Chaloupka 2004). A similar situation is likely occurring in nearby Kaloko-Honokohau bay where resident turtles show reduced growth rates and poor body condition, and ecosystem analysis has revealed that combined grazing consumption of herbivore groups including reef fish, sea urchins and turtles matched total algal production (Wabnitz et al. 2010). Recent observations of turtles at west Hawai'i locales such as Kiholo, Kaloko-Honokohau and Honaunau -Kona found that many individuals are moderately to severely emaciated (as seen in Fig.13) likely as a result of malnourishment due to lack of food. In comparison, turtles at east Hawai'i locales such as Kapoho Bay where macroalgae and estuarine grasses were abundant displayed "normal" robust body condition (Rice & Jim 2020).

Assessment of somatic growth dynamics of turtle populations foraging at Midway Atoll, Kaneohe Bay (Oahu), Pala'au (Molokai), and Punalu'u Bay (Hawai'i Island) and Kiholo Bay indicate that growth rates have decreased in all of those populations as the abundance of turtles has increased throughout the Hawaiian archipelago (Balazs and Chaloupka 2004). The same study notes that there has also been an increase in basking of turtles in the main southeastern islands since the early 1990s (as documented also in several other citations in this report), and some investigators suggest that basking may increase digestive efficiency to compensate for increasing abundance and reduced per capita food supply, and that basking may be an energy saving measure for under-nourished turtles.

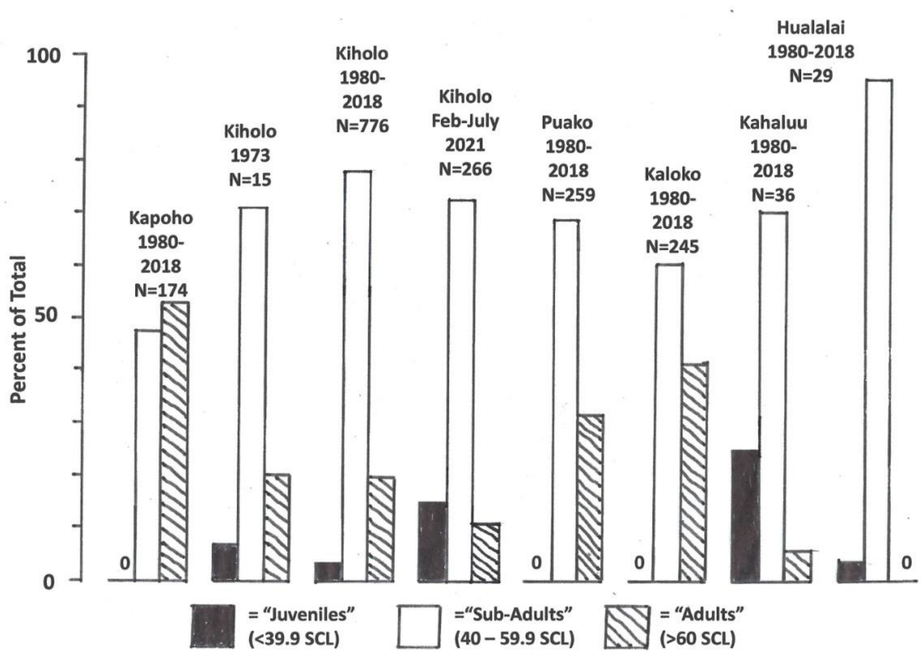
Figure 13. Emaciated turtle of estimated 50 cm SCL size basking at Kiholo lagoon east shore.
Photo by S. Henderson, 2/24/2021, 1522 hrs.

The suggestion that increased basking behavior is a response to reduced food supply is not supported by the recent trends observed within the Kiholo *Lagoon*, wherein numbers of basking turtles have instead declined to very low numbers and some of the remaining baskers appear emaciated (Fig.13). Additionally, turtles do not bask in significant numbers in other areas of Kiholo Bay as might be expected if they have greater need to bask to conserve energy and increase digestive efficiency.

Discussion that follows addresses the author's hypothesis that the trends and recent significant changes in turtle abundances within the primary Kiholo East Bay turtle use zones can be attributed at least in part to effects caused by the overall Kiholo Bay turtle population exceeding carrying capacity relative to nutritional needs.

