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Leatherback skull from Suriname in the late 1960s with signs of injury from a jaguar. Photo credit: N. Mrosovsky.

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Settling Down in Hawaii: Adaptation of Captive-bred Green Turtles (*Chelonia mydas*) Released from the Maui Ocean Center

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There is a continuing conservation interest in and need to obtain additional information on the adaptation of sea turtles released into the wild after extended times in captivity, particularly for green turtles (*Chelonia mydas*), which are the historical species for food harvest. Examples include turtles released from rehabilitation and educational display aquaria, and from facilities rearing hatchlings for varying periods of time for research or for restocking efforts. Arrays of local communities and entities throughout Oceania, Australasia and East Asia have long-standing traditions and policies for raising and releasing green turtles in head start programs seeking to increase survival in the wild. However, it is outside the scope of this paper to debate the pros and cons of such practices. The desire to rear and release in these areas is deeply rooted; hence it should be respectfully acknowledged and discussed in a sensitive manner for mutual learning leading to improved practices.

Inferences about successful adaptation into the wild can be made only if the turtles released have been: 1) effectively tagged or facially identified as individuals or tagged/marked by year-class cohort, 2) identified through molecular genetics techniques, or 3) tracked by remote electronic monitoring such as satellite telemetry. Furthermore, it seems intuitively logical that the release locations be ecologically congruent with the turtles' sizes (e.g., benthic coastal vs. offshore surface pelagic). Possible criteria to gauge successful adaptation, or lack thereof, may include: 1) survival in the wild over time; 2) movements and behaviors; 3) residency in habitats used by wild turtles for foraging and benthic resting; 4) somatic growth rates; 5) prey items; 6) body condition; 7) health; and ultimately, 8) successful reproduction through mating and egg deposition.

In the present study we employed satellite telemetry to glean insights into several of the above adaptation elements for four

captive-bred green turtles reared and released from the Maui Ocean Center in the Hawaiian Islands from 2003-2006.

Brief Background of Captive Breeding in Hawaii: Green turtles obtained from Hawaiian waters by Sea Life Park on Oahu in the 1960s have nested and produced hatchlings on a small artificial sand beach every year since 1976 (see Bourke *et al.* 1977; Owen & Blanvillain 2013; Wu 2011). Most of the ~14,500 hatchlings produced over these 38 years have been released shortly after emergence at a natural beach 500 m from Sea Life Park. Starting in 1989, a few hatchlings were retained each year for an educational loan program to facilitate the display of small turtles less than ~35-40 cm straight carapace length (SCL) at qualifying aquaria in Hawaii and the mainland USA. Steven Kaiser and Kanela Danny Akaka Jr., the program's originators, called this outreach the "Hawaiian Sea Turtle Ambassador Program." The rationale of the program was that living sea turtles, especially "baby" turtles, are their own best advocates for conservation when viewed by the public. The end-point of each loan occurred when the turtles approached the carrying capacity of their display tanks and were certified healthy by a veterinarian for release into Hawaiian waters. Head starting has not been the purpose of the program, although at times this aspect has been given inappropriate emphasis by the news media and others. The program's ongoing fundamental goal is the enhancement of public awareness on behalf of sea turtles. Although the data are not currently conclusive, recent studies have highlighted the potential importance of Sea Life Park's offspring in relation to a new 'founder' nesting colony at Kawa'aloa, Molokai, and a few other newly documented nesting locations in the Main Hawaiian Islands (Dutton *et al.* 2008; Dutton *et al.* 2014; Frey *et al.* 2013).

For the past 25 years, most (>200) of the captive-reared loaner turtles in the Sea Life Park program have been released as part of the July 4th "Turtle Independence Day" celebration at the Mauna Lani Bay Resort on the South Kohala Coast of the island of Hawaii (Balazs *et al.* 2002). However, starting in 1998, post-hatchling turtles born at Sea Life Park were sent to the Maui Ocean Center at Ma'alaea on the island of Maui. A total of 48 healthy and robust juveniles have thus far been PIT tagged and released into Maui's nearshore waters. Four of these turtles, ranging from 2.5-4.0 years in age, 45-56 cm SCL, and weighing 14.1-25.4 kg were equipped with carapace-mounted Telonics satellite tags. Straight carapace length (SCL) was measured to the nearest 0.1 cm and flipper tags and PIT tags were inserted into the hind flippers.

