Marine and Freshwater Behaviour and Physiology
December 2006; 39(4): 307–313

Taylor & Francis
Taylor & Francis Group

Short Communication

The behaviour of a hawksbill turtle data-logged during the passage of hurricane Georges through the Caribbean

SANDRA STORCH[1], GRAEME C. HAYS[2], ZANDY HILLIS-STARR[3] & RORY P. WILSON[2]

[1]*Leibniz-Institut für Meereswissenschaften, Experimentelle Ökologie, Düsternbrooker Weg 20, 24105 Kiel, Germany,* [2]*Biological Sciences, Institute of Environmental Sustainability, Swansea University, SA2 8PP, UK, and* [3]*US Department of the Interior, National Park Service, Buck Island Reef National Monument, Christiansted, US Virgin Islands 00820, USA*

(Received 5 April 2006; in final form 12 July 2006)

Abstract
Recent severe hurricanes in the Caribbean and south-east United States have had devastating socio-economic effects, and there is a pressing need to learn how animals are impacted by such events. We serendipitously deployed a multi-channel data logger onto a hawksbill turtle (*Eretmochelys imbricata*) during the breeding season in 1998 and logged various aspects of her behaviour before, during and after passage of hurricane Georges. As Georges passed by, the turtle made shorter dives, became more active and spent less time at the surface between dives compared with its baseline, non-storm activity. However, after passage of the hurricane the turtle quickly resumed its pre-hurricane behaviour and nested successfully a few days later. These results show that, in this case, the hurricane had a minor impact on the submerged animal presumably because of the dampening effect of depth on high winds over water.

Keywords: *Hurricanes, Caribbean, climate change, animal behaviour, hawksbill turtle*

Introduction

The responses of animals to their environment form the central foundation of many ecological studies because these responses may play key roles in driving the fitness and survival of individuals and hence the persistence of populations. Such studies also have important applied aspects by helping to identify the key processes that may threaten species. Set within this general framework, the literature is full of studies reporting behavioural responses to various anthropogenic and natural factors. However, a potentially important area that has received relatively little attention is the response of animals to massive storms (Butler 2000). Such studies are scarce because of the logistical problems associated with

Correspondence: Graeme C. Hays, Biological Sciences, Institute of Environmental Sustainability, Swansea University, SA2 8PP, UK. E-mail: g.hays@swan.ac.uk

ISSN 1023–6244 print/ISSN 1029–0362 online/06/040307–313
DOI: 10.1080/10236240600919796

recording behaviour during conditions that may threaten the survival of not only the study animal but also of the researchers themselves!

Storms certainly appear important in structuring communities in a variety of marine and freshwater systems (e.g. Spiller et al. 1998; Schoener et al. 2000; Calsbeek and Smith 2003; Steinhart et al. 2005). The advent of sophisticated data loggers (e.g. Hays et al. 2004a; Ropert-Coudert and Wilson 2005) that can record over extended periods means that it is now, in theory, possible to record animal behaviours before, during and after storm events. However, despite technological advances, such studies are still difficult to perform. Even with targeted studies to investigate storm effects on behaviour, there may be a low probability of getting these behavioural data because of the difficulties of predicting where the storms will occur relative to the location of mobile, tagged animals. Hence, successful studies will require a degree of serendipity. Nevertheless, there is a pressing need for such studies since the severity of storm events is predicted to increase under scenarios of global climate change (Bluestein 2005; Emanuel 2005).

In common with many marine vertebrate telemetry studies, it is often hard to initially achieve a large sample size, and yet, even studies with a few individuals can have great value (Hughes et al. 1998; James et al. 2005). Here, we report how passage of a major hurricane in the Caribbean influenced the at-sea behaviour of a free-living hawksbill turtle (*Eretmochelys imbricata*), and discuss the implications of this single data point for the survival of this species if applied more generally to its behaviour.

Methods

Study site and data logger deployments

We equipped an adult female hawksbill sea turtle (*Eretmochelys imbricata*) with a multi-channel data logger during the nesting season at Buck Island Reef National Monument (64°37′W, 17°47′N), US Virgin Islands (subsequently referred to as Buck Island). This protected, uninhabited island is 1.6 km long and 0.8 km wide, situated 2.7 km north-east of the island of St. Croix in the Caribbean. It is one of the most important nesting areas for hawksbill turtles within the US, and the recovery plan for hawksbill turtles in the US Caribbean Sea, Atlantic Ocean and Gulf of Mexico identified Buck Island as an index beach for the recovery of this species in the whole eastern Caribbean (National Marine Fisheries Service and US Fish and Wildlife Service 1993).

