Stormy oceans are associated with declines in sea turtle hatching

Kyle S. Van Houtan[1,3] and Oron L. Bass[2]

Many sea turtle populations are below 10% of their pre-Columbian numbers [1–4]. Though historic and systematic over-exploitation is the principal cause of these declines, sea turtles face similar threats today. Adults and juveniles are actively hunted and commercial fisheries catch them incidentally. Nesting suffers from beach development, egg poaching and the poaching of nesting females. Accompanying these familiar hazards is the largely unknown consequences of recent climate change. Here we report monitoring surveys from the Dry Tortugas National Park (DTNP, 24.64N 82.86W), Florida, and show that hurricanes and other storm events are an additional and increasing threat to loggerhead turtle (*Caretta caretta*) and green sea turtle (*Chelonia mydas*) nesting. Both species are listed by the US Endangered Species Act and the IUCN considers them 'endangered'.

In June of 1513, the explorer Juan Ponce de Leon named the DTNP area *Las Tortugas* as "in a short time of the night they took, in one of these islands, a hundred and seventy turtles, and might have taken many more if they wished" [5]. Indicative of populations throughout the Caribbean, the park's seven islands may now only host such numbers over an entire year (see Figure S1 in the Supplemental data available on-line with this issue).

From 1995–2004, researchers and volunteers monitored turtle nests at DTNP from April until November — the span of the nesting season. Teams conducted daily boat surveys of the park's beaches, and marked nests dug the previous night. Nests were monitored daily after 45 days of incubation and were hand-excavated after 70 days if no clutch emerged. Upon emergence or excavation, nest contents were documented and the fate of each egg recorded. Over the study, researchers consistently observed that strong weather systems in the Western Atlantic could create enough wave energy to erode beaches locally and flood or expose nests that females buried above the high-water line. Extreme weather events, like tropical cyclones, had potentially greater impacts — reshaping the park's features and annihilating scores of nests.

We used nest observations, inundation data and tropical cyclone intensity to assess the impacts of storms on egg hatching. Hatching success decreases over the study period, exhibiting for both species more than 50% declines (Figure 1A). This statistic isolates hatching declines not explained by predation, which only has a minor influence (see Supplemental data). The number of nests damaged by storm waves correspondingly increases over the study (Figure 1B, linear regression: $F_{1,6} = 7.0$, $P < .04$). Tropical cyclones have an increasing presence during the nesting seasons of our study period (Figure 1C). This measure stems from an index (Supplemental Material) that accumulates cyclone intensities over each nesting season within 3° latitude and longitude of DTNP. Importantly, nest flooding is higher in years where cyclone intensities are greater (Figure 1D, $F_{1,6} = 44.7$, $P = .0005$) and hatching success declines as cyclone intensity increases for both loggerhead ($F_{1,6} = 25.3$, $P = .002$) and green sea turtles ($F_{1,5} = 23.0$, $P = .005$).

Figure 2 plots the seasonal distribution of active nests, which in years without major storms appears as an unblemished 'bell-shaped' curve. Green sea turtles nest later in the year than loggerheads, their nests encounter tropical cyclones more often, and as a result frequently hatch fewer of their eggs. In 1998 and 2000, for example, when loggerhead nesting was nearly

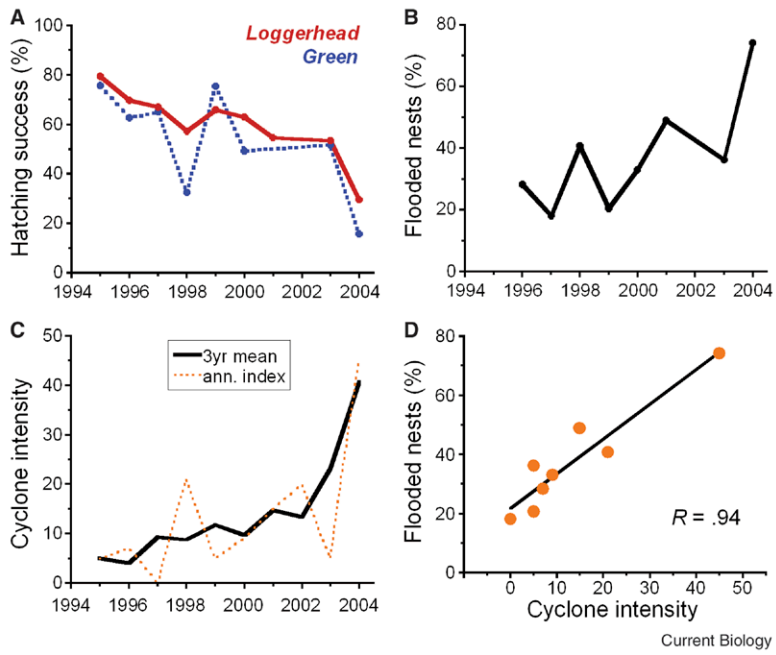

Figure 1. Tropical cyclones increasingly harm sea turtle hatching success.

