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Post-release behavior and feeding adaptations of head-started hawksbill turtles compared with wild turtles

Running head: Behavior of head-started hawksbill turtles

Authors' names and affiliations

Junichi OKUYAMA[1], Tomohito SHIMIZU[2,3], Osamu ABE[4,5], Kenzo YOSEDA[2,4], Nobuaki ARAI[1]

Authors' affiliation and address:

Junichi OKUYAMA[1]

[1] Graduate School of Informatics, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan

E-mail: okuyama@bre.soc.i.kyoto-u.ac.jp

Tomohito SHIMIZU[2,3]

[2] Yaeyama Station, National Center for Stock Enhancement, Fisheries Research Agency, Fukaiohta 148, Ishigaki, Okinawa 907-0451, Japan

Present address: [3] Management Section, National Center for Stock Enhancement, Headquarters, Fisheries Research Agency, Queen's Tower B 15F, 2-3-3, Minatomirai, Nishi-ku, Yokohama, Kanagawa, 220-6115, Japan

E-mail: tomos@affrc.go.jp

Osamu ABE[4,5]

[4] Ishigaki Tropical Station, Seikai National Fisheries Research Institute, Fisheries Research Agency, Fukaiohta 148-446, Ishigaki, Okinawa 907-0451, Japan

Present address: [5] Marine Fishery Resources Development and Management Department, Southeast Asian Fisheries Development Center, Taman Perikanan, Chendering 21080 Kuala Terengganu, Malaysia

E-mail: turtlea@affrc.go.jp

Kenzo YOSEDA[2,4]

[2] Yaeyama Station , National Center for Stock Enhancement, Fisheries Research Agency, Fukaiohta 148, Ishigaki, Okinawa 907-0451, Japan

Present address: [4] Ishigaki Tropical Station, Seikai National Fisheries Research Institute, Fisheries Research Agency, Fukaiohta 148-446, Ishigaki, Okinawa 907-0451, Japan

Nobuaki ARAI[1]

[1] Graduate School of Informatics, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan

E-mail: arai@i.kyoto-u.ac.jp

Corresponding author

Junichi OKUYAMA
Affiliation and postal address: Graduate School of Informatics, Kyoto University, Yoshida Honmachi, Sakyo, Kyoto, 606-8501, Japan
E-mail: okuyama@bre.soc.i.kyoto-u.ac.jp
Tel: +81-75-753-3296
FAX: +81-75-753-3133

ABSTRACT

To ensure the success of reintroduction programs, it is important to monitor the post-release behavior and survival of released animals. In this study, the post-release movement and behavior of five wild and five head-started hawksbill turtles (*Eretmochelys imbricata*) were monitored using ultrasonic telemetry. Their dispersal directions and recaptures may indicate that wild turtles performed homing migrations. However, the head-started turtles showed non-uniform patterns in dispersal movements. Four head-started turtles moved out of the monitoring area in various directions, whereas one turtle stayed within the monitoring area for approximately ten months. These results might indicate that head-started turtles wander aimlessly in their new surroundings. The signal reception patterns indicated that wild turtles were active in the daytime and rested under the coral at night. In contrast, although the head-started turtles also rested at night, their resting places did not seem to be sheltered from hazardous sea conditions or to be adequate for efficient resting dive. Therefore, head-started hawksbill turtles need pre-release training, such as exposing turtles to structures or ledges in the rearing tank so that they can use similar structures in the wild for shelter during rest periods and to maximize their dive duration. Prey analysis of a head-started turtles captured incidentally demonstrates that these turtles can exhibit the possibility of feeding adaptations in natural environments. These findings provide constructive information on the implementation and improvement of head-start programs.

KEY WORDS: Conservation, *Eretmochelys imbricata*, Feeding adaptation, Head-starting, Reintroduction, Ultrasonic telemetry

INTRODUCTION

Reintroduction with captive breeding and release programs have become important conservation measures for the recovery of threatened and endangered species around the world (Beck et al. 1994, Wilson & Price 1994, IUCN 1998, Stanley Price & Soorae 2003, Seddon et al. 2007). However, many reintroduction programs for captive-born animals are still not well organized, and improvements are necessary before they can be successful (Beck et al. 1994, Stanley Price & Soorae 2003, Seddon et al. 2007). In order for released animals to survive in the wild, the animals have to be able to find and process food, avoid predators, interact appropriately with conspecifics, find and construct shelters, and orient and navigate in complex environments (Kleiman 1989, Beck et al. 1994, IUCN 1998). Consequently, to ensure the success of reintroduction programs, it is important to conduct post-release monitoring of the behavior and survival of released animals, such as the mortality rate, cause of mortality, reproduction rate, and home range, as such data can provide information on the quality of animals for release and can also contribute to and/or improve reintroduction programs (Beck et al. 1994, IUCN 1998). The translocation of exclusively wild-caught animals is more likely to succeed than that of exclusively captive-born animals (Griffith et al. 1989), implying that experience of living in wild habitats enhances the survival probability of released animals. When captive-born animals are used in reintroduction programs, therefore, released animals are assumed to behave and survive in the same way as wild animals (Beck et al. 1994, IUCN 1998). Thus, it is also necessary to know behavioral features such as movements, home ranges, habitat selection, and survival behaviors of free-ranging, wild-born animals (Kleiman 1989, IUCN 1998).