The data logger (DK600, Driesen & Kern, Bad Bramsted, Germany) recorded temperature, light intensity, depth and compass heading throughout an internesting interval. Deployments of data loggers onto hawksbill turtles at this site are described in detail by Storch et al. (2005). Data readings of all channels were taken at intervals of 15 s in non-volatile 1 MB memory. The compass data came from signals from two Hall sensors, mounted on the outer shell of a miniature spherical ship-compass incorporated in the data logger and gave a measure of turtle activity. The temperature was measured to an accuracy of 0.1°C (−20 to +80°C). Depth readings could be taken up to a maximum depth of 400 m at a resolution better than 1 cm and an accuracy approximately 20 cm. The logger was approximately 12 cm in length, 6.5 cm in width, 3 cm in height and weighed less than 200 g in air and was attached to the carapace of a hawksbill turtle with quick-setting epoxy just after the turtle had completed nesting. The logger was then removed when the turtle returned to nest 16 days later. Data were downloaded from the loggers to a PC using Dklog200 (Driesen & Kern, Bad Bramsted, Germany). The data logger delivered data for an entire internesting interval lasting from 12 to 27 September 1998.

Hurricane Georges

Coincidentally, while the turtle was carrying the data logger, hurricane Georges passed through the study area. Georges was a category IV hurricane that passed through the Caribbean in September 1998 (http://www.nhc.noaa.gov/1998georges.html). The 602 direct deaths attributed to Georges made it, at that time, the 19th deadliest tropical cyclone in the Atlantic basin that century. Georges passed over Buck Island and St. Croix on 21 September 1998.

Results and discussion

In the morning hours of 21 September, hurricane Georges arrived at Buck Island with rainfall and wind gusts of 182 km h^{-1} (98 kt) from a NNW (338°) direction. After the eye had passed at noon, with a calm period of 30 min, the wind switched to SSW (190°) with maximum speeds of 150 km h^{-1} (81 kt). The phases are schematically marked in Figure 1(a) showing the satellite image of hurricane Georges 2 days before it reached Buck Island. The phases of extreme winds started with northern winds between approximately 9:00 and 12:00 h local time on 21 September 1998, followed by the passage of the calm eye of the storm (12:00 to 12:30 h) and an extended phase of southern winds from 12:30 to approximately 21:00 h.

The chronological data of light intensity, water temperature and dive depth are shown in Figure 1(b) to give an overview of the complete internesting interval. A more detailed view of the course of events during the storm is seen in Figure 1(c). The time span of extreme winds (as experienced at site) is shaded grey in Figure 1(b). The overview of the light data clearly documents the unusual condition of overcast skies, already apparent in the morning hours of 21 September and lasting the complete day. The light was back to normal levels on the following day. The amplitude of surface waves increased during the storm, the height of the waves being apparent as fluctuations in the dive depth data during periods of unchanged compass output, this latter indicating that the turtle was motionless at the time. Waves were increased by the storm from less than 0.5 m to ~1.5 m. The intensified wave action reached the study site ~12 h before extreme winds were observed, which lasted through 22 September. With increasing wave action the water temperature at the turtle site started to drop over the last few hours on 20 September, reaching the coldest measured temperature of 28.6°C on 22 September between 11:40 and 22:30 h local time. The additional sharp decreases of temperature recorded in the dark hours of the early and late 25 September are derived from evaporative cooling due to the animal surfacing. The water temperature remained lowered throughout the rest of the internesting interval, i.e. 6 days after the hurricane passed.

Another comparison of the behaviour of the turtle during the hurricane and at other times is provided in Figure 2, which shows data recorded over a 4-day period including passage of the hurricane. This figure serves to illustrate the increase in wave action, beginning in the afternoon before the hurricane passed the island, which is evident as increased fluctuations in the dive depths during the bottom phases of dives.

Mean dive values for the day before the storm (20 September, 09:00 to 21:00) were compared with values during the storm (21 September, 09:00 to 21:00). Mean dive duration before the hurricane (57.3 min, SD = 20.0 min, $n = 14$ dives) was significantly longer than mean dive duration during the hurricane (42.0 min, SD = 24.6 min, $n = 19$ dives) as was mean surface interval (1.4 min *vs.* 0.7 min, respectively) (t-tests, $P < 0.05$ and

