PAPER

Insights into Habitat Utilization by Green Turtles (*Chelonia mydas*) During the Inter-Nesting Period Using Animal-Borne Digital Cameras

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ABSTRACT

Many marine turtle habitat utilization studies have historically relied on inferences from logged data or direct visual observation. Here we remotely investigate aspects of the habitat utilization of inter-nesting female green turtles (*Chelonia mydas*), nesting on the Mediterranean island of Cyprus. Using an animal-borne digital video camera set to take only still images, with an integrated time-depth recorder, we recorded a total of 2375 images and 2899 dives for two nesting female green turtles. Both turtles spent over 80% of their time at depths of 5 m or less. Photographic evidence allowed us to categorize sub-surface behaviors from 66 of the deeper dives (turtle A with 40 dives and turtle B with 26 dives) containing more than 900 images into three categories: swimming, probable foraging and resting. Methodologically, our study highlights future utility in using camera technologies to clarify at-sea behavior of marine organisms, with a view to generating reliable time budgets.

Keywords: Green turtles, Foraging behavior, Digital imagery, Dive behavior, Mediterranean

Introduction

The first studies of marine mega-fauna, concerning their distribution and behavior, were primarily anecdotal and generally consisted of direct visual observations from either boats or in-water (Field 1892; Sclater 1897; Gray 1931). These initial studies had many limitations, including inherent disturbance effects on the behavior of study animals and observer bias in interpretation. The advent of progressively more advanced in-water technologies has enabled the monitoring of animals remotely, allowing greater elucidation of their sub-surface behaviors. The majority of dive studies have relied on data gathered by archival or transmitting time-depth recorders (TDR) to provide insights into an animal's time at depth and inferred habitat utilization (Hooker et al., 2007). Deployments have covered a wide range of marine mega-fauna from bony fishes to baleen whales (e.g., Block et al., 2001; Nowacek et al., 2001). Behavioral inferences, however, ultimately require some degree of ground truthing through direct observation (Schreer and Testa, 1995; Schofield et al., 2006; Blumenthal et al., 2009).

TDR technologies have been used to investigate the habitat utilization and behavior of marine turtles. These investigations have looked at foraging behavior (Gitschlag, 1996; Salmon et al., 2004; Hawkes et al., 2006), habitat utilization and diving behavior during inter-nesting periods (Hochscheid et al., 1999; Houghton et al., 2002), post-nesting migration (Hays et al., 2001; Godley et al., 2003) and over-wintering behavior (Broderick et al., 2007; Hawkes et al., 2007). Sea turtle dive profiles have now been behaviorally categorized (Minamikawa et al., 1997; Hochscheid et al., 1999; Hays et al., 2000) according to dive shape, with, for example, U-shaped dives thought to be either resting or foraging dives (Hays et al., 2000).

The use of animal-borne cameras is a recent technological development; National Geographic Television's "Crittercam", a video camcorder and data-logging system device, being one of the first and most widely used (Marshall, 1998). To date, Crittercams have been deployed on a wide range of marine taxa, including cetaceans, pinnipeds, sharks and turtles (Marshall, 1998; Parrish et al., 2000; Heithaus et al., 2001; Seminoff et al., 2006). Such studies highlight that strict behavioral designations to particular dive categories without thorough ground-truthing can lead to inaccuracies (Seminoff et al., 2006). For example, Heithaus et al. (2002) found that green turtles that exhibited dive shapes that might have previously been designated as foraging dives were actually rubbing their bodies against rocks and sponges undertaking self-cleaning behavior. This misinterpretation could result in a significant error in the calculation of time/energy budgets.

To more fully elucidate the behavioral patterns of inter-nesting of green turtles in Cyprus, we used a smaller, recently designed, camera system set up to record still images. At this site, previous TDR studies have suggested feeding (Hochscheid et al., 1999; Hays et al., 2002) despite the suggestion that foraging is atypical for the species during this part of their life cycle (Carr et al., 1974; Mortimer and Carr 1987). Our study aimed to (1) establish the utility of these new devices in providing an insight into the sub-surface behavior of marine turtles and (2) provide pictorial evidence as to whether sea turtles forage during the inter-nesting period at this site.