(A) Observed eggs that survive until hatching for loggerhead and green sea turtles. (B) Storm damage to nests measured in percent inundated or washed away. (C) Tropical cyclone intensity during turtle nesting seasons at DTNP. (D) Nests flood more frequently in years with earlier, stronger, and more frequent hurricanes and tropical storms. From a lack of funding, there were no turtle surveys in 2002 or after 2004. No green nests were observed in 2001.

complete, cyclones washed out a number of green nests, dropping their hatching success measurably below loggerheads (Figure 1A). The 2004 season was particularly costly for both species. Four strong hurricanes affected the park, completely destroying most active nests. The 2004 nesting curves are visibly truncated, demonstrating how strong storms wash away nests in great numbers.

Taken together, our results suggest that tropical cyclones are a significant factor in the observed turtle hatching declines. This raises concern given the link between warming sea surfaces and tropical cyclones. Theory alone [6] predicts global warming may amplify the potential power of tropical cyclones. Recent historical models [7,8] confirm this link and suggest that warming seas likely increase the frequency, duration and destructive power of tropical cyclones; particularly in the Atlantic Ocean. The potential prospects of earlier, more numerous, and more powerful storms pose an additional and significant threat to loggerhead and green sea turtles nesting in southwest Florida, and perhaps beyond. This may be especially true for turtle rookeries like those at DTNP where nesting beaches are exposed to high surf and storm surges that accompany strong storms.

Some sea turtle nesting populations in the Western Atlantic have recovered locally in recent decades as a result of beach protection and reforms in commercial fishing [4,9,10]. Regionally, however, these populations remain far below their historic numbers. Though strong conservation efforts have made measurable local differences, sea turtles now seem to face the challenges of climate change. Certainly extreme weather events are a common natural feature of most sea turtle nesting areas. Historically, however, these species likely buffered extreme weather events by their large populations and geographically widespread nesting [2]. Today sea turtles have no such luxuries. That makes conservation efforts that have proven successful to be even more urgent.

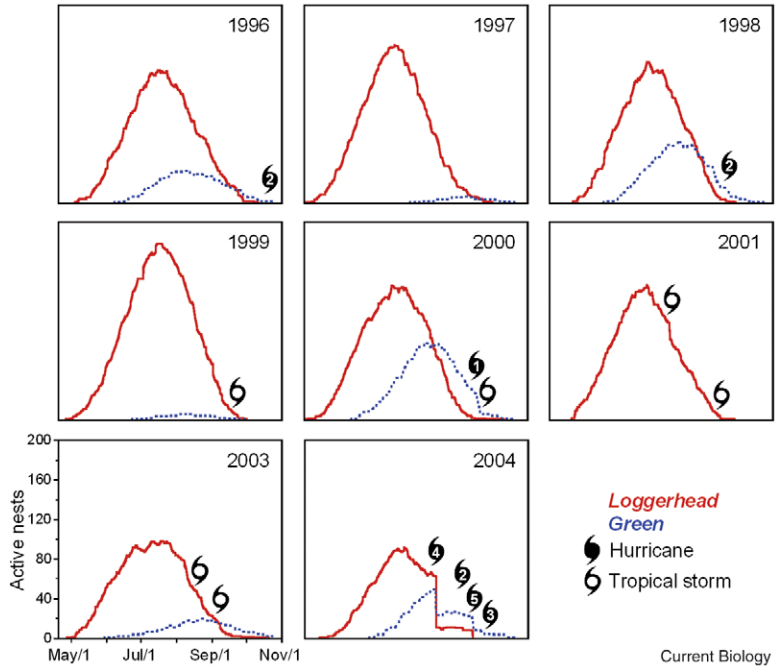

Figure 2. Seasonal distribution of active nests at the Dry Tortugas National Park.

In comparison to loggerheads, green sea turtle nests are more prone to flooding as they nest later in the season and encounter storms more often. Nest distribution, which might otherwise appear as a 'normal' curve, is visibly altered by strong cyclones as they erode the park's beaches and wash away entire nests. Hurricanes are labeled with their peak category on the Saffir-Simpson scale (see Supplemental data).

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Supplemental data

Supplemental data, including experimental procedures, are available at http://www.current-biology.com/cgi/content/full/17/15/R590/DC1

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[1]Nicholas School of the Environment and Earth Sciences, Duke University, Durham, North Carolina 27708, USA. [2]South Florida Natural Resources Center, Everglades National Park, Homestead, Florida 33030, USA. [3]Current address: Science and Society Program, Department of Biology, Emory University, 1510 Clifton Road NE, Atlanta, Georgia 30322, USA.
E-mail: kyle.vanhoutan@gmail.com