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# Sea Turtle Response to Climate Change: Analyzing Current and Predicting Future Impacts on Populations, Habitat, and Prey Populations

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University of New Hampshire

**Honors Thesis**

Sea Turtle Response to Climate Change:

Analyzing Current and Predicting Future Impacts on Populations, Habitat, and Prey Populations

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Marine Estuarine Freshwater Biology

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Fall 2015 – Spring 2016

**Abstract**

With the prediction of devastating global climate change effects for the near future, scientists are expanding their research and understanding of some of the most severely affected organisms. Because sea turtles rely on both marine and terrestrial habitats for survival, and because coastal areas are already experiencing great losses due to sea level rising, human development, and pollution, all seven species are already listed as threatened under the Endangered Species Act. In this literature analysis, I examined the many factors that contribute to a sampling of the current sea turtle population status as well as scrutinized turtle adaptability to the changing environment. After developing a broad global view of the effects of climate change and human practices on worldwide sea turtle populations, I focused my study on the populations found in the waters of America as a continent, which included case studies of Costa Rica and Cape Cod Bay. In these two unique regions, various species experience diverse threats, including cold stunning, problems feeding, and nesting pressures. From this literature review in combination with my own independent research projects, I examined how some turtle populations would be affected by changing environmental and anthropological factors, and congruently formed my own conclusions and predictions about current population statuses and potential future implications. Though global climate change is causing sea level rise, and sand and air temperature increases, humans greatly impact both the vital marine and terrestrial environments of foraging and nesting sea turtles through ocean acidification, development, and over exploitation. The future of sea turtle population conservation and management relies on research and understanding of anthropogenic and climate change effects on marine and coastal habitats.

## Introduction

It is relevant to look into past evolutionary processes in order to predict possible future population statuses. Exploring and understanding how current environmental factors, as well as predicted climactic changes, are influencing and shaping populations of organisms is vital in speculating the future of these populations. By constructing an overview of present species' endangerment statuses, one may predict, based on hypothesis and speculation, the future of the species and possible evolutionary responses to current strains.

Before delving into the stressors on sea turtle populations, it is important to understand some basic information about the seven unique species of sea turtles in the order Testudines. As reptiles, sea turtles are cold-blooded, air-breathing, oviparous organisms that spend most of their lives at sea in the pelagic zone. Females will nest in costal tropical and sub-tropical regions once sexually mature at around 10 to 30 years. The eggs must be laid along the shoreline in dry, protected sand; any water that contacts the eggs may result in drowning. Average clutch sizes are about 80 to 130 eggs depending on the species and age of the female, and number of previous breeding events. Almost all seven species have a hard carapace and plastron, excluding the leatherback, and sizes vary from less than 100 to 1300 pounds across species (Sea Turtle Conservancy, 2015). Some basic information is listed in the following table (Table 1).

Table 1. Basic sea turtle information by species. All information from: <http://www.conserveturtles.org>

Species Common Name	Scientific Name	Current Estimated # Nesting Females	Breeding Location	Common Food/Prey	Major Threats
<b>Hawksbill</b>	<i>Eretmochelys imbricata</i>	20,000 - 23,000	Tropical Atlantic and Pacific beaches	Sponges	Hunted for shell, bycatch
<b>Loggerhead</b>	<i>Caretta caretta</i>	40,000 -50,000	Temperate, subtropical, tropical regions of Atlantic, Pacific, Indian Ocean beaches	Benthic invertebrates	Loss of nesting beaches
<b>Green</b>	<i>Chelonia mydas</i>	85,000 -90,000	Global warm subtropical and tropical beaches	Sea grass	Fibropapilloma tumors
<b>Kemp's ridley</b>	<i>Lepidochelys kempii</i>	7,000 - 9,000	Gulf of Mexico, southern Atlantic Unites States, Caribbean, Central American beaches	Crabs, fish, squid, jellyfish, and mollusks	Most-endangered, cold-stunning
<b>Olive ridley</b>	<i>Lepidochelys olivacea</i>	800,000	Mexico, Nicaragua, Costa Rica, Panama, India	Algae, lobster, crabs, tunicates, mollusks, shrimp, and fish	Human egg consumption
<b>Flatback</b>	<i>Natator depressa</i>	20,000 - 21,000	Australia and Papua New Guinea	Sea cucumbers, jellyfish, mollusks, bryozoans, algae	Capture, harvesting eggs, pollution
<b>Leatherback</b>	<i>Dermochelys coriacea</i>	34,000 - 36,000	Global tropical beaches	Jellyfish	Overharvesting and illegal trade