Materials and Methods

Site and Monitoring

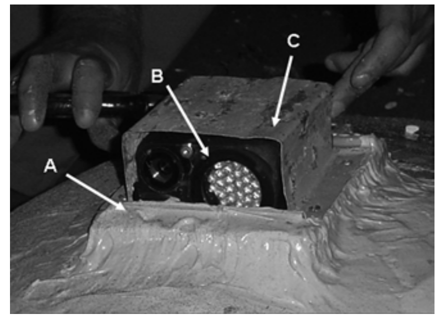
During June 2004, fieldwork was carried out at Alagadi beach, northern Cyprus (35.33°N, 33.48°E). Alagadi is situated on the north coast of Cyprus, a site of intensive annual monitoring of nesting green *Chelonia mydas* and loggerhead *Caretta caretta* turtles since 1992. For additional information on study site monitoring protocols, see the work of Broderick et al. (2002). Remigrant green turtles, with a known nesting history, were selected for this study because of their particularly high fidelity to this specific nesting beach. The two individuals selected were remigrant females having previously nested at Alagadi depositing a total of 13 and six clutches over four and three previous nesting seasons, respectively.

Underwater Timed Picture Recorder Dimensions and Specification

The device used was an underwater timed picture recorder (UTPR; Wild-Insight Ltd., Ely, Cambridgeshire, UK), which uses a digital camera (components from a Sharp VN-EZ1H) interfaced with an Mk7 TDR (Wildlife Computers, Redmond, WA, USA). These particular UTPRs have previously been deployed on Antarctic fur seals *Arctocephalus gazella* (Hooker et al., 2002). The UTPR dimensions were 10.5 × 8.5 × 5.5 cm (Figure 1) and weighed approximately 700 g in air (200 g in water, see Hooker et al., 2002 for further details). The curved carapace length of turtle A = 93.3 cm and turtle B = 98.7 cm. Using the linear regression equation of Hays et al. (2002), the estimated weights of each turtle were 92 kg and 112 kg, respectively. This meant that the estimated weight of the device in water constituted less than 1% of the overall mass of either turtle. All components were solid-potted in epoxy in order to withstand pressure at depth (tested to 750 m) and to protect the delicate electrical components from physical or water damage. A 64 MB SmartMedia card was the data storage medium. The camera flash unit was synchronized with the shutter opening mechanism, with the shutter speed varying automatically depending on ambient light levels (ranging between 1/4 and 1/4000 s in still mode). The light emitting diodes in the flash used were set at 735 nm because this wavelength is unlikely to overlap with the visual sensitivities of marine turtles (Granda and O'Shea 1972). The lens used was an adapted microscope objective together with an extra field lens (field of view 30° horizontal, 24° vertical). Camera focus was preset to 30 cm but could be fixed at any distance from 15 to 150 cm. An electronic link between the TDR and camera allowed the user to preset a depth range at which camera activation occurred. Each picture file was individually time stamped allowing every picture to be linked

FIGURE 1

Photograph of camera, housing and attachment. The base plate was made of wood and rebated (a) to allow the camera (b) to sit securely in place. The metal casing (c) was screwed into position by four screws at each corner. This was to fasten the camera firmly in place and to provide additional protection.



with the relevant dive data. Dive data were collected at 2 s intervals at a depth resolution of 1 m.

Camera Set-Up

The camera can be programmed to record in two separate modes: it can take still images in the form of JPEG files (Joint Photographic Experts Group format) or movie images as ASF files (advanced streaming format). To maximize the amount of time the camera was active, we opted to record still images (JPEG). We chose to set the camera to start taking still images during dives of greater than 5 m in the hope that we would record a range of behaviors, including resting, foraging and traveling. In addition, we used the duty-cycle feature to delay the start of the camera and TDR activation by eight (turtle A) and three (turtle B) days, respectively, to allow views of activities in early and mid inter-nesting. Each camera was set to take a still image every 9 s for a period of 3 min upon reaching the required depth.

