Turning Up the Heat on Sea Turtles

By Samantha G. Kuschke, Justin R. Perrault, and Jeanette Wyneken

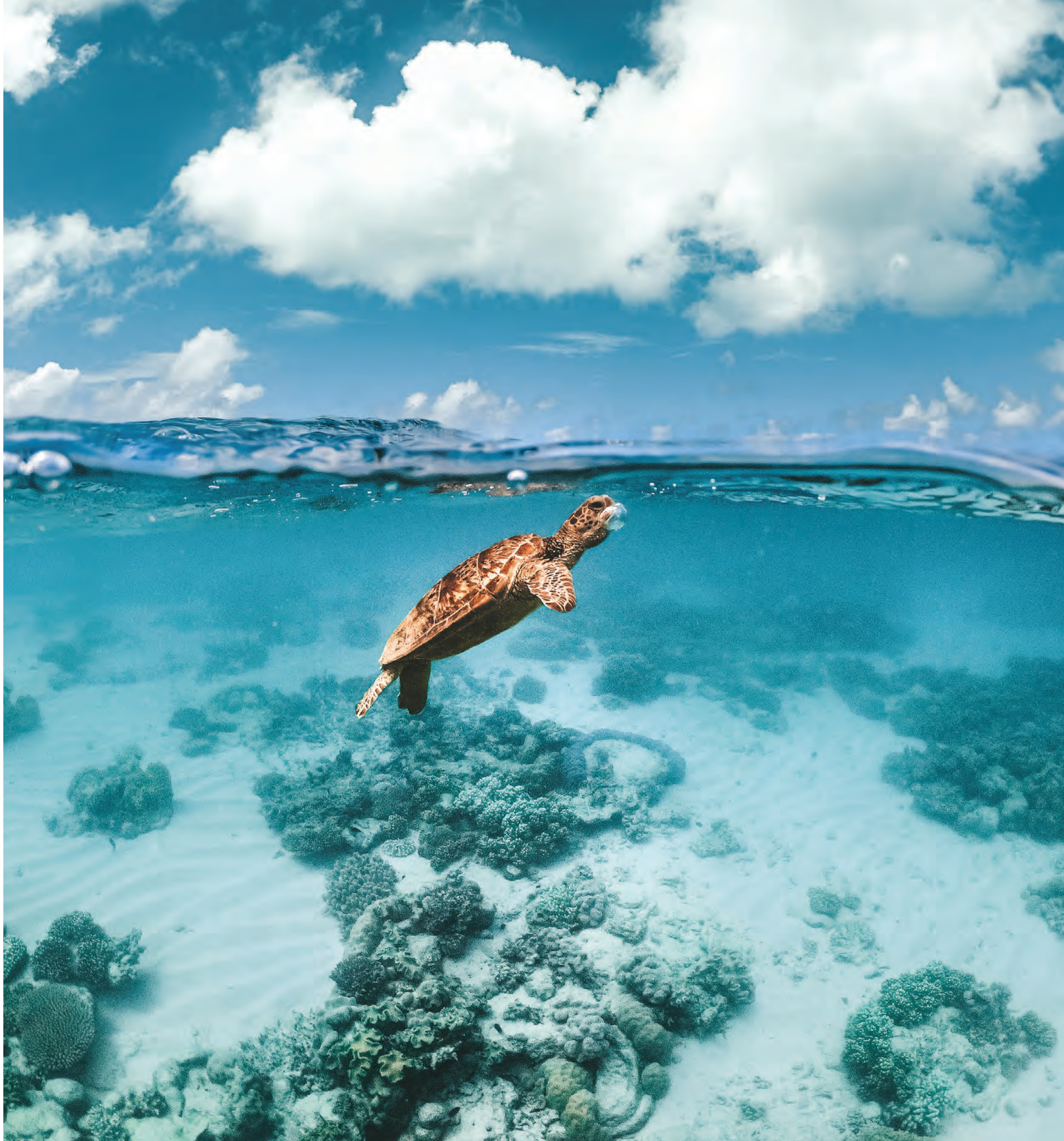
Climatic changes are occurring on a global scale and at a rapid pace, leading to elevated ocean and beach temperatures, prolonged heat waves, droughts, severe storms, and other abnormal weather events. Individually, each of those changes can negatively affect sea turtles, but when they occur together, the scope of the problem can be broad and pervasive. Sea turtles rely on healthy oceans, coastal waters, estuaries, and sandy beaches for their survival. Hence, there is an urgent need to characterize the full suite of climate change influences on sea turtles so that we can design adaptation strategies and mitigations.

