

THE EFFECTS OF OCEAN ACIDIFICATION ON HAWKSBILL SEA TURTLES (*ERETMOCHELYS IMBRICATA*): AN ECOSYSTEM APPROACH

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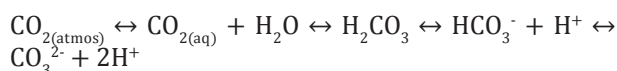
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Hawksbill sea turtles (*Eretmochelys imbricata*) are listed as critically endangered by the International Union for Conservation of Nature (IUCN), with global populations demonstrating a decline of more than 80% over the past century (Troëng *et al.*, 2005; Boden, 2008). Hawksbill sea turtles are one of the only vertebrate species that feed exclusively on sponges, relying on tropical coral reefs and their associated biodiversity for foraging grounds and shelter (Meylan, 1988; Eckert & Grobois, 2001). Coral reef ecosystems are directly threatened by ocean acidification, and may reach a point in the near future beyond which corals will no longer be the dominant benthic organisms (Hoegh-Guldberg *et al.*, 2007; Veron, 2008). Species which supplement the hawksbill sea turtle's diet may also be adversely affected due to their reliance on a high saturation state of aragonite and a stable pH, both of which will decline as emissions continue to rise (Kurihara, 2008). More research is needed on ecological and biological impacts of ocean acidification in order to understand how hawksbill sea turtles will respond or adapt to their changing environment.

Since the beginning of the Industrial Revolution, atmospheric carbon dioxide (CO₂) concentrations have risen by approximately 100ppm to around 395ppm, levels higher than those observed for the past 800,000 years (Feely *et al.*, 2008; Doney *et al.*, 2009; Tans & Keeling, 2013). This increase has led to the reduction of the average surface water pH from 8.21 (preindustrial) to the current 8.10 (Doney *et al.*, 2009). As CO₂ emissions continue, projections by the Intergovernmental Panel on Climate Change (business-as-usual emission scenario) show that atmospheric concentrations could exceed 800ppm near the end of the century, further decreasing the pH of surface water by approximately 0.3-0.4 units (Doney *et al.*, 2009; Feely *et al.*, 2008). Produced primarily by processes such as fossil fuel combustion, deforestation, agriculture, and cement production, these emissions are causing the ocean to become more acidic, leading to a fundamental alteration of marine ecosystems through a series of chemical

reactions (Doney *et al.*, 2009; Olivier *et al.*, 2012).



As the ocean absorbs CO₂, the molecules react with seawater to form carbonic acid (H₂CO₃), which then dissociates into bicarbonate (HCO₃⁻) and hydrogen ions (H⁺). This dissociation causes a reduction in pH. Acidification is buffered through the bonding of carbonate and hydrogen ions, lowering the calcium carbonate (CaCO₃) saturation state (Hoegh-Guldberg *et al.*, 2007; Doney *et al.*, 2009). The saturation state is calculated by the following formula, and represents the thermodynamic potential of dissolution or formation of calcium carbonate.

$$\Omega = [\text{Ca}^{2+}][\text{CO}_3^{2-}] / (K_{\text{sp}}')$$

The apparent stoichiometric solubility product for mineral phases of calcium carbonate is represented by K_{sp}'. Aragonite (Ω_{arg}) and calcite (Ω_{cal}) are the two phases, with aragonite being the most common in modern times (Kleypas *et al.*, 1999). Currently, the saturation state is determined by carbonate, as calcium ions are abundant. If the saturation state is less than one, it is considered undersaturated and results in the dissolution of calcium carbonate. If greater than one, the water is saturated, and mineral formation can take place (Kleypas *et al.*, 1999).

In waters with high saturation states, corals form their calcium carbonate skeletons through a process within the cell layers. The coral polyp precipitates calcium carbonate from solution, creating crystals within membrane-bound vesicles. The crystals act as nuclei for crystal growth and are extruded through the epidermis as the polyp lifts itself from the basal plate, creating a space in which a new plate is formed, allowing the polyp to grow upward (Goreau *et al.*, 1979).