Attachment

To enable easy attachment/removal and to provide some additional protection for the camera, each device was placed in a specially designed housing (Figure 1). This consisted of a rebated wooden base plate into which the UTPR sat snugly. In order for the camera to remain attached and to provide extra protection, a metal cover was fastened to the wooden base plate using four screws. Device housings were attached to the turtle's carapace using a two-part epoxy resin after suitable preparation of the carapace (Godley et al., 2002) during the egg-laying and covering of the nest. Glue was smoothed and fared around the devices' base plate in order to reduce hydrodynamic drag and bio-fouling (Watson and Granger, 1998).

Deployment and Removal

Both turtles were fitted with a UTPR during their first recorded nesting attempt on the nights of 11 and 13 June 2004. Neither turtle required any restraint during the attachment process and returned to the sea naturally. During the subsequent nesting attempts 12 (turtle B) and 14 (turtle A) days later, camera units were removed (by unscrewing the 4 screws); again, this required no form of restraint. The base boards were left attached to come off naturally.

Dive Analysis

The start and end of dives were defined by the period when the instrumented turtle exceeded and returned from depths greater than 1 m for longer than 1 min. For each dive duration (minutes), the maximum and modal depths occupied (metres) were calculated using custom designed code in MATLAB (The Mathworks, Massachusetts). Generalized linear mixed-effects models (GLMMs) were used to examine the relationship between dive metrics (i.e., bottom phase depth, bottom phase duration and bottom phase coefficient of variation [CV] (CV) = mean/standard deviation) and period of day (i.e., day or night as specified by the daily local sunrise and sunset times for the approximate latitude and longitude of the attachment site for the dates at which the turtles were at liberty) using either negative binomial or Poisson error distributions with log link functions in GenStat Release 11. GLMMs allow both fixed and random factors to be fitted and the random factors controlled for the use of repeated measurements. The significance of fixed terms in GLMMs is calculated using maximum likelihoods and is assessed by their Wald statistics. To summarize dive data, the number of dives, mean dive duration, maximum dive depth and modal dive depth was calculated for every 3-h period and reported as means ± 1 standard deviation. Variability in association with habitat/behavior of the bottom phase of 66 dives was analyzed by calculating the CV.

TABLE 1

A summary of camera and TDR functioning time and total number of images collected during the two deployments. Also a summary of basic descriptive statistics of dives performed for individual turtles. The camera was attached to turtle A on 11 June 2004 and turtle B on the 13 June 2004. Total dives were recorded for turtle A and B between days 8-14 and 3-12 post-nesting, respectively.

	Camera			Time Depth Recorder			Mean Dive		Maximum Dive	
Turtle	Start	Stop	Images	Start	Stop	Total Dives	Duration (min)	Depth (m)	Duration (min)	Depth (m)
A	19 June	24 June	1641	19 June	25 June	1031	7.0	2.5	22	6.9
B	16 June	17 June	734	16 June	25 June	1868	4.9	3.0	28	13.1

Results

We successfully deployed and retrieved two UTPRs, each for one green turtle inter-nesting period (12 and 14 days, respectively). The housing design was adequate for short deployment times of this study, and there was no damage to either device. A total of 2375 images (for details see Table 1) were captured during the deployment of these two devices. A total of 1031 dives were recorded for turtle A and 1868 for turtle B (between days 8-14 and 3-12 post-nesting, respectively; see Table 1 for summary). Both turtles spent the majority of their time at depths of 5 m or less (turtle A for 91.8%; turtle B for 83.3 %; Figures 2a and 2b). Bottom phase depths were slightly greater during the day than at night (predicted means: night, 2.5 m; day, 2.8 m) (GLMM, Wald Statistic 25.02, $P < 0.001$) although dives were shorter (predicted means: night, 6.3 min; day, 5.6 min) (GLMM, Wald Statistic 13.99, $P<0.001$) and bottom phases were more variable (predicted CV means: night, 0.16; day, 0.18 day) (GLMM, Wald Statistic 48.81, $P < 0.001$).