This past summer of 2015, through the University of New Hampshire's Summer Undergraduate Research Fellowship program, I spent 9 weeks abroad studying olive ridley, *Lepidochelys olivacea*, and hawksbill, *Eretmochelys imbricata*, sea turtles, examining environmental stressors as well as anthropological factors that affect nesting. This experience inspired the focus of this project; I wanted to examine how various species of sea turtle populations are reacting to a more widespread array of current climatic and environmental changes. Since my project in Costa Rica highlighted two major areas of impact - coastal foraging zones and beach nesting sites - I wanted to expand my understanding of various anthropogenic and climactic effects on different populations on a global scale,

So why do we care if sea turtles become extinct in the face of environmental and anthropogenic pressures? All seven species of sea turtles provide their respective habitats with individualized ecosystem services – defined as the goods and services, ranging from medicines and materials to soils and clean waters provided by natural ecosystems (Kareiva and Marvier 2015) – that are vital in maintaining the health of their systems. Some major services that sea turtles provide include nutrient recycling, benthic aeration, habitat for epibionts and roosting surfaces for sea birds. In coastal systems, reef and eelgrass foraging prevents overgrowth of grasses, sponges, and other prey organisms. Juvenile sea turtles also provide easily captured nutrients to predators as they have little defense against predation by larger organisms. Removing sea turtles from these systems would drastically alter reef composition, sea grass beds, and terrestrial and marine predator-prey relationships.

It is vital for conservationists to understand current states of populations and their respective habitats and systems to act quickly in order to preserve marine ecosystems. A quick response may potentially save species from endangerment or extinction if the species cannot respond rapidly enough to the changing environmental conditions. I wanted to dive into past research, synthesize and organize data from various peer-reviewed articles, and create a collage mapping the potential future of sea turtle evolution and population characteristics. I supplemented my research with a background of past, current, and future studies of conservation efforts to interpret an evolution of human involvement. I focused on two major categories: environmental consequences of global climate change, and anthropogenic impacts. Among environmental impacts, I focused on sea level rise, sex determination, and prey availability; I looked at human practices such as development and overexploitation, and included speculation on sea turtle evolutionary response to these pressures. I wanted to cite current conservation

research to clearly illustrate the present and future predicament that all seven sea turtle species face, with a greater emphasis on Costa Rican hawksbill, *Eretmochelys imbricata*, and olive ridley, *Lepidochelys olivacea*, foraging and reproducing populations, and the Gulf of Maine's Kemp's ridley, *Lepidochelys kempii*, juvenile populations.

## **Hypothesis**

I predict that food availability, climate change, ocean acidification, and human encroachment on nesting beaches will greatly affect sea turtle population behavior and characteristics; however, I cannot be certain exactly how the various populations and differing species will respond in the future. Regarding environmental impacts, I predict that populations will be migrating north toward areas that have not been greatly affected by ocean acidification or coral bleaching and some populations will expand the range of their northern migration with the warming ocean waters. When examining the impacts of sex determination, I predict that higher temperatures will produce a more female-dominated population in the coming years. Finally, regarding the effects of human interference on sea turtle populations, I predict that human encroachment on nesting beaches and the poaching of nests will ultimately narrow the sea turtle gene pool and may possibly select for traits that may favor more secluded nesting behavior.