According to Kleypas *et al.* (1999), estimates based on the last 8,000 to 10,000 years have shown that hermatypic,

or stony corals, have developed in conditions with a Ω_{arg} value of at least 4.0. Currently, the average saturation state in the tropics is 4.0 ± 0.2 (1 SD), but will decrease to 2.8 ± 0.2 by the end of the century. Coral calcification rates in some species stop, or become negative, at $\Omega_{\text{arg}} > 3.3$, which may occur if atmospheric CO_2 concentrations equal or exceed 480ppm (Kleypas *et al.*, 1999; Hoegh-Guldberg *et al.*, 2007). During periods of high acidification, some species of coral may survive as soft-bodied polyps, reforming their skeletons when CO_2 levels drop and ocean conditions return to levels more conducive to accretion (Hoegh-Guldberg *et al.*, 2007; Stanley, 2007). Though this is a beneficial adaptation for corals, many marine animals, such as the hawksbill sea turtle, are vulnerable to the loss of habitat and biodiversity that would result from the dissolution of coral reefs (Hofmann *et al.*, 2012).

If atmospheric CO_2 concentrations continue to rise, a tipping point may be reached beyond which tropical coral reefs may be dominated by other species, such as algae, grasses, or sedentary filter feeders such as sponges and gorgonians, resulting in a new equilibrium. A deviation of more than 2°C , combined with an atmospheric CO_2 content higher than 480ppm, and corresponding carbonate ion concentration of greater than $100\mu\text{mol kg}^{-1}$ may result in reefs that are no longer dominated by corals (Hoegh-Guldberg *et al.*, 2007). If this were to occur, reefs could take thousands to millions or years to reform into a system similar to those seen today, due to the slow process of evolution and neutralization process required to buffer ocean acidity (Veron, 2008). With increased pressures, including bleaching, human disruption, and disease, coral communities are declining worldwide, especially in the Caribbean where a decline of 80% has occurred since the mid-1970's (Hoegh-Guldberg *et al.*, 2007; Perry *et al.*, 2013). If declines continue, they may result in a drastic loss of biodiversity, which are considered necessary for reef systems and healthy hawksbill sea turtle populations (Meylan, 1988; Fabricius *et al.*, 2011). Hawksbill sea turtles will be directly affected by ocean acidification in a variety of ways. Though they migrate and use a variety of habitats throughout their lives, tropical coral reefs provide caves and ledges for rest and refuge, protection for nesting beaches, as well as the primary feeding grounds for adults and older juveniles (Eckert & Grobois, 2001). According to Meylan (1988), sponges contributed up to 95.3% of the dry mass of all food items recovered from the stomach contents of 61 hawksbills in the Caribbean. From the sponges identified, *Chondrilla nucula* was the most common, with *Ancorina sp.* being second. In a similar study by León & Bjorndal (2002), ingested prey species of hawksbill sea turtles in the SW Dominican Republic were compared with

their local availability in order to evaluate the effects of hawksbill foraging on reef ecosystems, as well as to identify prey species. The study found that hawksbills fed on six demosponges (*Chondrilla nucula*, *Geodia neptuni*, *Myriastra kalitetilla*, *Spirastrella coccinea*, and *Tethya crypta*). When compared to availability, results indicated that both *Spirastrella coccinea* and *Myriastra kalitetilla* were rare, yet highly sought by hawksbills, indicating that these sea turtles were beneficial to maintaining a balance between corals and the more competitive sponges (León & Bjorndal, 2002). Spongivory, particularly of the aggressive *Chondrilla nucula*, helps to maintain diversity within the reef, though currently to a lesser extent due to the low hawksbill population levels (Hill, 1998; León & Bjorndal, 2002). Thus, the declining number of hawksbill turtles has increased the stress on tropical coral reefs, exacerbating the effects of ocean acidification, and in turn resulting in the degradation of critical habitat (Hill, 1998).

In a study by Goodwin *et al.* (2013), sponge species and cover along pH gradients at CO_2 vents off Ischia in the Tyrrhenian Sea were recorded and analyzed in accordance to pH ranges (8.1-8.2 (normal), mean 7.8 (lowered pH), 6.6 (extremely low)). *Chondrilla nucula* was found to be restricted to sites with normal pH, along with *Phorbas tenacior*, *Petrosia ficiformis*, and *Hemimycale columella*. The limited range of *Chondrilla nucula* is significant due to the diet specialization of this species by hawksbills. Seven species were recorded in the areas with lower pH, while only one species (*Crambe crambe*) was found at the lowest average gradient in significant numbers. Sponges of the class Demospongia will be affected by increasing CO_2 emissions, altering sponge community structure, thus affecting hawksbill sea turtles (Goodwin *et al.*, 2013).