A range of activities were observed in the photo frames, including active swimming, resting on the seafloor and close association with seagrass with the head moving into the seagrass, suggestive of foraging. For 66 dives, 944 associated images were categorized to identify the three probable types of dive activity: (1) resting (Figure 3), (2) swimming (Figure 4), and (3) foraging (Figure 5). We used U-shaped dives with images for which we could accurately determine the behavior and/or habitat. Given the small number of dives, we decided not to over analyze but by graphical methods compare the small number of dives of the

FIGURE 2

Frequency distribution graph showing the percentage of time spent at a particular depth and mean dive durations (±1 SD) 3 h time bins during each day for 24 h period for (a, c) turtle A and (b, d) turtle B during the whole internesting period.

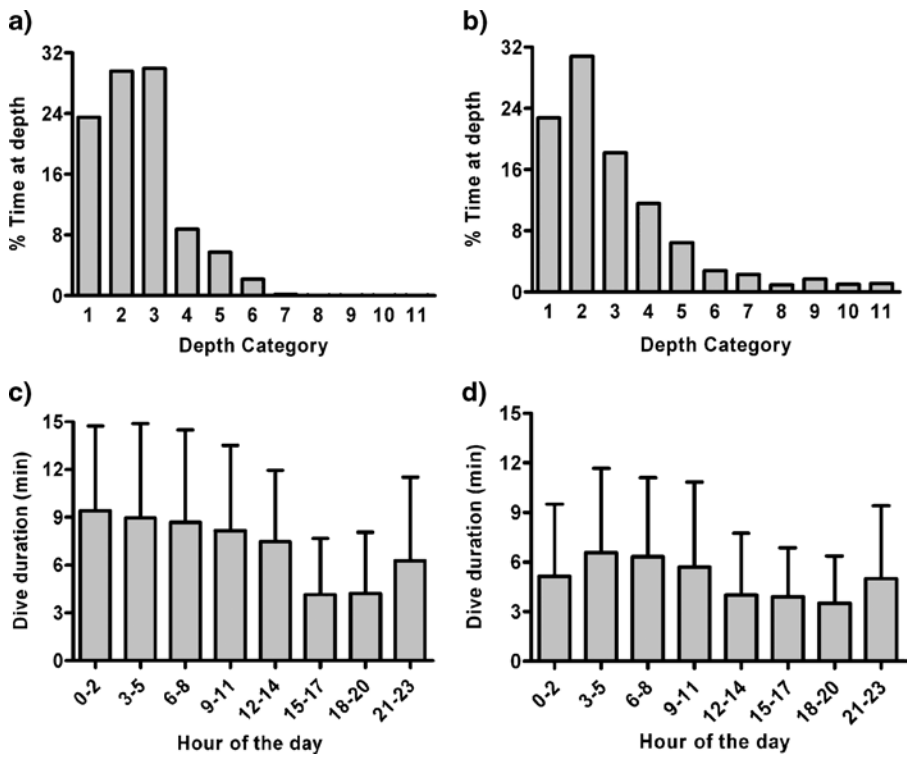


FIGURE 3

Dive profile with images from turtle A on 21 June 2004 associated with resting on the sea bed. The sequence of images shows the same sea floor scene; therefore, the turtle was presumed to be stationary on the sea bed.