## **Methods**

I carried out a literature review of various previously published articles on climate change, sea turtle evolution, sea turtle population characteristics, diet, prey population characteristics, sex determination, and human encroachment in order to compose a universal story about the potential future of sea turtle evolution and adaptation. I examined these articles,

synthesized information, and analyzed their implications. Though I focused on peer-reviewed journal articles, I supplemented this work with various sources: a personal, unpublished project about conservation and monitoring on the Pacific coast of Costa Rica, as well as information from a conference on sea turtle conservation in which two experts spoke about the current statuses of leatherback turtles and Kemp's ridley, interviews with local Cape Cod, Massachusetts sea turtle conservationists, and personal accounts of sea turtle necropsies. This project emphasizes speculation and includes elements of opinion as I formulated my interpretation of the environmental implications, but I worked hard to keep objectivity important and evident.

### **Environmental Impacts Overview**

Due to the pressing issue of climate change and its global environmental impacts on marine and terrestrial life, scientists have been concentrating on climate-change focused research for the past ten years and have made some important predictions. Climate change has various connotations, especially when examining marine organisms that visit the land during breeding events. Because marine turtles occupy terrestrial and marine habitats, many stages of the seven species' life history are closely tied to climatic variables. Their relation to marine and terrestrial habitats suggests that turtles can act as indicator species for environmental problems both at sea and along the coast.

Global climate change is greatly affecting global biodiversity, species' ranges, predator-prey relationships, and habitat quality and availability. When global temperatures rise, populations tend to migrate pole-ward, a spatial response, as well as change annual cycles, as part of temporal responses. Climate change issues are especially important to ectothermic organisms, like marine turtles, as they are much more sensitive to smaller changes in



temperature. Increasing global temperatures are predicted to greatly alter the sex ratios of marine turtle hatchlings, as gender is determined during the in-sand incubation process. Examining species' resilience, or the extent to which it can withstand perturbation on a physiological, genomic, or evolutionary scale can become a vital means of single species management and protection (Abella *et al.*, 2016).

### **Sea Level Rise**

Examining the effects of rising sea levels as a result of climate change on sea turtle behavior is key in modeling future nesting distribution. By some predictions, up to 32% of total beach area available could be lost with a 0.5-m rise in sea level. This dramatic increase, due to thermal expansion of water and glacial melt, may force nesting sea turtles to seek other beaches that are not as vulnerable, forcing populations to migrate (Fish *et al.*, 2005). Due to human development, which tends to encroach coastal regions and beaches, many areas may not allow for an inland migration of sea turtles. Hard surfaces and man-made obstructions like roads, bridges, sidewalks, walls, buildings, etc., directly prevent any potential inland migration; this is especially detrimental in tropical regions, where sea turtles nest, due to increased tourism and the need to expand housing (Abella *et al.*, 2016). If the females cannot move inland in these tropical nesting regions, they may be forced to expand their nesting range pole-ward.

It is important to note that waterlogging of nests results in 100% mortality rate of incubating embryos (Kraemer and Bell, 1980). This has strong implications for nest location; if a female lays eggs within the intertidal zone, and a high tide or a spring tide covers the nest, the eggs will drown and the nest will be rendered unviable. Similarly, flooding, as a result of higher wave run-up during storms, increased storm intensity, and mean sea level rise, will increase egg

mortality at most rookeries; this will greatly affect the overall recruitment of sea turtle populations. It has also been predicted that sea-level rise will cause increased erosion along the shoreline and saline intrusion into the water table in small tropical islands that have low elevation (Fuentes *et al.*, 2010). Consequently, these island habitats are often home to endemic species and vulnerable populations, which could include sea turtle prey as well as sea turtle populations themselves. Small island populations are at much higher risk of species extinction in the face of stochastic events – due to smaller size, smaller gene pool, and limited temporal and spatial refugia – which could be induced by sea level rise (Kareiva and Marvier 2015). With increasing high tides, and an average projected sea level rise that may result in the loss of vital nesting beaches in the tropics, conservation biologists may have to invest in transporting nests to dry, artificial clutch sites.