The largest change in 2021 turtle numbers took place in the *Lagoon* zone where counts of both basking and in-water turtles declined drastically within a relatively short time of three to four years (Table 2). This apparent movement of turtles away from the *Lagoon* could be consistent with an exceeded carrying capacity scenario, especially if biomass of algal turf in the *Lagoon* has declined to a level that can no longer sustain a sub-population of 50+ turtles in that zone.

Figure 14. Histograms of "juvenile", "sub-adult" and "adult" size classes of Hawai'i Island turtle populations. The three size classes are result of grouping 5-cm intervals data from the listed references into larger SCL groups of <39.9 cm, 40-59.9 cm and >60 cm. References: Kiholo, 1973 (G. Balazs, 1973, unpublished data**); Kiholo, Feb-July 2021** (S. Henderson data reported in Sections 4 and 5 above); **Kapoho, Puako, Kaloko, Kahaluu & Hualalai, Kiholo, 1980 to 2018;** (Rice and Jim 2020).



However, it is not immediately obvious where the *Lagoon* turtles have moved to. There is no evidence from past and recent studies to suggest that there has been a significant recent influx of turtles into the nearby *Inner Bay*, *Shoreline* or *West* and *East Ponds* zones. Thus, the cumulative abundance data for all Kiholo turtle use zones point toward an overall recent significant movement of turtles away from the east sector of Kiholo Bay, either into other areas of greater Kiholo Bay or into other coastal areas of Hawai'i Island where algal/plant forage is more abundant (e.g. windward coasts). Indeed, it appears that turtles may have routinely emigrated away from Kiholo Bay for decades as they approach maturity and reach size of of about 80 cm SCL, when their energy requirements begin to expand beyond what is available from sparse algal turf in east Kiholo Bay.

An emigration scenario is reinforced by the fact that none of the somatic body lengths measured or estimated on all initially-captured, recaptured and transect-sighted 1,057 Kiholo turtles from 1973 to 2021 exceeded 80 cm. Additionally, length measurements of 569 initially-captured and recaptured turtles at four other west Hawai'i island sites from 1980 to 2018 also recorded no turtles of SCL greater than 80 SCL. In comparison, 174 measurements of SCL on turtles at Kapoho, an east Hawai'i island bay, found that 53 percent of that population was in size range of 60 to 90 SCL. Thus, it could be surmised that since no Kiholo turtle of greater than 80 cm SCL has ever been recorded, they very likely emigrate away from Kiholo before attaining that size.

Size-class plots of Kiholo turtle SCLs obtained in 1973, 1980 to 2018 and 2021 show remarkably similar abundances of sub-adult (40 to 59.9 SCL size class) turtles expressed as percent of total number of measured (observed) turtles (Fig.14). Those values are 72, 79 and 74 percent for the three sample periods. Percent of total values for juvenile turtles (25 to 39.9 SCL size class) are very similar for the 1973 and 1980 to 2018 samplings (seven and four percent, respectively). But by 2021 the percent of juveniles increased substantially to 15 percent. For large sub-adult turtles (60 to 79.9 SCL size class), percent of total values are similar for the first two samplings (20 and 21 percent), but decrease to only 11 percent by 2021 sampling (Fig.14).

The substantial increase in percentage of small size class turtles seen in the 2021 data (Fig.14) is most likely attributable to increased recruitment of pelagic juveniles into the Kiholo population, whereas the low percentage of large sub-adult turtles in the same population is most likely a result of continued out-emigration of that size class, possibly to more algal-rich east Hawai'i island coast sites.

Section 8. Results & conclusions summary. Abundance of turtles in Kiholo Bay increased dramatically from 1980 to 2015. Initially, feeding and resting behavior of the growing Kiholo Bay turtle population occurred primarily in the lagoon and inner bay zones. In the late-1980s, turtles began to transit *West Pond* and *East Pond*, initially using the pond environs for resting and subsequently for foraging and infrequent basking. Numbers of turtles observed in the inland ponds peaked at about 58 in 2017 and hovered in a relatively stable range of 42 to 53 from 2018 through early 2021.