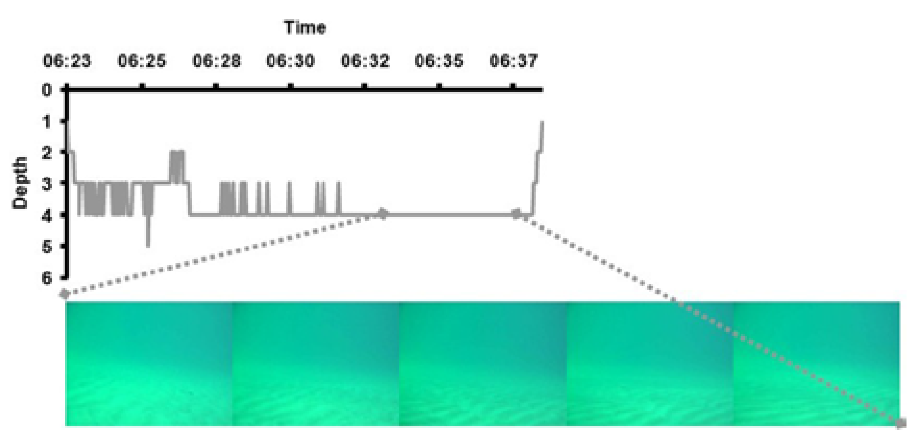
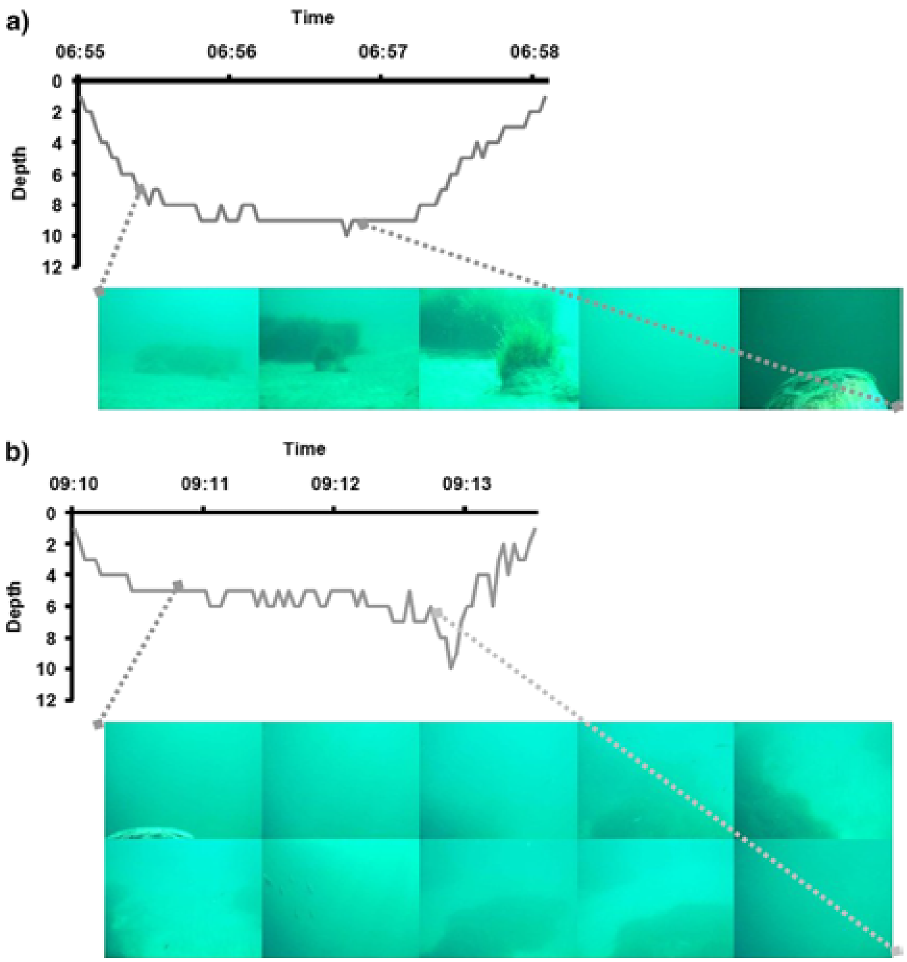


FIGURE 4

Dive profile and images showing the swimming activity of turtle B on 16 June 2004. Images from panel (a) show the turtle swimming towards an underwater structure, and images in panel (b) show that the turtle is moving above the structures on the sea floor.



three stages. There is clearly a great deal of overlap in both the dive duration and CV of depths during the bottom phase of the different activities (Figure 6). There is a suggestion that swimming dives are shorter and more variable, but this is equivocal and would need more extensive testing with larger numbers of individual animals and longer recording durations.