### **Sex Determination**

Sea turtles are reptiles that have incubation temperature-based sex determination. Though the key sex determining temperatures vary among species, increased global sand and air temperatures will affect all seven species. Through experimentation and observation, 29 °C has been recorded as a common pivotal temperature (Hays *et al.*, 2003). In *L. olivacea*, the MPT, or male-promoting temperatures, are between 26 and 27 °C and the female-promoting FPT are higher at 32–33 °C. This being said, nests that experience an average temperature between the MPT and FPT limits produce a ratio of about 1:1 male to female (Torres Maldonado *et al.*, 2002). Nests that experience higher temperatures tend toward a female-dominated clutch, and the opposite is true for male-dominated clutches. From my interpretation, as the success and

survival rate is so low for sea turtle hatchlings – only about 1 in 1000 hatchlings survives to reproductive age – this ratio is vital in predicting the surviving population.

For the St. Eustatius populations of *C. mydas*, *E. imbricata*, and *D. coriacea*, researchers have created an overview of current and future hatchling ratios by combining sand temperature measurements with historical and current environmental data and climate projections; they included rainfall and spring tides as important cooling events factored into their modeling. Their research suggested that all three species have experienced female-biased ratios for the past several decades, with percentages of males produced ranging from 15.5% to 36.0%. Their model showed that global warming would only exacerbate this female-skewed ratio and produce nests with 0.4% male production rates by 2090 for the most affected *C. mydas* populations (Laloë *et al.*, 2016). To combat localized extinction due to extremely female-biased populations, management strategies that cool nest temperatures – relocation or shading of nests – must be created and implemented in affected rookeries.

Higher climactic temperatures indicate a female-dominated population. Many experts are focusing on sex determination research as population sex ratio can and is being greatly influenced by global climate change. Through monitoring current and modeling predicted temperature, future sex ratios can be projected and analyzed in conservation strategies (Laloë *et al.*, 2016). Researchers are already monitoring sand and air temperatures of key rookeries. Populations that nest on southern United States beaches are highly female biased, and are projected to become ultra-biased with 1°C of warming; these same populations are predicted to experience dangerous levels of mortality if warming exceeds 3°C (Hawkes *et al.*, 2007). Currently, many models are projecting hatchling mortality; however, some species may exhibit degrees of resilience, which may maintain a more balanced hatchling sex ratio, due to spatial and

temporal refugia. Because these populations exhibit the ability to migrate nesting sites, they may have enough resilience to accommodate the increasing temperature rise and seek cooler beaches toward the poles or with lighter sands. Routinely monitoring the temperature of these light-sand beaches, which maintain cooler subsurface temperatures, may become increasingly important in predicting nesting migration over the next century (Hays *et al.*, 2003).

### **Prey Availability**

When examining the consequences of current and future climate change, it is important to look at effects on food sources and prey populations as well as those on the predator organism. I believe it is vital to examine any research that has been conducted regarding irregularities in prey populations in the past as well as note any current research. Each sea turtle species has a unique diet and life history, so researching current prey availability is case-specific. Over this past summer, I was able to conduct my own project examining the sponge populations along the Pacific coast of Costa Rica. I observed major bleaching events, which could have been caused by various factors including temperature increase due to El Niño, increased sedimentation from the Río Térraba, or ocean acidification. As my study in Costa Rica suggests, I believe it is important to monitor current local prey populations for each of the seven sea turtle species in their respective foraging zones, as climate change, overfishing, and acidification affect each habitat differently.

Currently, many populations are experiencing localized declines in foraging zone size, health, and prey community composition. Around 29% of sea grass beds have disappeared in the last 130 years, and rates have accelerated since 1990 (Waycott *et al.*, 2009). These beds are the main food source of *C. mydas*, and losses in food source could lead to dramatic decreases in

population for this species. Other species are affected by food availability fluctuation: though dense jellyfish aggregations are common, recently-reported severe blooms are increasing in frequency (Richardson *et al.*, 2009). Though these blooms could be a result of over-fishing and eutrophication, climate change is also a likely culprit. Only one marine turtle species, the leatherback sea turtle or *D. coriacea*, solely feeds on jellyfish, so these spikes in prey population will not provide increased nutrients for all sea turtles. In contrast, increases in jellyfish species populations often indicate a severe decrease in other pelagic species, which could only buttress the negative effects of climate change.