Present-day foraging by sub-adult turtles in the bay is concentrated in the *Inner Bay*, *West Pond* and *East Pond* zones with minimal feeding activity occurring in the *Lagoon*. Large numbers of juvenile and small sub-adult turtles feed primarily in the inner bay beach-front shallows and in the *West Pond* shallows near the 'auwai channel inflow. Numbers of turtles using the *Lagoon* for day-time foraging and resting have fallen to extremely low levels over the last decade.

Size structure of the overall Kiholo turtle population has remained fairly constant from 1973 to 2018, but very recently has experienced a three-fold increase in percentage of juveniles and nearly a two-fold decrease in percentage of largest size-class adults, indicative of a recent surge in recruitment of juveniles and a simultaneous increase in emigration of larger adults away from Kiholo Bay.

To date there are only rough estimates of total numbers of turtles extant in the eastern Kiholo Bay population (e.g. about 260 turtles in 2000). Additionally, there are no reliable estimates of annual recruitment or out-emigration of turtles in the bay. Therefore, it is not possible at present to determine quantitative effects of estimated annual mortality rate of four to seven turtles per year potentially caused by various human and predatory factors (from Section 3 above) on the Kiholo Bay turtle population. But none of those factors were likely to have played a significant role in the recent substantial decline of turtles present in the *Lagoon*.

In the mid to late 1990s, turtles began basking on *Lagoon* shores and basking numbers increased steadily to 30 to 55 commonly seen in 2013-2015. Only a very small number of turtles have been seen basking in Kiholo areas other than the lagoon. From about 2015 to present day, turtle basking in Kiholo Bay, primarily in the *Lagoon*, has declined about 10-fold to very low numbers.

In the lagoon, benthic and planktonic algal biomass was likely very high before 1960 when only one narrow pass existed in the Lagoon, and low flushing and long residence time of water in the *Lagoon* would have supported high-nutrient (eutrophic) conditions conducive to algal growth. However, benthic algal biomass in east Kiholo Bay has been consistently low since about 1970, existing largely in the form of very closely cropped algal turf that is intensely grazed by fish, invertebrates and turtles. Steady growth of algal turf in the inner bay and inland ponds is sustained by high influx of dissolved nutrients carried in high volume of groundwater inflow.

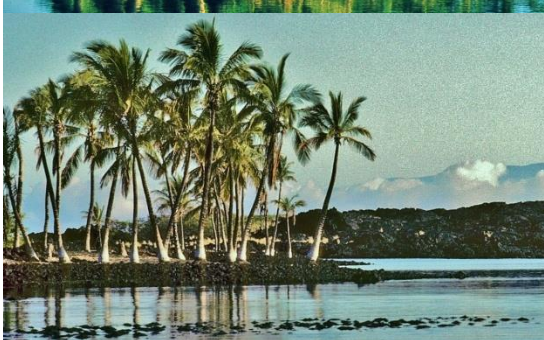
The recent extreme decline in daytime use of the *Lagoon* by turtles may be linked to the fact that the overall abundance of turtles in the bay has apparently reached carrying capacity. Increasingly large numbers of turtles grazing in the *Lagoon* have had to compete with an abundance of other grazing organisms for several decades, possibly now resulting in an over-grazed status of *Lagoon* algal turf to a degree wherein it can no longer sustain large numbers of turtles. Most juvenile and sub-adult turtles may have moved away from the *Lagoon* to richer feeding grounds in the inner bay shallows and inland ponds as evidenced by their higher abundances in those areas. Adult turtles, no longer able to efficiently sustain themselves on sparse algal turf of east Kiholo Bay apparently emigrate to richer grounds away from Kiholo Bay.

It has been suggested by some researchers that basking behavior by turtles may be a means of conserving energy, particularly in settings where they must expend considerable amount of effort in grazing of depauperate algal turf, such as on the *Lagoon* substrates. However, this theory is not backed by data presented in this report indicating that basking by Kiholo turtles has drastically declined, even as the population has apparently exceeded carrying capacity and might be expected to employ energy saving behaviors.

APPENDIX A. Environmental history of Kiholo lagoon and coconut palms planted on the lagoon shores.