Images

Images retrieved varied from very good to rather poor, depending on light level and water conditions. During daylight, images appeared to show as much as would be visible to the human eye underwater, with objects visible at distances of tens of meters, which were of sufficient quality to ascertain habitat type and/or activity. Above-water images had a visible range of hundreds of meters. However, during the night, the flash (set to minimize interference with the vision of marine fauna) only illuminated approximately 1 m ahead of the turtle; therefore, most of the nocturnal images were featureless. We do not think the flash failed because there are some images in which we can identify seagrass or the ocean floor, but it appears that the object to be photographed has to be very close to the camera in order for the flash to illuminate the field of view. One surprising result from these camera attachments were the images captured above the sea surface. In a few still images, it was possible to pick out recognizable land marks along the coast of north Cyprus, which forms the backdrop to the nesting beach (Figure 7). This allowed us to establish the location of individuals at specific times during their inter-nesting period. These images were captured 2 and 3 days prior to re-nesting and were at the nesting site. Images of interactions with other conspecifics were also captured (Fig. 7 a & b); however, it was not possible to ascertain the sex of these individuals.

Discussion

The study of sub-marine animals is always challenging, especially when trying to elucidate sub-surface behavior from logged data. However, with the current advances in data logging technology, the unlocking of these behaviors is becoming ever more tractable. The current study has afforded new insights into the in-water behavior of green turtles but perhaps more importantly gives pointers as to how this technology may inform future studies. By setting the camera to record only still imagery, we not only used less memory but were also therefore able to capture images over a far longer time frame than previous studies, which used video images (Heithaus et al., 2002; Seminoff et al. 2006). However, there is obviously a tradeoff between sampling rate and the number of events captured (Hooker et al., 2008).

FIGURE 5

Dive profile with images of turtle B foraging on seagrass on (a) 16 June 2004 and (b) 17 June 2004.

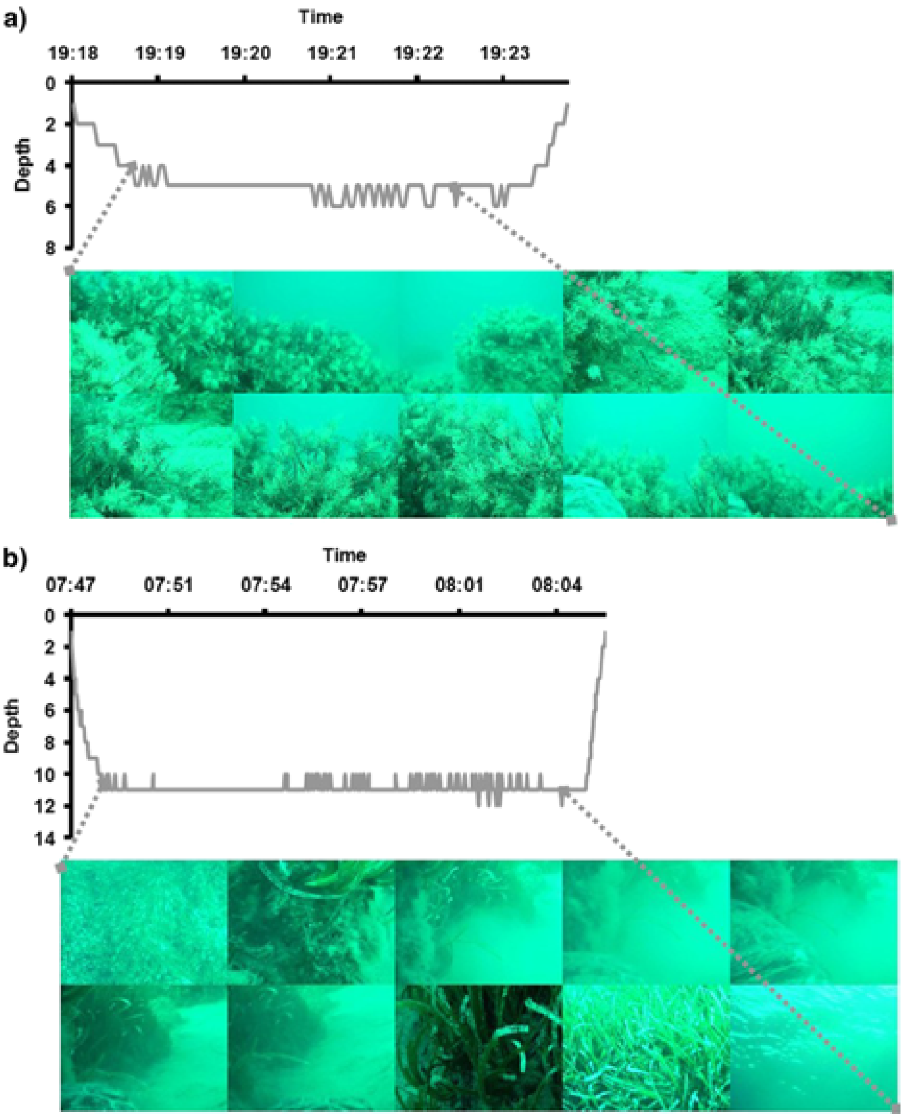
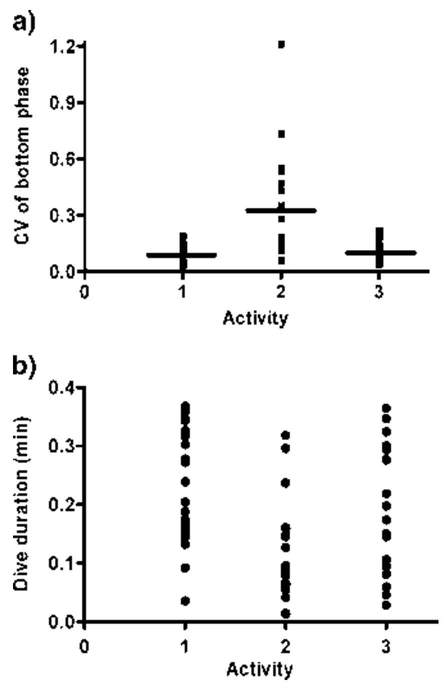