An increasingly important player in prey availability is ocean acidification. Due to atmospheric carbon dioxide concentrations exceeding 500 parts per million by 2100, corals are projected to become increasingly rare on reef systems as ocean pH increases, inhibiting calcium carbonate production (Hoegh-Guldberg *et al.*, 2007). Reef-building corals, which are vital to coral systems, will experience reduced calcification, decreased linear extension, and a reduction in skeletal density. This density reduction will render coral structures vulnerable to erosion by grazing and a projected increase in storm intensity. With a reduction in the structural complexity of reefs, habitat and biological diversity will greatly decline, potentially leading to the extinction of key prey items for sea turtles (Hoegh-Guldberg *et al.*, 2007). Though some of these systems have been observed as more resilient than expected, once the system is pushed too far out of its equilibrium by a rapid rate of acidification and temperature rise, returning to coral-dominated reef systems may be impossible.

## **Anthropogenic Impacts**

Humans have a direct impact on both the terrestrial and marine habitats of sea turtles. Regardless of their importance to nesting turtle populations, humans have claimed most beaches. We have influenced their division and pristineness by building edifices and increasing human access. Installing artificial lighting and altering the beaches for recreational uses directly and negatively affect hatchling success. Few undisturbed beaches still remain along the Atlantic Coast of the United States (Antworth *et al.*, 2006). Furthermore, sea turtle eggs are considered a delicacy in many Latin American and Caribbean countries. Humans destroy nests, dig up eggs for human consumption, scare female turtles into returning to the water before they can lay eggs, and cause hatchling confusion with light pollution; all of which contribute to human impacts on population sizes.

Additionally, overfishing and pollution cause major problems in the marine world. Many sea turtles become entangled in nets and die as bycatch, others die from boat strikes in popular waterways. One study in Brazil found that in Atlantic waters of the USA, only 7–13% of the turtles that die due to interaction with fisheries wash up on the beaches. In only one year, this study found 92 stranded turtles; this large number represents only a small fraction of the total deaths caused by fisheries (Bugoni *et al.*, 2001). This interaction is the greatest anthropogenic cause of death for all life stages of sea turtles. The study also examined the effects of material pollution on the organisms, and out of the 38 specimens examined, over half of the individuals' guts, esophagi, and stomachs contained plastic (Bugoni *et al.*, 2001).

Other studies show the deleterious effects on sea turtle population size of fisheries through bycatch pressures. A study in Libya and Tunisia highlighted the importance of neritic habitats for loggerhead turtles from many of the Mediterranean rookeries. In these specific

areas, bycatch pressure is an increasing threat; anthropogenic mortalities occurred in North Cyprus, Syria and Egypt, in their near-shore marine areas where small-scale fisheries operate (Snape *et al.*, 2016). This merely touches upon the pressures of fisheries on migrating populations. Managing fisheries and protecting species in regions that span multiple countries' jurisdictions is often one of the most difficult barriers conservationists face. Creating unified and monitored policies and practices can be virtually impossible when dealing with varied governments and political views.

Not all current human impacts are negative, and a possibility for redemption still exists if conservationists act soon. A positive article, "Intensive beach management as an improved sea turtle conservation strategy in Mexico," examines the success of conservation efforts on clutch size, birth rate, and hatchery-based nesting rates in Mexico. The 9-year study highlighted the impacts of human encroachment and how unprotected beaches lead to low survival rates of hatchlings (García *et al.*, 2003). This study shows that the impacts of human encroachment, poaching, and presence are evident and can be linked directly to population loss; however, I believe that a reversal of these effects is partially attainable with subsequent conservation efforts.