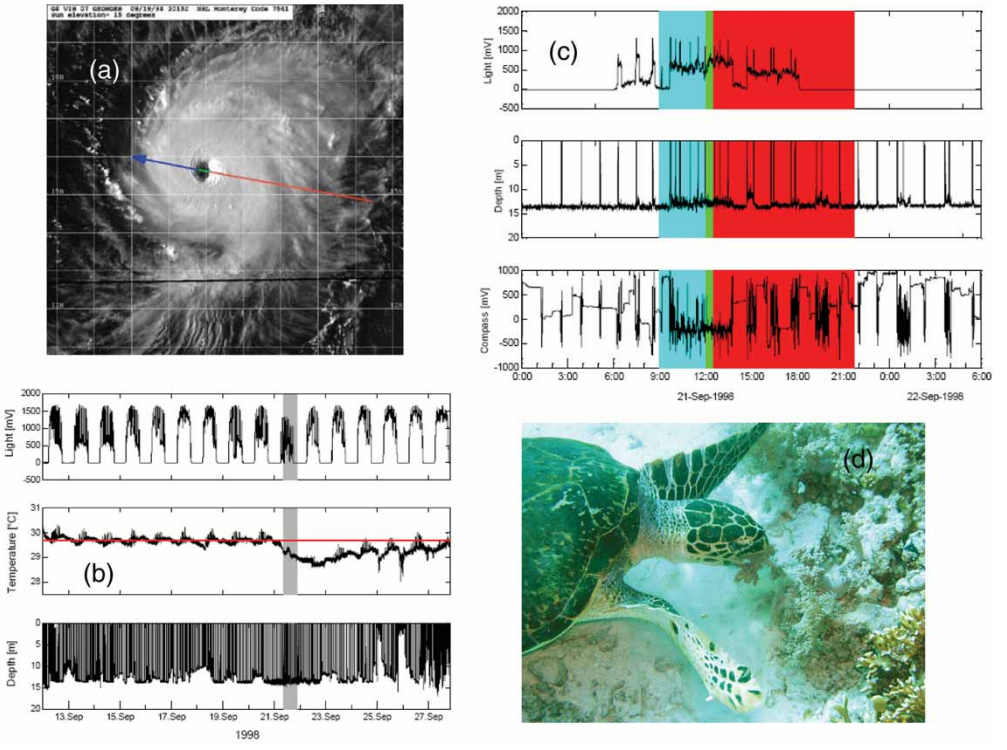

Figure 1. (a) Satellite image of hurricane Georges taken on 19 September 1998 (National Climatic Data Center). The line indicates the direction of travel of the storm. The coloured sections of the line (fitted by eye and not to scale) represent the phases of extreme wind conditions with northern winds (blue), a calm eye (green) and an extended phase of southerly winds (red). (b) Overview of parallel data of light (top), water temperature (middle) and dive depth (bottom) measurements obtained from the equipped turtle. The grey patches mark the time hurricane Georges passed over the study area. The red line marks the mean temperature of 29.7°C calculated over all data points obtained before the storm. (c) Chronological data of light intensity (top), depth (middle) and motion (bottom) recorded during hurricane Georges. The phases of the storm, as defined by wind conditions (see text), are coloured according to Figure 1(a) as northern winds (blue), calm eye (green) and southern winds (red). (d) The hawksbill turtle (pictured feeding) was historically exploited so its shell could be turned into jewellery. Photograph courtesy of David Sims.

0.005, respectively). During the extreme winds the variability of the compass signal suggests that the turtle either actively moved or was moved by wave action.

The hawksbill turtle (Figure 1d) is the subject of current high-profile interest due to the possibility of resumed international trade in hawksbill shell (Mrosovsky 1997, 1998; Meylan 1998; Robinson and Thorbjarnarson 2000), which was historically used for making jewellery. Hawksbill turtles in the Caribbean are a key focus of attention because the harvesting of individuals in Cuba has been muted and discussed at length by CITES. In addition to man's direct impact on turtles (targeted capture, bycatch, etc.), it is generally assumed that the role of natural environmental perturbations such as storms may be considerable. However, their impact on sea turtles is unclear except for studies that have documented storm damage to nesting beaches (Starbird and Hillis 1992; Milton et al. 1994; Hillis 1995; Hillis and Phillips 1998). The effects of hurricane George on the turtle's