Argos satellite-linked transmitters (model ST-24 manufactured by Telonics, Inc., Mesa, AZ) were attached to four juvenile green turtles between 2003 and 2006. Transmitters were attached to the turtle's carapace safely and securely with polyester surfboard resin and fiberglass cloth following the procedures used in Balazs *et al.* (1996) with the size and placement of the fiberglass strips modified for the smaller transmitter size. Transmitters were programmed with a duty cycle of 12 hours on and 48 hours off. Units were turned on at a time computed to synchronize with optimum satellite overpass coverage. The raw Argos data were processed by CLS using least squares analysis. Only positional data were collected with data and estimates of location accuracy provided by Argos (CLS-America, Inc., www.argos-system.org). Data were then assessed and positions were considered unacceptable if: 1) they were located on land, 2) the speed of travel between two locations was over 5 km/hr, or 3) the position made a turn greater than 90 degrees in less than a 24 hr period. Decisions for excluding a position were rigorously based on these criteria. The best daily location and the great circle equation with the WGS84 ellipsoid were used to compute distance traveled (Bowditch 1995). When available, location classes (LCs) of 1, 2, or 3 were used for distance calculations; when unavailable, distance was calculated using positions closest to noon UTC (Coordinated Universal Time) after unacceptable positions had been removed. The final location of a track was determined either by the last Argos position or when positional locations clustered in one general area for more than 1 month. The earliest date at an end point was considered the end date for distance calculations. Maps were created for each turtle using the Generic Mapping Tools program developed by Wessel & Smith (2014) following procedures of Ellis & Balazs (1998).

Tracking durations for the four turtles ranged from 267-481 days (Table 1, Figs. 1-4). The 2003 turtle was set free 11 km south of Maui in the Alenuihāhā Channel, while the other three turtles were released <1 km of shore near 'Ahihi Bay, Maui. Three of the turtles exhibited discrete movements away from their release site, while turtle ID 50139 (Fig. 1) remained within 4 km of the release site throughout satellite tag transmissions. Turtle ID 50139 was seen often and was reported by divers at popular dive areas from Makena to Pu'u o Lai a total of 6 times (approximately once or twice a year) between 2006 to 2010, after which any identifying marks including remnants of fiberglass from the transmitter attachment had faded. The turtle remained healthy looking and robust for up to 4 years after release based on the photographs sent to us for ID confirmation.

Of the turtles that moved away from the release site, two stayed primarily in Maui's coastal waters. Turtle ID 23537 (Fig. 2) traveled for 31 days to the northern coast of West Maui, spending 80 days

Argos ID	SCL (cm)	Tag nos.	Release age	WT (kg)	Deployment Date	Deployment Location	Final location	Date terminated	Days traveling	Total days transmitting
50139 Maile	44.6	YQ-82, 4526517C6A, 4528446710	3 yr	14.3	09 Aug 2006	20.6N 156.4W	Maui 20.7N 156.6W	03 May 2007	0	267
23537 Kimo	47.1	445473205A, 4438572504	4 yr	15.2	09 Aug 2006	20.6N 156.4W	Maui 20.9N 156.9W	02 July 2007	184	327
22279 Kupualoha	56.8	ZG08 (tag lost), 422D517229, 4237526A39	4 yr	24.9	28 Oct 2004	20.6N 156.4W	Maui 20.9N 157.4W	26 Sept 2005	90	333
19603 Nakine	46.2	ZG01, 42502F041B, 424D380C5A	2.5 yr	15.4	08 Mar 2003	20.5N 156.3W	Oahu 21.7N 158.0W	08 July 2004	55	487

Table 1. Data for the four green turtles released from Maui with Telonics ST-24 satellite tags between 2003-2006. Information includes straight carapace length (SCL), age, weight (WT), date and location deployed, number of days traveling and total days the tags transmitted.