Time to Prepare, Conservationists!

There remains an overall lack of knowledge about the effects of shifting climate on different sea turtle species and life-stage classes, and we have even less information about those impacts at population scales. Yet these types of knowledge will be essential for defining management options. Classically important quantifiable measures for sea turtles (called *vital rates*) such as hatchling production and death rates, hatchling health, age to maturity, sex ratios, and population age structure are all affected by climate; however, baseline measures for those vital rates are sorely lacking.

Meanwhile, climatic effects on food chains and how the changes may affect the growth and survival of juvenile sea turtles also are understudied. Slowing growth rates of sea turtles have been linked to ecological shifts, including losses of basic or intermediate links in food chains that affect nutrient availability, ratios of dissolved gases, and more. Such disruptions can have population-scale responses in some cases. Furthermore, severe storm events can cause large-scale movements of undersea sediments that disturb submerged vegetation or silt coral reefs, thereby reducing available food items for both juvenile and adult turtles.

AT RIGHT: A juvenile green turtle off Cape Tribulation in Australia's Great Barrier Reef, which has experienced severe coral bleaching due to climate change. © Jackson Groves/journeyera.com



Visible Impacts

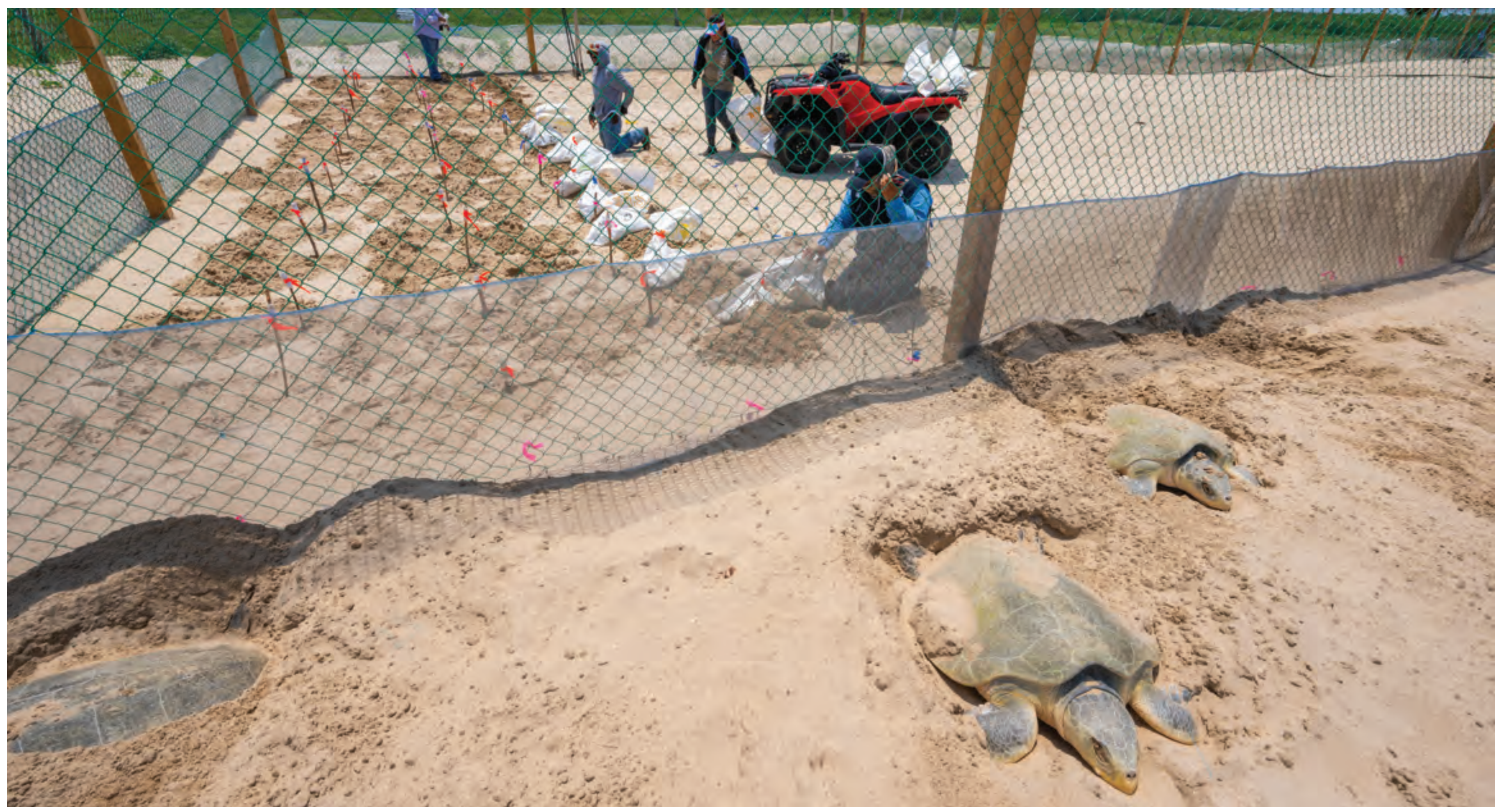
The planet already is experiencing irrefutable changes in sea levels and storm severity that have direct impacts on the reproductive success of turtles. Prolonged seawater inundation of nests and nest overwash events have been shown to greatly reduce reproductive output. In addition, extreme onshore wind events, which also are on the upswing globally, can lead to excessive sand erosion or accretion, sometimes exposing or deeply burying eggs—scenarios that can lead to nest failure. Loss of entire beaches to rising seas is an increasing reality, and in some locations, efforts to nourish beaches replace sand where it was eroded. At other sites, full armoring of beaches can protect upland structures but results in the loss of suitable nesting habitats for turtles. Some armored beaches actually present vertical walls to break waves and prevent wave runup; not only are such obstacles impassable by inbound nesting turtles, but also they prevent the natural renewal of suspended sand required for healthy nesting beaches.