FIGURE 6

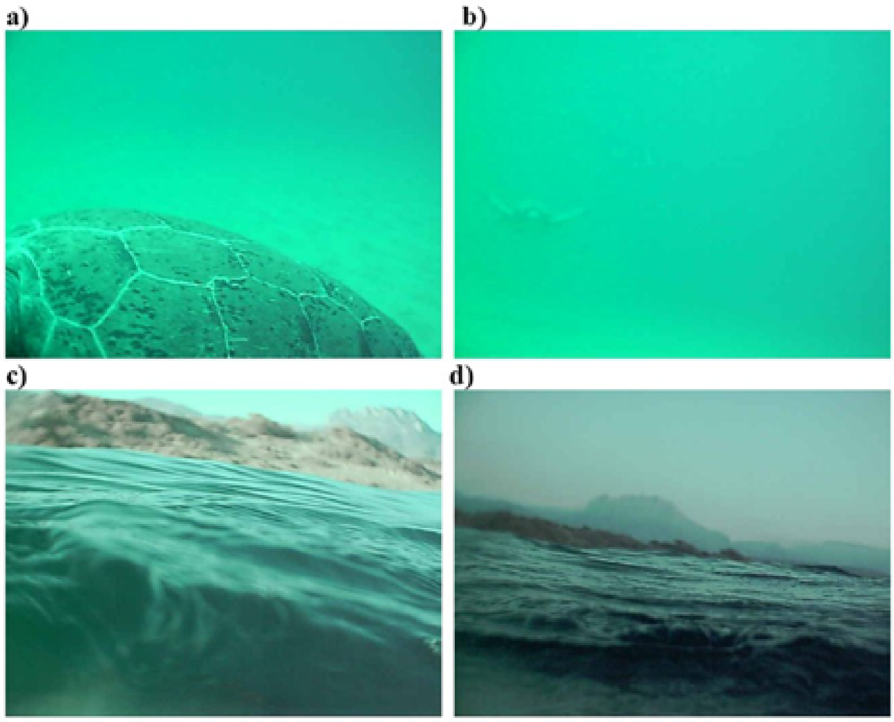
Activities were categorized as follows: (1) sea floor/resting, (2) swimming/open-water, (3) seagrass/feeding. (a) Variation in depth (CV) of the bottom phase for dive profiles where the camera provided images that showed the habitat and/or activity. The horizontal bar signifies the mean CV of the bottom phase for each category. (b) Duration of the bottom phase for each of the above behaviors.