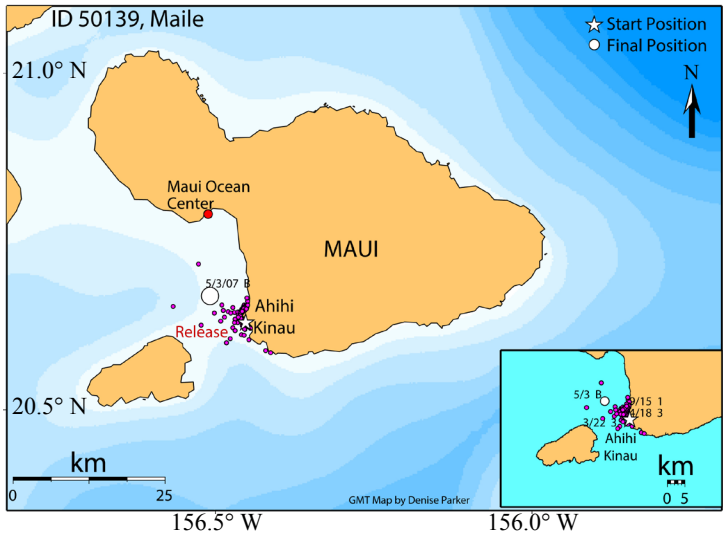

Figure 1. ID 50139, "Maile." Released in 2006, Maile stayed near its release point near Pu'u o Lai, Ahihi Kina'u, Maui. The tag transmitted for 267 days and the turtle was re-sighted in this area for 4 years after release. Bathymetry is represented with a change of color every 250 m.

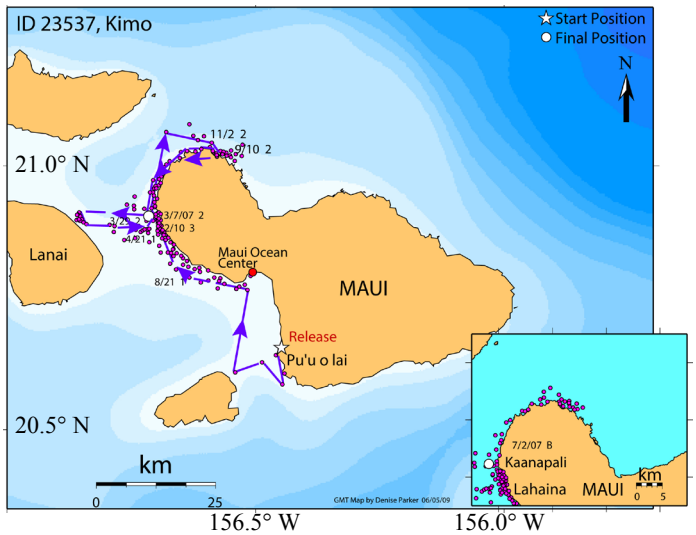

Figure 2. ID 23537, "Kimo." Released in 2006, Kimo traveled clockwise around the island of Maui, settling near Waihikuli after 184 days. Bathymetry is represented with a change of color every 250 m.

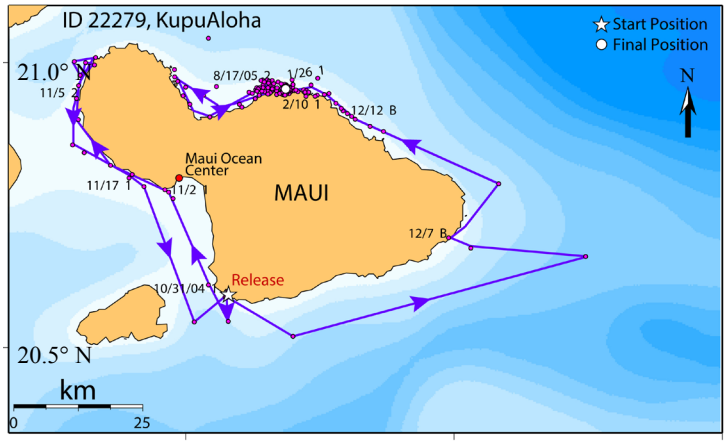

Figure 3. ID 22279, "Kupualoha." Released in 2004, Kupualoha initial traveled clockwise around Maui up to Napili Bay before reversing direction and traveling counter-clockwise around the island of Maui to settle near Haiku, Maui after 90 days. Bathymetry is represented with a change of color every 250 m.