In the early 1920s, several hundred coconut palm seedlings collected at Waipio Peninsula, Pearl Harbor, Oahu were transported to Kiholo and were planted at Kiholo beaches and several other shoreline locales in North Kona (Marion Kelly, 1996). About 40 of the seedlings were planted along the eastern edge of the lagoon peninsula and the extreme southeast shore of the lagoon, and about 150 seedlings were planted at beachfront of inner Kiholo Bay (at present properties of TNC, Hind, Gendreau and Porteus). By the mid-1950s, all of the seedlings planted at the lagoon and at beachfront inner bay had matured into 20 to 30-foot tall palms (Figs. A-1 and A-2). However, from about 1970 to present day (mid-2021), the 37 palms planted on the eastern shores of the lagoon have steadily died off to point where only two survive (Figure A-2). Over the same time interval, over 90 percent of the inner bay shoreline grove of over 150 palms (planted at the same time as the lagoon palms) have survived with low mortality and reached heights of 30 to 70 feet (Figure A-3). Those groves are now nearly 100 years old, but are in generally good health, with small numbers of those palms succumbing to a fungal disease *(Phytophthora)* that has been prevalent throughout Hawai'i for several decades.

Figure A-1. Progression of die-off of the coconut palm grove at Kiholo lagoon peninsula beach in 1957 (left), **1982** (center left), **2005** (center right) **and 2016** (bottom left).



In an attempt replace the iconic coconut palms that were rapidly dying at the lagoon, volunteer work crews planted 150 common coconut palms (obtained from various Island of Hawai'i locales), seven loulu palms and 10 Samoan palms from 2002 to 2018 along the eastern shore of the peninsula. Only four of the Samoan palms and one common coconut palm survive today, and are showing signs of poor viability. Several treatments of common fertilizers, trace element supplements, insecticides and fungicides were applied to some of the young palms, with no visible positive effect on survival.

Figure A-2. Coconut palm grove on Kiholo inner bay shoreline in 2018 (at ca 96 yrs age). This grove was planted at same time as the lagoon peninsula beach grove of Fig A-1, above.

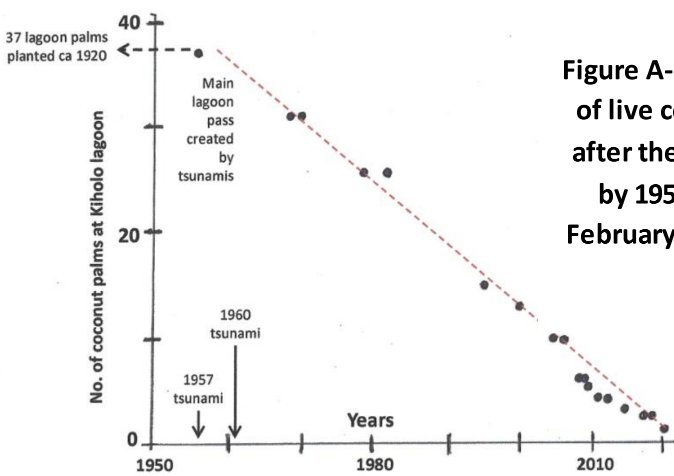


Figure A-3. Temporal decline in number of live coconut palms at Kiholo lagoon after the main lagoon pass was formed by 1957 and 1960 tsunamis. In late February 2022, only one highly stressed palm remained.

Eventually, it was concluded that elevated ground water salinity was the primary cause of mortality of palms at the lagoon. Refractometer measurements of lagoon surface and ground (anchialine) waters in the area where most of the replacement palms were planted at the peninsula beach yielded salinities in range of 18 to 24 ppt over time frame of 2011 to 2020 (Table A-1). In contrast, measurements that characterize ground water salinities in the vicinity of the inner bay shoreline palm groves over the same time interval show average salinities of only 3 ppt. As mentioned earlier, major increase of ocean water intrusion into the lagoon following the 1957-1960 creation of a new large pass likely caused salinity levels in the lagoon and in the surrounding ground water to increase markedly from low levels, that were probably consistently less than 10 ppt, to the levels of 18 to 24 ppt seen over the last decade.