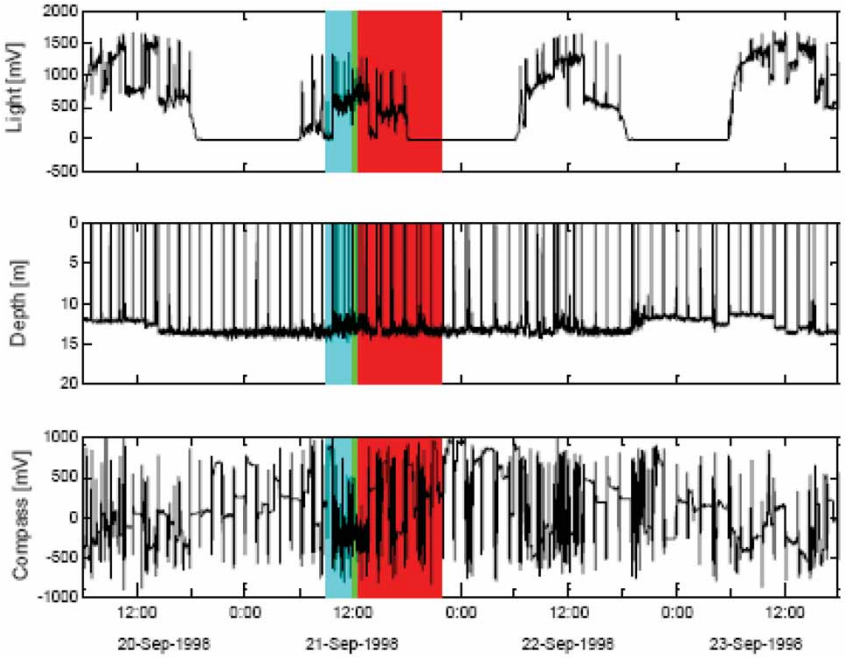

Figure 2. Data recorded over a 4-day period including the time of the passage of hurricane Georges (see Figure 1 for description of axes and colour codes).

behaviour appear to be relatively minor and transitory. It is well known that undisturbed hawksbill turtles routinely conduct long dives (van Dam and Diez 1997; Storch et al. 2005), and this same behaviour is seen in other marine turtle species such as the green turtle (*Chelonia mydas*) (Hays et al. 2002, 2004b). The shortened dive duration during the hurricane can be interpreted as an indication of increased metabolism resulting from active swimming behaviour. The short events of motionlessness during the second half of the storm indicate that the turtle was lying on the bottom, probably in the shelter of some rigid structure at a depth of 13.5 m. This indicates the turtle remained in the shallow area around Buck Island instead of moving over to the close drop-off to take shelter at great depth. It can be speculated that either the conditions of the southern winds allowed this motionless resting, contrasting the phase of northern winds with no such events, or that the turtle adjusted its behaviour or position to the conditions of the hurricane after approximately 4 h of storm.

Adult hawksbill turtles live specifically in reef habitats, where they forage on sponges and corals (Meylan 1988). It is known that hurricanes can have a range of effects on coral reef systems, ranging from relatively minor short-term reef destruction to long-term impacts that can change sponge and coral species (Woodley et al. 1981; Connell et al. 2004; Gardner et al. 2005). Following reef destruction there is a general trend for fast-growing species to replace long-lived slow-growing forms. However, the long-term impacts of such structural changes to reef communities on the fitness of turtles remains unknown and may define how turtles in general cope with any increasing hurricane frequency and severity. Concerns that severe hurricanes may increase under scenarios of climate change (Bluestein 2005; Emanuel 2005) highlight the importance of this area of research.

Acknowledgements

This work was funded through a grant to R.P.W. from the Deutsche Forschungsgemeinschaft (Wi 1023/5-1 and Wi 1023/5-2) and to G.C.H. from the Natural Environment Research Council (NERC). We thank C. Begler and S. Zankl for help with data analysis. The study greatly benefited from the staff and volunteers at Buck Island Reef NM and was conducted under permit from the DOI, NPS, Buck Island Reef NM, Division of Resource Management, St. Croix, VI (permit to Z.M. Hillis-Starr).

References

Bluestein HB. 2005. Before the storm. Nature 437:953–954.

Butler RW. 2000. Stormy seas for some North American songbirds: Are declines related to severe storms during migration? Auk 117:518–522.

Calsbeek R, Smith TB. 2003. Ocean currents mediate evolution in island lizards. Nature 426:552–555.

Connell JH, Hughes TE, Wallace CC, Tanner JE, Harms KE, Kerr AM. 2004. A long-term study of competition and diversity of corals. Ecol. Monogr. 74:179–210.

Emanuel K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436:686–688.

Gardner TA, Cote IM, Gill JA, Grant A, Watkinson AR. 2005. Hurricanes and Caribbean coral reefs: Impacts, recovery patterns, and role in long-term decline. Ecology 86:174–184.

Hays GC, Glen F, Broderick AC, Godley BJ, Metcalfe JD. 2002. Behavioural plasticity in a large marine herbivore: Contrasting patterns of depth utilisation between two green turtle (*Chelonia mydas*) populations. Mar. Biol. 141:985–990.