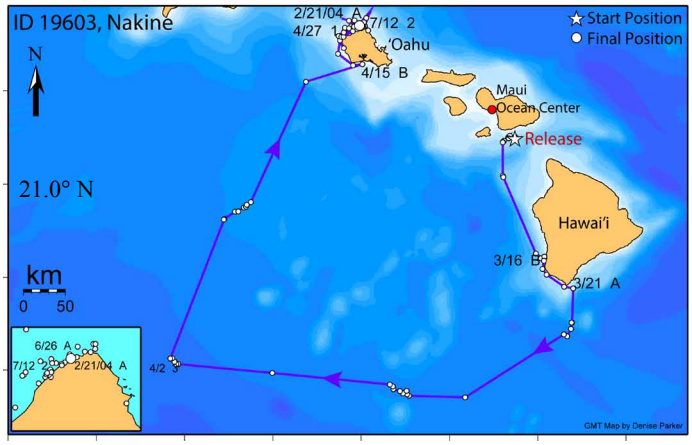

Figure 4. ID 19603, "Nakine." Released in 2003 11 km offshore of Maui in the Alenuihāhā channel, Nakine traveled 1,418 km along the coast of the island of Hawai'i and south of the islands in the open ocean before stopping near Waiale'e, Oahu after 55 days. Bathymetry is represented with a change of color every 250 m.

near Nakale'le and the Poelua Bay area. Subsequently, an 8-day foray was made 15 km across the Auau Channel to the northeast coast of the island of Lanai before returning to Maui and remaining in the Wahikuli area between Lahaina and the Kaanapali Beach Resort. Transmissions for this turtle lasted 327 days. Turtle ID 22279 (Fig. 3) first swam to the Napili area at the northwest end of Maui over a 16-day period. The turtle then reversed direction and swam counter-clockwise around Maui, past the Ahihi Kina'u site of release, to settle into the Haiku Kuhiaha area of Maui's north coast 90 days post-release. At one point during this segment, the turtle appears to have traveled 25 km into the 'Alenuihāhā channel before returning closer to Maui's eastern shore. After 51 days at Haiku Kuhiaha, the turtle moved east and spent 10 days near Waihe'e (Fig. 3) before returning to Haiku Kuhiaha where transmissions continued for 166 days, resulting in 333 days of total tracking.

Turtle ID 19603 (Fig. 4) was released 11 km off Maui's south shore in the 'Alenuihāhā Channel separating Maui from the island of Hawaii. Over the next 13 days the turtle traveled 224 km (0.7 km/hr) to the southern-most point of Hawaii before swimming to the west out to sea for 548 km over a 12 day period (1.9 km/hr). At 18.1°N 160.2°W, the turtle made a discrete and significant course change to the northeast traveling 379 km over 8 days (2.0 km/hr) to the Barber's Point area of the island of Oahu. During the next 22 days the turtle moved 86 km along the coast clockwise to the North Shore of Oahu and remained in the Waiale'e area between Sunset Beach and Kahuku Point until transmissions ceased after 426 days of residency. Turtle ID 19603 was tracked for 481 days post-release.

The information obtained during 267-481 days of remote monitoring using satellite tracking gave strong support to the premise of successful adaptation to the wild by the four captive-

reared juvenile green turtles released by the Maui Ocean Center. Potential foraging habitats may be found virtually along all coastlines of the Main Hawaiian Islands (Chaloupka & Balazs 2007), yet each captive-raised turtle settled into a coastal area that historically had reported use by wild green turtles on the islands of Maui and Oahu. Recapture of the turtles in order to ascertain somatic growth rates and health status was not possible, however none of the turtles in this study are known to have stranded, either alive or dead, as of May 2015 (8 - 12 years post-release). A comprehensive stranding, salvage, and necropsy research program has been conducted in the Hawaiian Islands since 1982 (Chaloupka *et al.* 2008). Coastal areas of Maui and Oahu receive excellent reporting coverage by the public and dedicated stranding personnel. These two islands (including Lanai and Molokai) account for ~87% of the 6,346 green turtle strandings documented from 1982 through August 2014. Since 2002 the Maui Ocean Center has released 44 other captive-bred juvenile green turtles originating from Sea Life Park. All were individually identified by double tagging with PIT (passive integrated transponder) tags. None of these 44 turtles are known to have stranded, although not all dead turtles will wash ashore (Epperly *et al.* 1996).