Sea turtles are well-recognized marine reptiles that are known to be endangered worldwide. In an attempt population recoveries of sea turtles, head-starting, which is a type of reintroduction program, has been conducted at various locations throughout the world (e.g. Huff 1989, Sato & Madriasau 1991, Bell et al. 2005, Fontaine & Shaver 2005). Head-starting is the practice of growing hatchlings in captivity to a size that protects them from the high rates of natural predation that would have otherwise occurred in their early months, and then releasing them into the sea (Klima & McVey 1995, Mortimer 1995, Shaver & Wibbels 2007). However, the effectiveness of head-starting has been unproven due to a lack of data regarding the survival, adaptation, and eventual breeding of the turtles following their release (Shaver & Wibbels 2007). Therefore, close monitoring of the behavior, survival, and adaptation processes of post-release turtles and the accumulation of such data are important for evaluating head-starting, although many controversies and concerns regarding head-starting have been expressed (Shaver & Wibbels 2007).

In this study, we closely monitored the behavior and dispersal process of head-started hawksbill turtles (*Eretmochelys imbricata*) in order to determine how the head-started turtles behaved compared to those in the wild. We also monitored the behavior of wild hawksbill turtles for comparison purposes. In this study, we employed ultrasonic telemetry to track the turtles after their release. The purpose of this study was to increase knowledge of the post-release behavior, and the survival and feeding capabilities of head-started hawksbill turtles, and then to suggest improvements to the methods used to rear turtles before release.

MATERIALS AND METHODS

Study area and experimental animals

This study was conducted on the north part of Ishigaki Island, which is one of the Yaeyama Islands located in the southwestern part of Japan (Fig. 1a). Immature hawksbill turtles with straight carapace lengths (SCL) of 39.3 to 63.1 cm have been reported in the Yaeyama Islands (Kamezaki & Hirate 1992). Yaeyama Station, part of the National Center for Stock Enhancement (NCSE), Fisheries Agency, Japan, is located on Ishigaki Island and has succeeded to obtain hatchlings from long-term captive brood, and started experimentally head-start program of captive-reared turtles for stock enhancement since 2003 (Yoseda & Shimizu 2006).

Five wild and five head-started hawksbill turtles were used in this study. Wild and head-started turtles had similar SCL and body weights (BW), and neither SCL nor BW were significantly different between the two groups according to t-tests ($t = 1.74$, $P > 0.05$, for SCL; $t = 1.33$, $P > 0.05$, for BW; Table1). The wild turtles were caught at different locations in the Yaeyama Islands with the permission of Okinawa prefecture (no. 16-19) (Fig. 1a, b). The captured turtles were of sizes common in the Yaeyama Islands (Table 1). The captured wild turtles were maintained in the two or five kiloliter rearing tanks at Yaeyama station for about four months before the start of the experiment. The head-started turtles were reared from eggs for two and a half years at the Yaeyama station. The eggs used in this study were laid on east Hirakubo beach in the north of Ishigaki Island (Fig. 1a). Fifty eggs were translocated to the Yaeyama station, and then hatched in the incubators setting at about 29 C^{o} of the temperature and at more than 90 percent of the humidity. After hatched, the turtles were reared in the 60 liter tank. Then, we changed the size of the rearing tanks with the growth of the turtles (From the age of two months; 200 liter, from the age of two months; two or five kiloliter, from the yearlings; 15 kiloliter tanks). Each tank housed 10 to 20 turtles. These turtles did not experience the imprinting procedure allowing them to crawl down to the beach and enter the surf when they hatched like the previous head-start project for Kemp's ridley turtles (see Shaver 2005). The rearing tanks were placed in a building with sunroofs and windows. Therefore, the photoperiod in the rearing houses shifted naturally. The sea water in the rearing tanks was pumped up from the sea at the front of the Yaeyama station. Five healthy-looking turtles were selected from the reared turtles as experimental individuals. Both the wild and the head-started turtles were fed on the pellet mixed with fishmeal and vitamins twice a day, in the morning and early evening. The daily amount of feed was two to three percent of each turtle's weight. During rearing, the head-started turtles approached humans being around the tanks. On the other hand, the wild turtles did not show approaching humans like that shown by the head-started turtles. The wild turtles were often still at the corner of the tank.

Experimental protocol and tracking method

We employed ultrasonic telemetry to monitor the behavior of the turtles. The turtles were fitted with transmitter, either model V16P-6H (diameter, 16 mm; length, 106 mm ; weight, 16 g in water; approximately 853 days of battery life; Vemco Co. Ltd., Canada) or V16-6H (diameter, 16 mm; length, 90 mm; weight, 14 g in water; approximately 876 days of battery life) which were attached to the center of carapace using epoxy putty (Konishi Co., Ltd. Osaka, Japan) and two-component epoxy resin (ITW Industry Co., Ltd. Osaka, Japan). The turtles were also marked with plastic, metal and passive integrated transponder (PIT) tags. The transmitters were coded with a unique pulse series for each turtle and transmitted signals at randomly spaced intervals of between 5 and 30 seconds. The V16P-6H transmitters were equipped with built-in depth sensors (See Table1). Ultrasonic transmissions were 69.0 Hz, which is known to be outside the hearing capacity of green turtles (*Chelonia mydas*) (30-1000 Hz, Ridgeway et al. 1969) and juvenile loggerhead turtles (*Caretta caretta*) (250-1000 Hz, Bartol et al. 1999), although the hearing capacity of hawksbill turtles has not been investigated. Previous studies using ultrasonic transmitters did not report behavioral inhibition caused by ultrasonic waves or transmitter attachment (Brill et al. 1995, Seminoff et al. 2002, Blumenthal et al. 2009). Therefore, we believe that the ultrasonic telemetry did not affect the behavior of the hawksbill turtles in this study.