Hays GC, Metcalfe JD, Walne AW, Wilson RP. 2004a. First records of flipper beat frequency during sea turtle diving. J. Exp. Mar. Biol. Ecol. 303:243–260.

Hays GC, Metcalfe JD, Walne AW. 2004b. The implications of lung regulated buoyancy control for dive depth and duration. Ecology 85:1137–1145.

Hillis Z-M. 1995. Buck Island Reef National Monument Hawksbill Sea Turtle Research Program, 1991. In: Richardson JI, Richardson TH, editors, US Dept. Commerce, NOAA Tech Memo NMFS-SEFSC-361, pp. 47–51.

Hillis Z-M, Phillips B. 1998. 1995 – The hurricane season of the century, Buck Island Reef National Monument, St. Croix, Virgin Islands. In: Byles R, Fernandez Y, editors, Proceedings of the Sixteenth Annual Symposium on Sea Turtle Biology and Conservation. US Dept. Commerce, NOAA Tech Memo NMFS-SEFSC-412, pp. 67–69.

Hughes GR, Luschi P, Mencacci R, Papi F. 1998. The 7000-km oceanic journey of a leatherback turtle tracked by satellite. J. Exp. Mar. Biol. Ecol. 229:209–217.

James MC, Eckert SA, Myers RA. 2005. Migratory and reproductive movements of male leatherback turtles (*Dermochelys coriacea*). Mar. Biol. 147:845–853.

National Marine Fisheries Service and US Fish and Wildlife Service. 1993. Recovery Plan for Hawksbill Turtles in the US Caribbean Sea, Atlantic Ocean, and Gulf of Mexico. National Marine Fisheries Service, St. Petersburg, Florida, USA, 52 pp.

Meylan A. 1988. Spongivory in hawksbill turtles: A diet of glass. Science 239:393–395.

Meylan A. 1998. Hawksbill turtles still endangered. Nature 391:117.

Milton SL, Leone-Kabler S, Schulman AA, Lutz PL. 1994. Effects of Hurricane Andrew on the sea turtle nesting beaches of South Florida. Bul. Mar. Sci 54:974–981.

Mrosovsky N. 1998. Plight of hawksbill turtles. Nature 392:646.

Mrosovsky N. 1997. IUCN's credibility critically endangered. Nature 389:436.

Robinson JG, Thorbjarnarson J. 2000. Endangered harvest? Nature 404:704.

Ropert-Coudert Y, Wilson RP. 2005. Trends and perspectives in animal-attached remote sensing. Front. Ecol. Environ. 3:437–444.

Spiller DA, Losos JB, Schoener TW. 1998. Impact of a catastrophic hurricane on island populations. Science 281:695–697.

Schoener TW, Spiller D, Losos JB. 2000. Natural restoration of the species-area relation for a lizard after a hurricane. Science 294:1525–1528.

Starbird CH, Hillis Z-M. 1992. The effect of Hurricane Hugo on the nesting behavior of Hawksbill Sea Turtles on Buck Island National Monument, United States Virgin Islands. In: Salmon M, Wyneken J, editors, Proceedings of the Eleventh Annual Workshop on Sea Turtle Biology and Conservation. US Dept. Commerce, NOAA Tech Memo NMFS-SEFC-302, p. 114–116.

Steinhart GB, Leonard NJ, Stein RA, Marschall EA. 2005. Effects of storms, angling, and nest predation during angling on smallmouth bass (*Micropterus dolomieu*) nest success. Can. J. Fish Aquat. Sci 62:2649–2660.

Storch S, Wilson RP, Hillis-Starr Z, Adelung D. 2005. Cold-blooded divers: Temperature-dependent dive performance in the wild hawksbill turtle *Eretmochelys imbricate*. Mar. Ecol. Prog Ser 293:263–271.

Van Dam RP, Diez CE. 1997. Diving behavior of immature hawksbill turtles (*Eretmochelys imbricata*) in a Caribbean reef habitat. Coral Reefs 16:133–138.

Woodley JD, Chornesky EA, Clifford PA, Jackson JBC, Kaufman LS, Knowlton N, Lang JC, Pearson MP, Porter JW, Rooney MC, Rylaarsdam KW, Tunnicliffe VJ, Wahle CM, Wulff JL, Curtis ASG, Dallmeyer MD, Jupp BP, Koehl MAR, Neigel J, Sides EM. 1981. Hurricane Allen's Impact on Jamaican Coral Reefs. Science 214:749–755.