### **Future State of Sea Turtles and Evolutionary Responses**

One of the ways to speculate the future of marine turtle populations is to interpret how they have responded to past stressors and to examine the species through an evolutionary lens. About 200 million years ago, the turtle lineage Testudines diverged, and since then, the climate has cooled drastically, the sea levels have dropped about 25 m and the earth has undergone several cycles of glacial eras (Hedges and Poling, 1999). During these glacial cycles, the tropics most likely served as refuge for nesting turtles (Formia *et al.*, 2006), and it is probable that

nesting females were continually displaced by climactic cooling and sea level differences (Bowen and Karl, 2007). An Australian case study on green sea turtles, *Chelonia mydas*, evidences past marine turtle adaptation to climate change, though exact details are difficult to decipher and are based on speculation (Dethmers *et al.*, 2006). Current nesting beaches were inaccessible 21,000 years ago, suggesting that two sea turtle populations must have diverged in northern and southern Australia. Those breeding in the Gulf of Carpentaria altered the timing of their breeding from austral summer to the austral winter in order to adapt to temperature changes (Dethmers *et al.*, 2006). This suggests the species' adaptive powers regarding temporal changes. Though this does not involve the target American populations, I believe that this information is important historical background that can aid in understanding the species' adaptive powers.

Presently, one the major issue facing sea turtles is temperature change because of their temperature-based sex determination of hatchlings. With warmer temperatures, female-dominated populations are appearing, and the warming events expected over the next century may result in beaches with 100% female production (Poloczanska *et al.*, 2009). Some species of identical genetics are demonstrating their capacity to alter breeding season, which suggests the ability to adapt to increasing ambient temperatures (Pike *et al.*, 2006). This adaptation, however, may not occur at rates consistent with those of predicted climate warming. Similarly, natal beach fidelity occurs at lower rates than previously thought; a study of 2891 nesting green turtles, *C. mydas*, along the Australian east coast revealed that 6% changed rookeries between nesting seasons and 1.6% within a nesting season (Dethmers *et al.*, 2006). This suggests some adaptive ability within populations, which may allow for the successful nesting of turtles that choose less-affected beaches. Regarding the increasing number of female hatchlings reared in each clutch at warmer beaches, little information exists on the ability of populations to thrive



when dominated by female turtles; however, historically, many populations have been surviving with this bias for decades (Poloczanska *et al.*, 2009).

Even if turtle populations can survive and adapt to the changing climate, their resilience may not be enough to cope with human habitat encroachment and nest degradation. Human progress and beach development decreases available nesting sites and subsequent pollution and eutrophication threatens coastal foraging zones of many species, including *E. imbricata*, or the hawksbill sea turtle (Poloczanska *et al.*, 2009). Coral reefs, hawksbill foraging zones, are experiencing dramatic bleaching events due to acidification. The world has lost 19% of its coral reefs with an additional 20% under serious threat from anthropogenic degradation (Wilkinson, 2008). Human stressors may reduce species' capacity to cope with climate change as habitats are continually compromised.

### **Current Research in Pacific Populations**

This past summer, through a an independent Summer Undergraduate Research Fellowship grant from the University of New Hampshire, I was able to research two distinct populations of nesting and foraging sea turtles on the Pacific coast of Costa Rica. My project, entitled Challenges to Foraging and Nesting Sea Turtles: Sponge Population and Erosion in Costa Rican Habitats, was advised by Andrew Ogden of the Department of Biological Sciences, University of New Hampshire, Dr. Larry Harris of the Department of Biological Sciences, University of New Hampshire, and Oscar Brenes and Adrián Bonilla Salazar of the Reserva Playa Tortuga, Costa Rica.

Over the 9-week period I was in Costa Rica, I participated in La Reserva Playa Tortuga's conservation efforts of olive ridley turtles, *L. olivacea*, in Ojochal de Osa, Costa Rica. I was also

able to conduct my own surveys of nesting beach conditions. As my own independent project, I performed an ecological survey of Uvita's Marino Ballena National Park; through a series of dive surveys, I examined benthic communities in relation to hawksbill sea turtle, *E. imbricata*, foraging. This research allowed me to examine the current effects of climate change and human encroachment on these populations *in situ* in regards to nesting location, effects of salinity and erosion, sex determination, prey community composition, ocean acidification effects, and direct anthropogenic impacts.