All of the turtles were released from the release point (24°28'06.84"N, 124°12'42.26"E, Fig.1c) at the same time on 19 April 2005 after one hour of sea-acclimation in an enclosure net (L × W × H = 4 m × 4 m × 5 m). Twelve fixed receiver monitoring systems (VR2, Vemco Co. Ltd., Canada) were used. The receivers were deployed on the sea floor at about 18 m depth along the reef edge on the north side of Ishigaki Island (Fig.1c). Turtle identification, depth, date, and time were recorded when the turtles came within the detection range, which was expected to be about 500 m in radius. The monitoring period was from 19 April 2005 to 3 March 2006.

Because turtle HH4 was hand-captured by a local fisherman who was fishing underwater on 15 July 2005, we rereleased it at the point of capture on 26 July after researching its growth rate and prey items it had consumed in the natural environment. This rerelease was defined as the second release of turtle HH4. We also measured the growth rates of turtles WH1 and WH2, which were recaptured on 24 October 2005 and

10 November 2005, respectively, and then rereleased them from their respective recapture points.

Prey sample collection and identification

We conducted research on the prey items ingested by turtle HH4, which was captured incidentally. This turtle was measured and then kept in a tank at Yaeyama Station. While the turtle was in captivity, its discharged droppings were sampled to investigate the diets of head-started turtles in a natural environment. The wet mass and weight of samples were measured and then preserved in 100% ethanol solution, after which the samples were identified.

Data analysis

Signals from the turtles were generally received by several receivers per day, in response to the migration routes of the turtles. Thus, the daily location of the turtles was defined as the location of the receiver detecting the maximum number of signals from each turtle during a day. In order to compare the number of signal receptions between diurnal and nocturnal periods, we defined the diurnal period as the time between 05:00 and 18:59 and the nocturnal period as the time between 19:00 and 04:59, based on the approximate times of sunset and sunrise during the experiment.

Because signal receptions from the turtles were not continuous, time-series analyses for data reception patterns and dive depths were difficult to construct. Therefore, data collected over a one-hour period were defined as a data unit. For the analysis of data reception patterns, the data were treated as binary data, that is, presence or absence during a one-hour period. Turtles were defined as being present during a period if signals were received at least once during an hour-long period. For the analysis of diving depth, mean dive depth over a one-hour period was defined from the dive depth data during that period.

Wilcoxon signed-ranks tests for paired comparisons were used to determine whether turtle signal receptions differed between diurnal and nocturnal periods. Differences in signal receptions between wild and head-started turtles during each period were determined using Mann-Whitney *U*-tests. Mann-Whitney *U*-tests were also employed to detect differences in dive depth between wild and head-started turtles, and between diurnal and nocturnal periods. P-values of less than 0.05 were considered to be statistically significant.

For turtle HH4, which was rereleased, behavioral data gathered from after the rerelease were omitted from the behavioral comparisons between wild and head-started turtles due to the differences in the times of release and the experience that the turtle had previously had of living in the sea. In order to determine the time-series changes in diel patterns of signal receptions and dive depths, we divided the monitoring period into five periods, consisting of Period 1 (19 April-18 May 2005, days of data = 26), Period 2 (19 May-18 June 2005, days of data = 25), Period 3 (19 June-15 July 2005 (date of capture), days of data = 24), Period 4 (26 July (date of second release) -24 August 2005, days of data = 17), and Period 5 (4 February-3 March 2006 (date that the fixed receivers were retrieved), days of data = 12). Kruskal-Wallis tests were used to determine whether signal receptions or dive depths changed significantly throughout the five periods. We employed Wilcoxon signed-ranks tests for paired comparisons to determine whether differences in signal reception patterns existed between diurnal and nocturnal periods over the five periods.

RESULTS

General results

The wild hawksbill turtles were tracked for a mean of 5.4 ± 3.0 days, whereas the head-started turtles were tracked for 32.6 ± 37.0 days (Table 1). During the tracking period, post-release data were obtained for 4.8 ± 2.6 days for the wild turtles and for 20.4 ± 31.7 days for the head-started turtles (Table 1, Fig. 2). No significant differences were found in tracking periods and days of data between wild and head-started turtles (Mann-Whitney *U*-test, Z = 0.86, P = 0.39 for tracking period, Z = 1.48, P = 0.14 for days of data).

Four of the five wild turtles (WH1, WH2, WH4, and WH5) moved west, and the other one (WH3) moved north along the reef edge (Fig. 2a). Assuming that the directions of their migration pathways were only north and west, because they moved along the reef edge, the directions of their movement significantly corresponded with the place where each turtle had been captured before the experiment (Binominal test, P < 0.05). In fact, turtles WH1 and WH2 were recaptured at the locations where they initially had been captured 182 and 199 days after the release, respectively. During the periods between release and recapture, the growth rates of these turtles were 3.9 cm in SCL and 1.6 kg in BW for WH1 and 1.9 cm in SCL and 2.0 kg in BW for WH2.