As in previous studies investigating inter-nesting dive behavior at this site (Hochscheid et al., 1999; Hays et al., 2002), all dives were relatively shallow and short in duration. If the minimization of energy consumption were the primary concern for these study animals, one would hypothesize that they should choose to perform U-shaped resting dives (Hays et al., 2002) at neutral buoyancy, i.e., at greater depths and thus achieve longer dive durations (Minamikawa et al., 1997; Hays et al., 2000). Neither individual spent any time at depths >14 m. This was not because of a lack of available deep water close by, and we suggest that this is, at least in part, a result of foraging in shallow seagrass beds. Images collected by the camera also support the suggestion that the turtles were feeding. A large number of images showed turtles among the seagrass, and some image series showed the turtle with its head in seagrass. Further support for this hypothesis is that in the past two necropsies of gravid, females have revealed large amounts of seagrass in the gut (Godley and Broderick, unpublished data). It seems highly likely that whenever there are locally available resources, an individual would utilize these in order to augment its energy reserves during an energetically demanding part of its life. The locations where green turtles are reported to fast during the inter-nesting period (Ascension Island [Bjorndal, 1985]; Malaysia [Liew and Chan, 1992]) are devoid of suitable foraging habitat, and therefore, these turtles have no other alternative but to rely on stored energy reserves for the entire nesting period.

FIGURE 7

A selection of photographs from turtle A showing interactions with conspecifics (a & b) and a view from the water surface of the Pentadaktylos Mountain which forms a backdrop to the nesting beach at Alagadi (c & d).



Advances in Technology and Improvements in Methodology

It is clear that with the current advances in the capacity of memory cards, these cameras could be deployed to capture images at a far greater frequency or for longer time periods allowing detailed imagery at all depths. The use of duty cycles would allow further temporal targeting. For instance, considering these turtles spent a considerable amount of time at such shallow depths and the shortest dives occurred during the afternoon, a duty cycle could be used to sample at a specific period during the day. Considering also the poor quality of the night time images gathered during this study, it would be worth considering sampling only during daylight hours, unless there are future advances in the development of stronger flash units, which would enable reasonable night images to be captured. Regarding the attachment of the camera, because most of the images we collected either showed the top of the turtle's head or the view directly in front of the turtle, it may be prudent in the future to attach the camera in a more anterior position, angled downwards, so as to increase the chances of capturing images of feeding. Alternatively, with the advances in the miniaturization of cameras, it would be possible to use head-mounted cameras, not only to confirm feeding, but also possibly even to describe feeding rate. These head-mounted units could be connected by cables to the battery pack, logging unit, etc., which could be mounted on the carapace. This would reduce the weight and size of the unit. Another possibility would be the use of technologies such as jaw-mounted Hall sensors (Wilson et al., 2007) as a means of triggering the recording of still or video imagery. In this way, images would only be recorded (still/video) when the turtle's mouth is opening and closing. Additionally, the use of multi-dimensional data loggers to record a wide range of parameters is advancing fast (Wilson et al. 2008). Augmentation of these studies with underwater cameras would have great utility.

Time Budget

Our images have allowed us to examine preliminary differences in dive characteristics dependant on animal activity. We add to the findings of Heithaus et al. (2002), showing that U-shaped dives can also be traveling dives, although preliminary evidence suggests that, in general, these have different characteristics from resting and foraging dives. However, considering most of the dives (ca. 90%) in this study were less than 5 m, an accurate picture of the animals' time budgets is difficult to elucidate. Considering that a vast amount of time is spent at such shallow depths, further studies should be made to confirm which behaviors are occurring at these shallow depths.

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