In summary, 1960 creation of the large pass into the lagoon would have had a two-fold effect on the lagoon ecosystem; firstly, by drastically reducing water residence time of the lagoon waters, thereby reducing availability of nutrients and causing decline in growth of benthic and planktonic algae in the lagoon and secondly, by exposing the mature lagoon palm grove to deleterious effects of sharply increased salinity levels.

Table A-1. Refractometer salinities measured over period of 2011 to 2020 at Kiholo lagoon and inner bay shore locations proximal to recently planted or mature palms. Most measurements were made at or near high tide levels. Numbers are averages (in parts per thousand of salinity) with number of values (N), S. Henderson data.

<u>LAGOON SURFACE & PENINSULA ANCHIALINE WATERS</u>	
Lagoon end, surface water near max spring flows	**18.2** ppt (5N)
Lagoon beach, surface water 80 m from main pass	**22.2** ppt (5N)
Lagoon mid-peninsula, anchialine puddles near coco palms plantings	**24.0** ppt (3N)
<u>INNER BAY SHORE WELL & ANCHIALINE WATERS</u>	
Bay shore well or anchialine puddles in vicinity of mature palm groves	**3.0** ppt (9N)
Bay shore beach houses well-derived tap water	**3.1** ppt (9N)
Hind anchialine fish pond, 50 m from bay shoreline	**3.0** ppt (3N)

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The following website maintained by George Balazs provides link to a section called "West Side Stories-Marc Rice and the Hawaii Preparatory Academy" with an extensive listing of references related to studies of honu at Kiholo Bay: https://georgehbalazs.com/himb-historical/west-side-stories/

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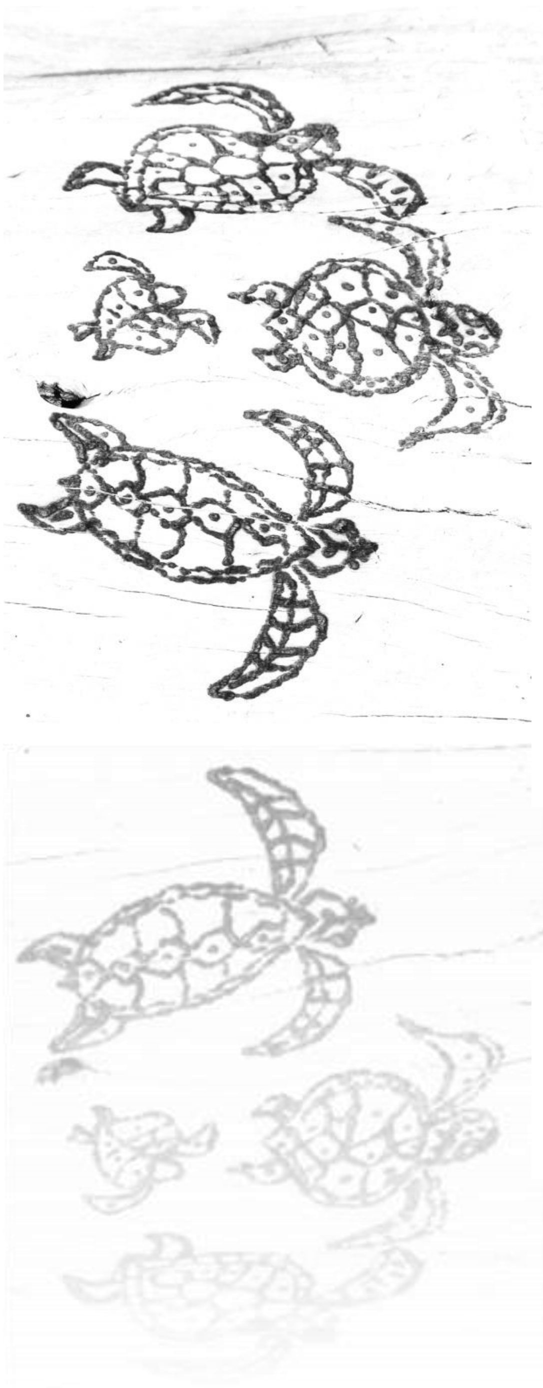

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An informal report to Hui Aloha Kiholo

authored by Scott Henderson

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