Less Visible Impacts

Sea turtle embryos, hatchlings, and posthatchlings are facing increased amounts of physiological stress as a result of increasing beach temperatures. The warming of nesting beaches is a major issue directly related to sea turtle reproductive success and feminizing effects on sea turtle hatchling sex ratios. However, data to support those observations remain scant (see sidebar at right), and rising beach temperatures have even more profound effects on nests and eggs, which need further study and attention. Fundamentally, eggs are enclosed, stationary life support systems for developing embryos. As the embryos grow, their eggs breathe, in a way, exchanging respiratory gases with the external environment. Eggs also take in and release water vapor. Up to a point, the temperature of the nest is positively related to the rate of development, and a range of temperatures (within extremes often termed the *thermal minimum* and *thermal maximum*) can support normal hatchling development. Some researchers report that eggs incubated closer to the thermal minimum rarely hatch. Yet, with global temperatures increasing, there are now very few nesting beaches where that occurs. Sea turtle species differ somewhat in their thermal maxima, with olive ridleys tolerating warmer temperatures than leatherbacks, loggerheads, and green turtles tolerate.

A suite of consequences can occur when nests reach or exceed the maximum temperature limit, and typically, reproductive success declines when incubation temperatures exceed the maximum for prolonged periods. When loggerhead eggs are exposed to an average temperature of 33.5 degrees Celsius (92.3 degrees Fahrenheit), the incubation period becomes less predictable, and the embryos may perish or respond by using less energy for growth. Leatherback and loggerhead nests from southern Florida also show significant declines in hatching and emergence success at average incubation temperatures of 32 degrees and 33 degrees Celsius (89.6 degrees and 91.5 degrees Fahrenheit), respectively.

Proteins perform essential roles as the building blocks for muscles, viscera, enzymes, and hormones, and they aid in the transport of molecules around the body. Embryonic death can occur when temperatures reach the threshold that prevents normal protein synthesis. When the thermal maximum is reached, turtle embryos experience hyperthermia and can suffer developmental abnormalities, including orofacial defects (cleft palate), eye abnormalities, or diverse gastrointestinal defects, or they may die if thermal stress is too high. However, far more research is required to understand the timing of thermal maxima impacts from a variety of perspectives.