The head-started turtles showed different movement patterns (Fig.2b). Four of the five head-started turtles (HH1, HH2, HH3, and HH5) moved out of the monitoring area in 2-14 days. Turtles HH2, HH3, and HH5 moved northward, and the signals from turtle HH1 were lost in the middle of the monitoring area. Turtle HH5 re-entered the monitoring area 34 days after its disappearance from that area and then moved westward in 2 days. However, one turtle (HH4) stayed around the release point and adjacent area for 88 days, growing 1 cm in SCL and 0.11 kg in BW, until it was captured incidentally. The diet composition of turtle HH4 included eight pieces (total wet weight 13.4 g) of demosponges (*Chondrosia* sp.) and a thin piece of plastic (0.27 g in wet weight).

Diel patterns in signal reception

The mean signal receptions per hour from wild and head-started turtles were calculated. Signal receptions from the wild turtles were concentrated during the diurnal period (05:00 to 18:59) and were very rare during the nocturnal period (19:00 to 04:59) (Fig.3a). A significant difference in signal reception was found between diurnal and nocturnal periods (Wilcoxon test, $Z = 2.02$, $P < 0.05$). Conversely, all of the head-started turtles were detected many times, with, like wild turtles, significantly more data receptions during the diurnal period (Wilcoxon test, $Z = 2.02$, $P < 0.05$) but with nocturnal receptions being also detected (Fig.3b). During the nocturnal period, significantly more signals were received, on average, from head-started turtles than from wild turtles (Mann-Whitney *U*-test, $Z = 2.48$, $P < 0.05$), whereas during the diurnal period, no significant difference was found between receptions from wild and head-started turtles (Mann-Whitney *U*-test, $Z = 0.31$, $P = 0.75$).

Dive depth

The dive depths of four wild and four head-started turtles are summarized in Table 2. The nocturnal dive depths of one head-started (HH1) and three wild (WH1, 2, and 4) turtles could not be obtained due to a lack of signal receptions. The mean dive depths of the wild turtles during the diurnal and nocturnal periods were 7.3 ± 3.1 m and 2.1 m, respectively, and those of the head-started turtles were 8.5 ± 1.8 m and 9.5 ± 2.1 m, respectively. The head-started turtles did not change their dive depth significantly between diurnal and nocturnal periods (Mann-Whitney *U*-test, Z = 0.71, P = 0.25). No significant difference was observed in dive depth between wild and head-started turtles during the diurnal period (Mann-Whitney *U*-test, Z = 1.15, P = 0.48).

During the diurnal period, signals from wild turtles were recorded at various depth zones, although the signals were not recorded continuously, indicating vertical movements of the wild turtles during the diurnal period (Fig.4a). Similarly, signals from head-started turtles were also recorded at various depth zones in the diurnal periods (Fig.4b), whereas signals during nocturnal periods were almost all recorded at constant depth zones, indicating an absence of vertical movement during the nocturnal period (Fig.4c).

Behavior and signal reception patterns of turtle HH4 after the second release

Turtle HH4 was detected intermittently within the monitoring area until 3 March 2006 (220 days after the second release), when the fixed receivers were retrieved. The habitat utilization of turtle HH4 after the second release (Periods 4 and 5) was wider compared to that recorded from after the first release (Periods 1 to 3) (Fig.5a). The utilized habitat often shifted westward and northward from the second release point. The mean dive depths changed significantly among the five periods (Kruskal-Wallis test, H = 54.3, P < 0.01) (Fig. 5a). Significantly more signal receptions were received in diurnal periods than in nocturnal periods during the five periods (Wilcoxon test, Z = 2.02, P < 0.05) (Fig. 5b). Throughout the five periods, the signal receptions from both diurnal and nocturnal periods significantly changed (Kruskal-Wallis test, $H = 18.9$, $P < 0.01$ for the diurnal period, $H = 36.9$, $P < 0.01$ for the nocturnal period).

DISCUSSION

Dispersal patterns

Avens & Lohmann (2003) reported that juvenile loggerhead sea turtles had site fidelity and returned to their habitat if released in another place. In addition, according to earlier reports, immature hawksbill turtles tend to remain in the same developmental habitat for an extended period (Limpus 1992, van Dam & Diez 1998, Blumenthal et al. 2009). In this study, the wild turtles were captured from various locations throughout the Yeayama Islands (Fig. 1). The correspondence of the direction of each turtle's dispersal with its place of capture and the recapture of two turtles (WH1 and WH2) at their initial capture location may indicate that the wild turtles performed homing migrations after release. However, previous studies conducted in the Yaeyama Islands reported that wild juvenile hawksbill turtles underwent some distance migration (Kamezaki 1987, Kamezaki & Hirate 1992). Therefore, further studies are needed in order to clarify the homing behavior of juvenile hawksbill turtles.

A few previous studies have conducted radio-telemetry tracking of juvenile head-started turtles following release (11-month-old Kemp's ridleys, Wibbels 1984; yearling Kemp's ridleys, Klima & McVey 1995; 1.5- and 2.5-year-old loggerheads, Nagelkerken et al. 2003). Their results indicated that the turtles exhibited various dispersal directions, with some turtles moving offshore and others moving along the shore. In one study, many of the released turtles were found to have remained relatively close to the release area at the end of the 27 day-study period (Wibbels 1984).