Playa Tortuga, the nesting beach of *L. olivacea* is closely monitored and protected by the dedicated researchers at the Playa Tortuga Reserve guided by Oscar Brenes. Brenes, the leading tropical biologist at the reserve, actively conducts research in the field to be presented at the Annual Symposium for Sea Turtle Conservation. He has researched the effects of transplanting clutches of eggs to raised platforms of sand, which results in a male-dominated hatchling group. His experiments may lead to future conservation efforts that could help cope with the projected female-dominated populations of the warming climate.

Under Brenes' guidance, I conducted two independent projects that will contribute to the reserve's knowledgebase and provide key survey data to allow for the continuation of monitoring climate change related effects on these two Costa Rican populations. It has been previously noted that the Parque Nacional Marino Ballena's coastal patch reef systems have experienced localized decline as a result of changing environmental factors: increased sedimentation, overfishing within the marine protected area, and ocean acidification (Cortés *et al.*, 2010). This has foraging implications for *E. imbricata* as they feed on sponges and tunicates that grow on coastal reef systems. Costa Rica has only three marine protected areas: Parque Nacional Marino Las Baulas, Parque Nacional Marino Ballena, and Área de Conservación Marina Isla del Coco

(Wilkinson, 2008). It is important to monitor these protected areas to establish the viability of the foraging zones and the success of the management plan on supporting local, natural biodiversity. In regards to nesting patterns, Costa Rican nesting rates have declined dramatically between 1956 and 2003 by 77.4-94.5%, *L. olivacea* could experience dramatic population declines in the near future (Troëng *et al.*, 2005).

Through my research, I wanted to understand and define these foraging and nesting zones to determine the state of these current populations and provide vital information for the continuation of their monitoring in the marine protected area and along the nesting beach. While diving, I examined six known foraging sites: Tombolo Norte (TN), Tombolo Sur (TS), Viuda (VI), Ballena (BA), Tres Hermanas (3H), and Punta Pargo (PP) (Figure 1). Over a series of six field days, a total of 36 dives, I observed the benthic communities. At each site, I laid two 10-meter long transects and observed the communities within ten 1-meter quadrats (Figure 2) and measured each observed sponge and any potential signs of foraging (Figure 3). Though we observed the most *E. imbricata* from the dive boat at the site Punta Pargo (Figure 4), Viuda had largest prey sponge population (Figure 5). Table 2 explains the abbreviations found in both Figures 5 and 6. It is important to mention that Tombolo Norte had the most observed *Rhopalaea birkelandi*, a tunicate prey item (Figure 6). Through these dive surveys, I compiled baseline data for the Reserva Playa Tortuga, who continued to conduct survey dives after my project ended. I was also able to observe firsthand the effects of ocean acidification on corals as I noted bleaching events over a period of two months. Future surveying of these sights is vital in monitoring *E. imbricata* foraging and fluctuation in prey ecology. Consequences of climate change can be observed *in situ* in Marino Ballena National Park, which could have lasting impacts on *E. imbricata* foraging ecology.