The majority of sponges included within the studies by Meylan (1988) and Goodwin *et al.* (2013) belong to the class Demospongia, and use spicules made of silica for support and defense (Meylan, 1988). Spicules form the sponge skeleton, and are either calcareous or siliceous. Siliceous spicules are amorphous hydrated silica, making up much of the class Demospongia, while calcareous spicules are comprised of either crystalline calcite or aragonite (Simpson, 1984). Future research must be conducted on the effects of ocean acidification on sponges (and their differing spicules) to understand the potential impacts on hawksbill sea turtles and tropical reef ecosystems, as little information is currently available on the subject.

While many studies have found that hawksbill sea turtles are mainly spongivores, Bell *et al.* (2013) surveyed the ingested prey species to determine feeding strategies in

regards to climate change. Gastric lavage (467 samples) and buccal cavity ingesta (71 samples) items were obtained from 120 hawksbills in the reefs in the Far North Section of the Great Barrier Reef (GBR) Marine Park. Of the total samples examined ($n = 538$), 72.7% came from three algal taxonomic divisions. Only 10.4% of the samples were sponge material, while 12.6% were invertebrates, and 5.4% were inorganic material. Citing that hawksbills are spongivores in most reef locations, this varied diet may benefit GBR hawksbills through increased algal growth if corals decline as predicted due to ocean acidification and climate change (Bell *et al.*, 2013).

The invertebrates that hawksbill sea turtles consume to supplement their diet will also be directly affected by ocean acidification (Bodin, 2008; Byrne, 2011). As atmospheric CO_2 increases, increased acidification and temperature will negatively impact various life stages of these marine invertebrates. It is expected that metabolism, skeletogenesis, molting, reproduction, larval development dispersal and settlement of invertebrates will be negatively impacted, while some will be further affected due to their limited abilities to compensate for acid-base disturbances (Kurihara, 2008; Byrne, 2011; Whiteley, 2011; Hofmann *et al.*, 2012). Acidification is especially detrimental to organisms which begin calcification in their larval and/or juvenile stages (Ross *et al.*, 2011). These impacts may lead to species extinctions as effects accumulate and acidification increases. Because tolerance differs between life stages, some organisms may survive to a particular stage, only to succumb to acidification at a later phase. Many invertebrate species are not important only to hawksbill sea turtles; they are also keystone species and will thus cause further changes in tropical reef ecosystems as they are affected by acidification (Bodin, 2008; Kurihara, 2008).

The effects of ocean acidification on marine ecosystems are varied and require additional studies. Though there is no indication yet of the direct physiological effects of acidification on hawksbill sea turtles, it is clear that these turtles will be greatly affected through drastic changes in their environment and prey species. The current rate of change is occurring at a rapid pace, with projected atmospheric CO_2 levels and temperature much higher than those of the past 42,000 years, during which most extant marine organisms evolved (Hoegh-Guldberg *et al.*, 2007). There is a critical need for information on the ability of corals and other marine invertebrates to adapt and evolve. Long-term studies will help to forecast how hawksbill sea turtles, and the tropical reef ecosystems and organisms they rely on, will be affected as the world's oceans warm and become increasingly acidic.

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BIOLOGY AND STATUS OF SEAGRASSES IN GULF OF KACHCHH MARINE NATIONAL PARK AND SANCTUARY, INDIA

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The lesser known but vibrant coastal ecosystem of seagrass meadows are very important for coastal communities as they are a critical component of the interdependent and interconnected series of coastal ecosystems; coastal mangroves, coral reefs, seagrasses and sand dunes that are often in close proximity and form a mosaic of micro-organism, algal, fungal,

floral and faunal communities (Kallesoe *et al.*, 2008).

Seagrass components and habitat

Seagrasses are seed-bearing, flowering, rooted plants, which grow submerged, exclusively in marine coastal waters and coastal wetlands. Like grasses in terrestrial