Additionally, the results of a study by Klima & McVey (1995) showed that turtles tended to stay in the same area for about 10 days after their release. In the present study, our results also demonstrated that head-started turtles showed non-uniform patterns of dispersal movement after their release. Four turtles moved out of the monitoring area in various directions, while one turtle stayed within the monitoring area for approximately ten months. They did not seem to have a pre-determined destination, as the wild turtles appeared to have. Therefore, our results suggest that head-started turtles might wander aimlessly in their new surroundings. A possibility exists that such aimless wanderings might lead them on long-distance migrations, as has been reported in studies on head-started Kemp's ridley turtles (Wibbels 1983, Manzella et al. 1988).

Diel behavioral patterns

Wild juvenile hawksbill turtles are known to be active during diurnal periods and to be inactive and resting during nocturnal periods in Caribbean habitats (van Dam & Diez 1996, van Dam & Diez 1997a, Blumenthal et al. 2009). Many of the signal receptions from various depth zones from the wild turtles in this study (Fig. 3, 4a) indicate that the wild turtles in the Yaeyama Islands are also active during diurnal periods. On the other hand, during the nocturnal period, signal receptions from wild turtles were rare. While resting, hawksbill turtles are occasionally observed wedged under coral reefs (van Dam & Diez 1997a, Houghton et al. 2003, Blumenthal et al. 2009, Okuyama pers. obs.), possibly in order to use for shelter (van Dam & Diez 1997a, Storch et al. 2006) and maximize dive duration (Houghton et al. 2003). The ultrasonic telemetry signals are known to be blocked when the transmitter is surrounded by structures such as rock reef and raised corals (Arendt et al. 2001, Mitamura et al. 2005, Yokota et al. 2006, Kawabata et al. 2008). Therefore, the lack of signal receptions during the nocturnal period strongly suggests that wild turtles rest under the coral reef and/or some rocks.

The dive profiles (Fig. 4b) and the signal receptions from head-started turtles, which were as frequent as those from wild turtles (Fig. 3), indicated that the head-started turtles were also active during the diurnal period. During nocturnal periods, some signals were received from head-started turtles, but most of these signals were transmitted from constant depth zones (Fig. 4c). These results suggest that the head-started turtles were resting during the nocturnal period, but that their resting places were not as surrounded by structure as were those of the wild turtles. This might force head-started turtles to get drifted away by strong currents under hazardous sea conditions like a hurricane, or consume unnecessary energy to remain in the same place, because it was reported that the wild turtle probably took a shelter during the hurricane (Storch et al. 2006). In addition, they might not maximize their dive duration, because they have positive buoyancy in shallow water when they breathe fully (Houghton et al. 2003). An effect of the rearing conditions and environment, such as the feeding schedule, on the diel behavioral pattern of the head-started turtles after release could not be ruled out from the results of this study, although no such effects were identified from the analysis of the diel signal reception patterns. Our results suggest that head-started hawksbill turtles need pre-release training, such as exposing turtles to structures or ledges in the rearing tank so that they can use similar structures in the wild for shelter during rest periods and to maximize their dive duration, because released animals are expected to behave in the same way as wild animals (Beck et al. 1994, IUCN 1998, see Introduction).

Dive depths

Head-started turtles were expected to be poor divers because they had been raised in a very shallow tank measuring about two meters in depth. However, the mean dive depths of the head-started turtles were not significantly different from those of wild turtles, indicating that the small space available to them in captivity may not affect the vertical range of their living space after release.

Some wild juvenile hawksbill turtles in Caribbean habitats are known to change their depth utilization between diurnal and nocturnal periods (van Dam & Diez 1996, Blumenthal et al. 2009), whereas some turtles do not exhibit this change (van Dam & Diez 1997). In this study, the head-started turtles did not change their dive depths between diurnal and nocturnal periods (Table 2). However, from our results, we could not determine whether such unchanging patterns of utilization in vertical living area were normal for wild hawksbill turtles in the Yaeyama Islands because signals were not received from wild turtles during nocturnal periods. Further study is needed on the depth utilization of wild turtles during nocturnal periods in the Yaeyama Islands.

Feeding adaptations of head-started hawksbill turtles

The post-release diet of head-started turtles is an indicator of their ability to successfully adapt to the wild (Shaver & Wibbels 2007). Head-started Kemp's ridley turtles were reported to have adaptive ability to feed in the wild (Shaver 1991, Werner & Landry 1994). However, these are the only reports available on Kemp's ridleys, and no studies have been conducted on other species of head-started turtle. Juvenile hawksbill turtles are known to feed primarily on benthic invertebrates, notably sponges

(Meylan 1988, van Dam & Diez 1997b, León & Bjorndal 2002). Our result demonstrates that a head-started juvenile hawksbill turtles has the capability to forage for their natural prey, a demosponge (*Chondrosia* sp.). The head-started turtle's growth rates of 1 cm in SCL and 0.11 kg in BW over 88 days were similar to the growth rates of wild turtles in the Yaeyama Islands (WH1 and WH2) and in other regions (Limpus 1992, Diez & van Dam 2002). The turtles reared in captivity in Yaeyama Station are fed on pellet mixed with fishmeal and vitamins from the time of hatching. Therefore, it is very interesting that a head-started turtle without training has the ability to forage natural prey in about three months and to grow normally in its natural environment. This result is an important finding promoting the release of head-started turtles as a conservation tool.