Kemp's ridley turtles nest just outside a hatchery in Rancho Nuevo, Mexico. Rising beach temperatures are affecting sea turtle eggs, embryos, and hatchlings in many ways. © Tui de Roy/Princeton University Press

Although egg health is challenging to measure, understanding hatchling health is more straightforward. Research on Florida's beaches shows that leatherback, loggerhead, and green turtle hatchlings that come from warmer nests show signs of dehydration and inflammation, and alterations in other blood analytes suggest additional physiological stress. Increased incubation temperatures also appear to have long-term effects on hatchlings, causing physiological stress well into the first month of life and possibly beyond.

Aside from the eggs, respiratory gases, and moisture in a turtle nest, an array of microbes also thrive in turtle nests and on hatchling skin under different thermal and hydric ranges. The nest environment is home to diverse communities of bacteria, fungi, and archaea that can also be found on and within healthy animals and likely play important roles in development, disease resistance, and response to outside stressors. When maintained in a healthy balance, these microbes are benign or even beneficial, but overgrowth of opportunistic pathogens can lead to skin infections, yolk sac infections, or systemic disease. Initial data suggest there are changes to the microbial communities present on the skin of hatchlings that emerge from hotter nests. Moreover, hatchlings from nests that have been overwashed show significantly higher white blood cell counts than those that are not overwashed, indicating that excess moisture alters the nest microbial community and hatchling physiological responses. It also appears that increasing nest temperatures cause a decrease in the microbial diversity on the skin of leatherback hatchlings, which is generally thought to have a negative impact on hatchling health.

Our data, and those from other populations and locations, suggest that higher beach temperatures may indeed drive decreased hatching, emergence, and survival rates in sea turtles.

Sounding the Alarm

The impact of climate change on sea turtles is a complex interaction of environmental events that together affect a wide range of species and life stages, and the examples given here could be just the tip of a much larger iceberg. From the moment sea turtle eggs are laid on the beach until the offspring return as sexually mature females or breeding males, turtles are physiologically combating the negative effects of climate change, and all species of sea turtles are now struggling to adapt at pace with these changes to their ocean and terrestrial habitats. Though we currently have some baseline knowledge, a more comprehensive understanding of the impacts of climate change on sea turtles is essential to our efforts to assure their survival. •

Be Careful with Your Predictions about Sea Turtle Sex Ratios

By Marc Girondot

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Ever since the discovery of temperature-sensitive sex determination (TSD), research has been hindered by scientists' inability to estimate hatchling sex ratios using nonlethal methods, because the sacrifice of embryos is inconceivable in species that we wish to protect. But numerous methods have been attempted. Typically, average incubation temperature is measured in nests, then compared to a profile obtained from a nest at constant temperature; sometimes that comparison is conducted over just one-third of the incubation period. Other methods use the duration of incubation as an integrating proxy. Scientists sometimes validate those methods by sacrificing a small number of embryos, but often no validation is done.

Although it is tempting to presume that average temperatures or incubation duration can be used as sex ratio proxies, it has been shown clearly that this is not the case; average nest temperature is not a reliable indicator for hatchling sex ratio; neither is the incubation period. Indeed, after 50 years of work on the subject, we still do not have a simple method for estimating sex ratios from a series of nest temperatures.

The most precise method to estimate sex ratios is to (1) obtain a TSD pattern from incubation at constant temperatures, (2) model embryo growth to define the precise thermosensitive period of sex determination using embryonic stages (not incubation duration), and (3) apply the constant temperature equivalent with the TSD pattern using a weighting scheme to correct for the fact that some temperatures have a greater capacity than others to sexualize the gonad. Such a model is difficult to apply; moreover, it should be calibrated for each specific nesting site to ensure accuracy. This approach is not simple field-based science by any means.

Recent promising results could do much to advance TSD research. It is possible using a blood test called ELISA (enzyme-linked immunosorbent assay)—or DNA methylation—to nonlethally determine the sex of hatchling turtles. The practicality of such techniques, however, remains to be determined. Meanwhile, it is important to continue to gather accurate data about nest temperatures globally only when those data will contribute to research goals that adhere to the strictest standards of analysis—as well as to monitor hatchling sex ratios whenever possible while minimizing the loss of animals. It is good to remember that marine turtles have numerous ways to control their own nest temperature by shifting phenology. Management is not always the best solution, and shading in hatcheries or cooling nests by watering will never be a practical solution to manage the tens of millions of nests laid annually. Sea turtles have survived global temperature peaks and valleys for millennia, and it is likely they will continue to do so.