The transition of one of the four turtles (ID 19603, Fig. 4) from Maui out to sea, eventually settling into residency on the northern coast of Oahu may be due to the turtle being released 11 km offshore at a depth of over 1,370 m, while the other three turtles were released close to shore at depths of 3-16 m. All four turtles were of sizes ecologically appropriate for release in either nearshore benthic habitats or offshore surface pelagic habitats. In the Hawaiian Islands, green turtles less than 35 cm SCL are never seen in nearshore benthic habitats. Therefore 35 cm should be the very minimum size for releasing captive-reared turtles near shore, and ideally in the range of 40-50 cm SCL or larger. Although 35 cm is the minimum size for recruitment from surface-pelagic habitats to nearshore benthic habitats, green turtles in Hawaii occasionally recruit from pelagic habitats up to 55 cm SCL, based on discernible characteristics, which include whitish plastron, and sharp edges to the marginal scutes and tonium.

Balazs *et al.* (2002) reported on the outcome of 102 captive-bred green turtles reared for educational outreach and released between 1990-1999 at the Mauna Lani Bay Resort on the island of Hawaii. These turtles ranged from 25.5-68.0 cm SCL (mean = 40.7 cm) and all were tagged with PIT and/or Inconel alloy flipper tags for long-term recognition. Since 1987, the Kona/Kohala coastline of West Hawaii has been a region of vigorous ocean research involving the hand capture of free-ranging turtles with nets and snorkel/scuba gear (Balazs & Chaloupka 2004; Rice *et al.* 2002). In contrast, similar capture efforts have not been possible on the island of Maui due to logistical and personnel safety considerations. Similar to Maui, the Kona/Kahala coast has excellent research coverage of stranded turtles. Eighteen (17.6%) of the 102 Mauna Lani turtles were seen from 1-5 times 0.8-7.3 years post-release. Twelve (11.8%) were recaptured in the sea, and 6 (5.8%) stranded ashore, two of which were dead and four were alive. Overall, Balazs *et al.* (2002) concluded that 50% of the 18 turtles encountered had successfully adapted to the wild, while the other half showed evidence inconsistent with adaptation. However, Wabnitz *et al.* (2010) subsequently demonstrated through ecosystem modeling that algal carrying capacity had been reached at the Kaloko-Honokohau green turtle foraging pasture on the Kona/Kohala coast, a site considered to be representative of most others used by green turtles throughout this area. Although entirely possible, similar ecosystem conditions that would severely limit green turtle adaptation to the wild do not appear to exist on Maui and coastal areas of the other Hawaiian Islands, based on low rates of somatic growth (Balazs & Chaloupka 2004).

Green turtles in the Hawaiian Islands form a genetically and geographically discrete population, considerably isolated from continental landmasses and other islands of the North Pacific (Dutton *et al.* 2008; Frey *et al.* 2013; Wallace *et al.* 2010). Since the ban on commercial turtle fishing in 1975 (Bennett & Keuper-Bennett 2008), Hawaiian green turtles have increased substantially in numbers and have increased the utilization of available as well as new foraging habitats (Chaloupka & Balazs 2007; Chaloupka *et al.* 2008; McDermid *et al.* 2015; Pilcher *et al.* 2012). The Maui Ocean Center and other educational outreach partners of Sea Life Park have played an integral and prominent role in the restoration of Hawaii's green turtles through enhancement of public awareness, and by providing captive-bred green turtles for a variety of research projects, including the present study. Release of captive-bred turtles should take place into habitats (either offshore surface pelagic habitats or nearshore benthic habitats) appropriate for the size of the turtle. While the present study only involved four individuals, results indicate that captive-reared turtles are able to find suitable resting and foraging areas to adapt successfully into the wild; this will hopefully contribute to the continuing health of the green turtle population in the Hawaiian Islands.

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