Behavior of a head-started turtle over approximately one year

Long-term monitoring provides important information on the survival and environmental adaptation processes of reintroduced animals following release (Kleiman 1989). For post-release monitoring, it is obvious that longer is better, because more information on released animals can be collected over a longer period of time. In this study, a head-started turtle (HH4) was monitored until about 7 months after its second release, indicating that head-started juvenile hawksbill turtles are able to survive in natural environments for at least 7 months.

The signal detection locations and depth utilization patterns of this turtle changed through the study periods (Fig. 5a). This indicates that the head-started turtle shifted its habitat with the passage of time. Previous studies on wild juvenile hawksbill turtles in the Yaeyama Islands reported that wild turtles underwent short- or long-distance migrations (0.5 to 470 km) (Kamezaki 1987, Kamezaki & Hirate 1992). Thus, the habitat shifts demonstrated by the head-started turtle in our study seem to be natural behavior. In addition, Limpus (1992) reported that none of the wild hawksbill turtles relocated to another reef settled at the release point, while only one turtle was recaptured at the original place. This indicates that the wild juvenile hawksbill turtles may search for appropriate habitats when released at the other places. Therefore, habitat shifts by head-started turtles might indicate that they are searching for more appropriate settlement habitat.

During the year of monitoring, with monitoring periods after the first and second releases combined, the activity of the head-started turtle (HH4) during diurnal periods and its inactivity during the night did not change among the five periods (Fig. 5b), indicating that the turtle's diel activity rhythms were normal throughout a year after release. However, some signals were received during nocturnal periods in periods 2 and 3. From this result, we did not determine whether the head-started turtle (HH4) came to rest under coral due to the intermittent signal receptions.

Conclusion

Our results demonstrate that head-started hawksbill turtles have the ability to survive in the wild for a period of at least seven months, and can exhibit the potential of feeding adaptations in their natural environment. Our study also found that head-started hawksbill turtles need pre-release training to use ridge structures during a period of rest. These findings provide constructive information on the implementation and improvement of head-start programs. However, available post-release behavioral and ecological data on head-started turtles is not sufficient to determine the effectiveness of head-starting program. For example, the imprinting mechanism that guides turtles to their nesting beach and the migration ecology following release are still not clear (Shaver & Wibbels 2007). If the nesting female turtles marked with tags were reconfirmed in the future, the location where turtles lay the eggs without the experience of the imprinting procedure (Shaver 2005) will contribute to increase the knowledge for treatment of reared turtles, and imprinting mechanism. In order to establish head-starting as an appropriate conservation tool and a successful reintroduction program, we need to continue monitoring and to accumulate much more knowledge about head-started as well as wild turtles.

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Table 1. *Eretmochelys imbricata*. Summary of physical and experimental data on the turtles.

Table 2. *Eretmochelys imbricata*. Summary of dive data from diurnal and nocturnal periods.

Figure legends

Fig. 1. *Eretmochelys imbricata*. Study site. (a), (b) Map of the Yaeyama Islands and capture points of wild turtles. Crosses represent the location of capture points. The area surrounded by a rectangle represents the experimental area. (c) The release points of the experimental turtles and the monitoring area. Asterisk represents the release point. The circles indicate the locations of the receivers (1 to 12) and the expected detection ranges of receivers, which was 500 m in radius. The dotted line represents the reef edge.

Fig. 2. *Eretmochelys imbricata*. Post-release horizontal movements of (a) wild and (b) head-started turtles for the initial 4 weeks (19 April-16 May 2005). The symbols are plotted at the days on which the data were obtained.

Fig. 3. *Eretmochelys imbricata*. The signal reception patterns of (a) wild and (b) head-started turtles during a day. Gray and white zones show the nocturnal and diurnal periods, respectively. The vertical bars represent the mean proportion of hourly signal detections and standard deviations.

Fig. 4. *Eretmochelys imbricata*. Typical diving profiles of (a) a wild turtle (WH1) during the diurnal period (12:00-17:00) and a head-started turtle (HH2) during (b) diurnal (12:00-17:00) and (c) nocturnal (19:00-0:00) periods.

Fig. 5. *Eretmochelys imbricata*. Time-series variations in (a) horizontal movement and dive depth, and (b) signal detections during diurnal and nocturnal periods from the head-started turtle (HH4) over five periods (P1 to P5). Open circles and closed triangles represent the mean proportion of signal detections in the diurnal and nocturnal periods during each period, respectively. Vertical bars represent standard deviations.

Table 1

Turtle ID	SCL (cm)	BW (kg)	Depth sensor	Last detection (dd/mm/20yy)	Days of data	Recapture
Wild turtles						
WH 1	37.0	4.5	y	20/04/05	2	y (182 days later)
WH 2	47.0	9.5	y	21/04/05	3	y (199 days later)
WH 3	48.6	11.6	y	27/04/05	8	n
WH 4	43.3	8.4	y	23/04/05	4	n
WH 5	43.3	6.7	n	26/04/05	7	n
Head-started turtles						
HH 1	39.6	6.6	y	22/04/05	4	n
HH 2	42.0	7.8	y	22/04/05	4	n
HH 3	40.2	7.2	y	02/05/05	8	n
HH 4	41.2	7.0	y	15/07/05 + 02/02/06*	77 + 29*	y (88 days later)
HH 5	44.0	8.4	n	10/06/05	9	n

* Tracking periods in first release plus second release after the recapture
SCL = Straight carapace length, BW = Body weight

Fig.1

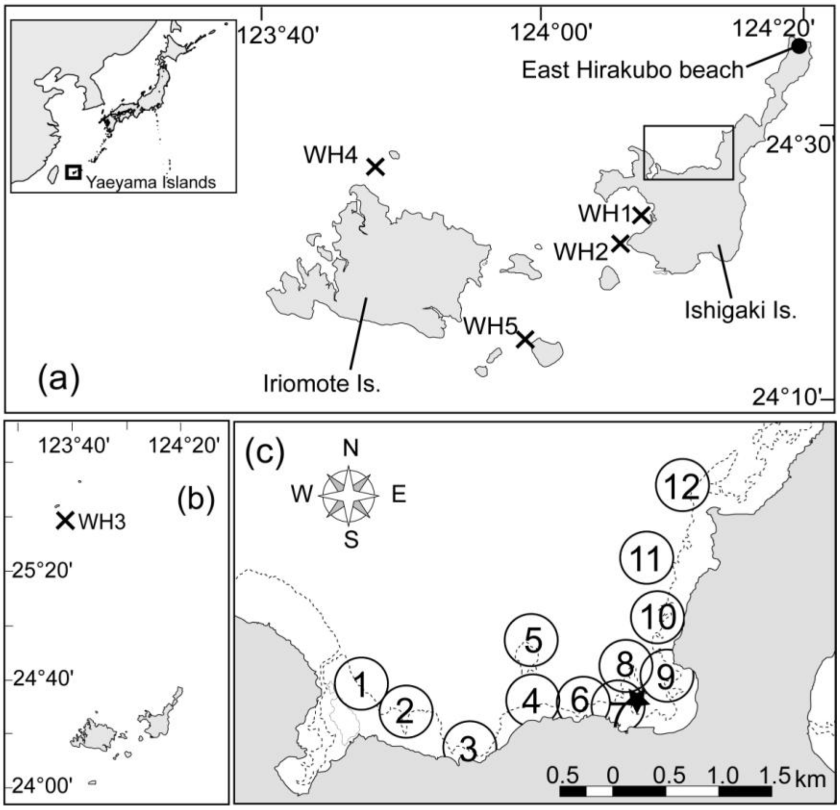


Fig.2

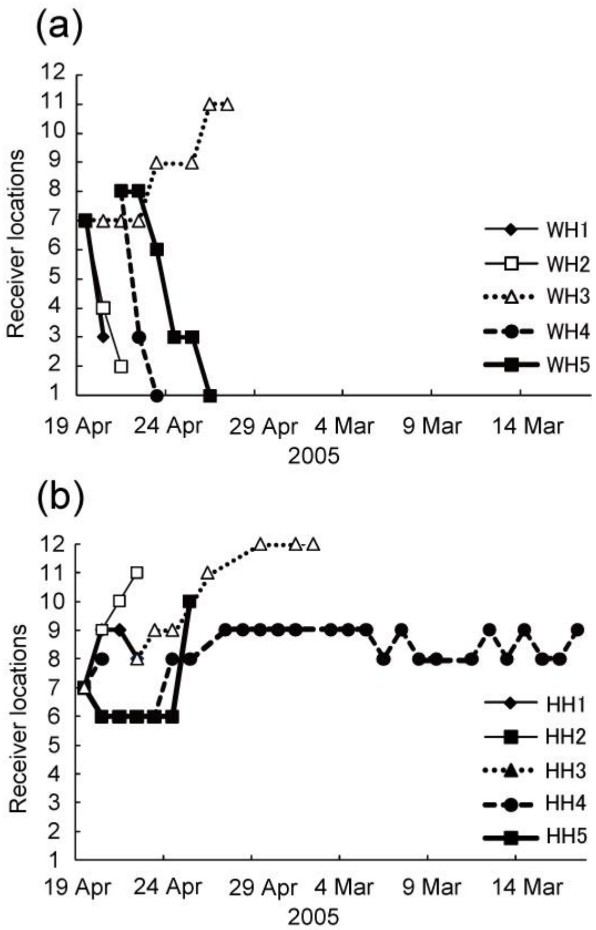

(a)
Receiver locations
12
11
10
9
8
7
6
5
4
3
2
1
19 Apr
24 Apr
29 Apr
4 Mar
9 Mar
14 Mar
2005
WH1
WH2
WH3
WH4
WH5
(b)
Receiver locations
12
11
10
9
8
7
6
5
4
3
2
1
19 Apr
24 Apr
29 Apr
4 Mar
9 Mar
14 Mar
2005
HH1
HH2
HH3
HH4
HH5

Fig3

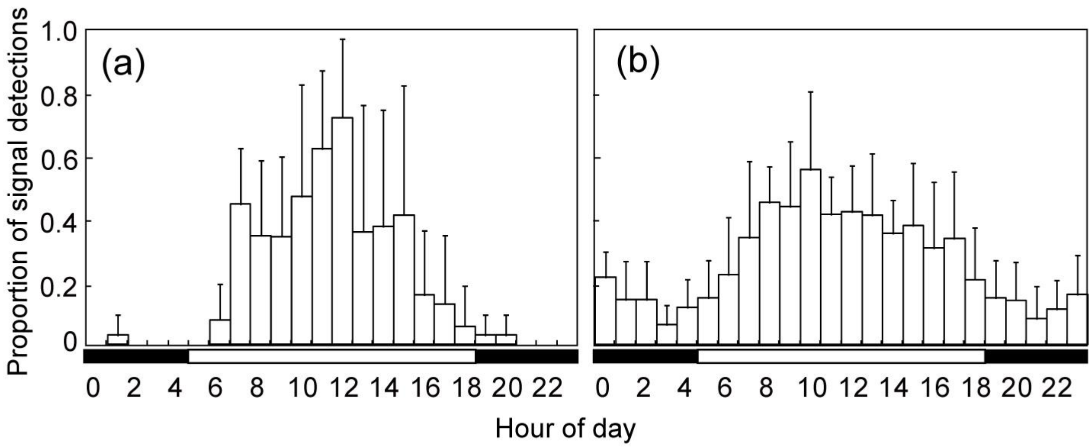

Proportion of signal detections
1.0
0.8
0.6
0.4
0.2
0
(a)
(b)
0 2 4 6 8 10 12 14 16 18 20 22
0 2 4 6 8 10 12 14 16 18 20 22
Hour of day

Table 2

ID	Diurnal period		Nocturnal period	
	Mean depth (m)	N	Mean depth (m)	N
Wild turtles				
WH 1	11.9 ± 4.2	13	-	0
WH 2	5.5 ± 2.2	10	-	0
WH 3	5.7 ± 3.3	20	2.1 ± 0.6	3
WH 4	6.0 ± 4.2	14	-	0
Head-started turtles				
HH 1	7.3 ± 6.3	17	-	0
HH 2	6.9 ± 3.4	22	8.1 ± 1.5	9
HH 3	10.9 ± 2.6	39	11.9 ± 2.7	12
HH 4	8.9 ± 0.9	299	8.4 ± 0.2	57

Fig.4

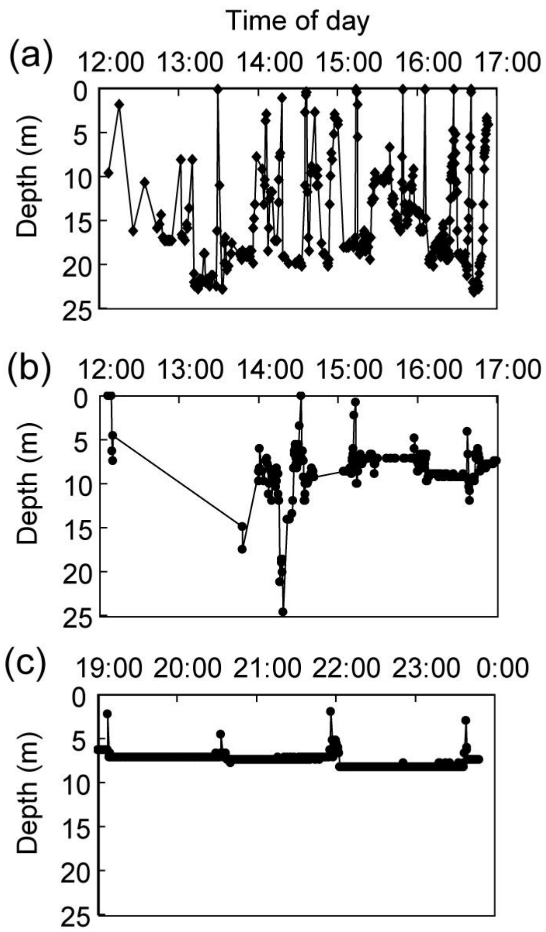
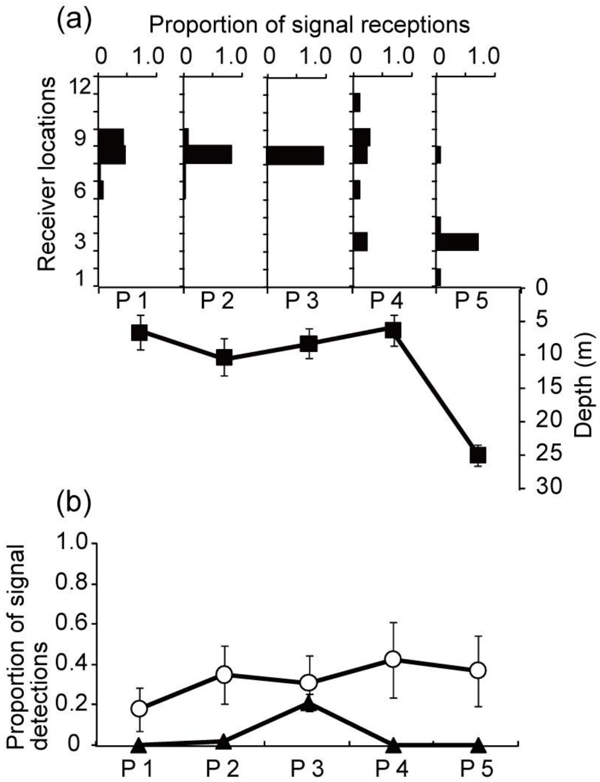


Fig.5



(a)
Proportion of signal receptions
0 1.0 0 1.0 0 1.0 0 1.0 0 1.0
Receiver locations
12
9
6
3
1
P 1 P 2 P 3 P 4 P 5
Depth (m)
0 5 10 15 20 25 30
(b)
Proportion of signal detections
1.0 0.8 0.6 0.4 0.2 0
P 1 P 2 P 3 P 4 P 5