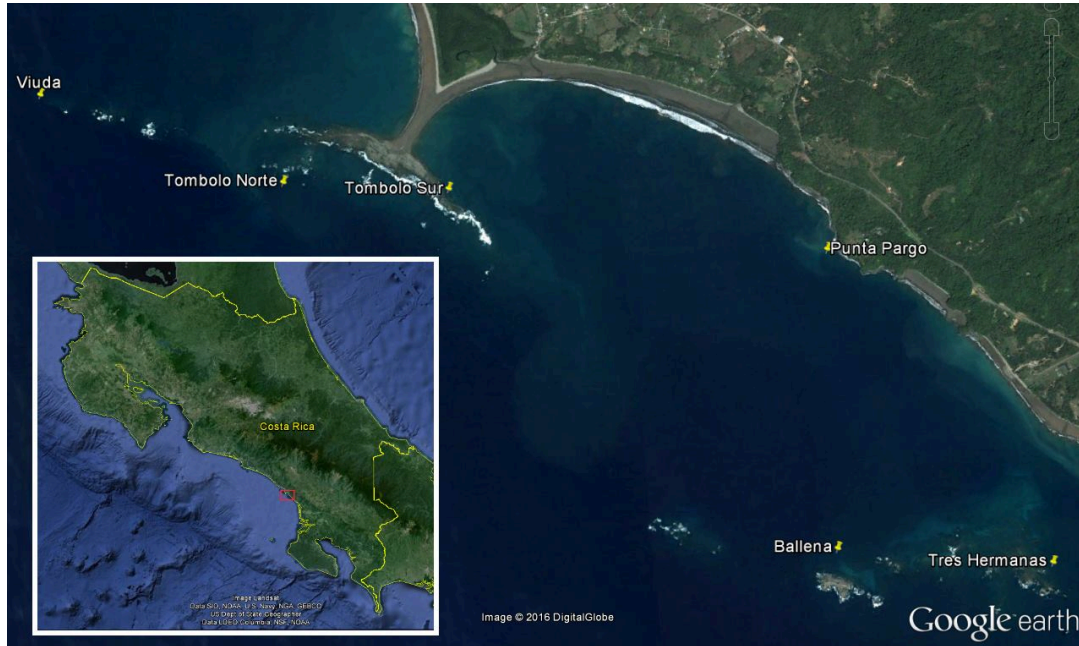


Figure 1: Marino Ballena National Park dive sites

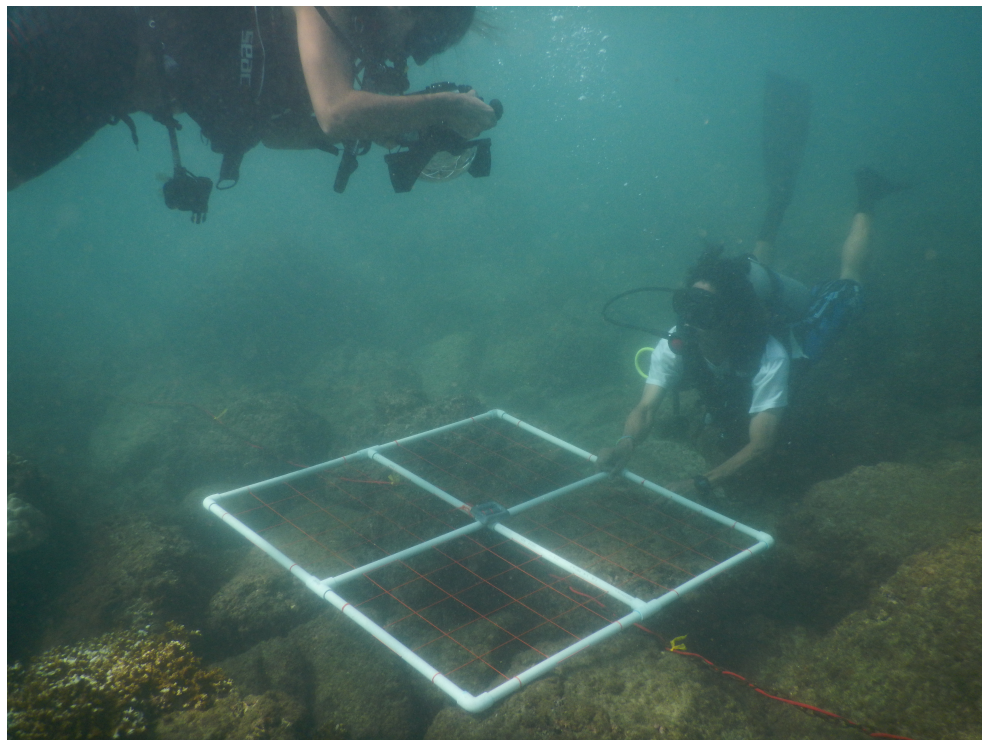


Figure 2: Dive methods



Figure 3: Measuring sponge specimens

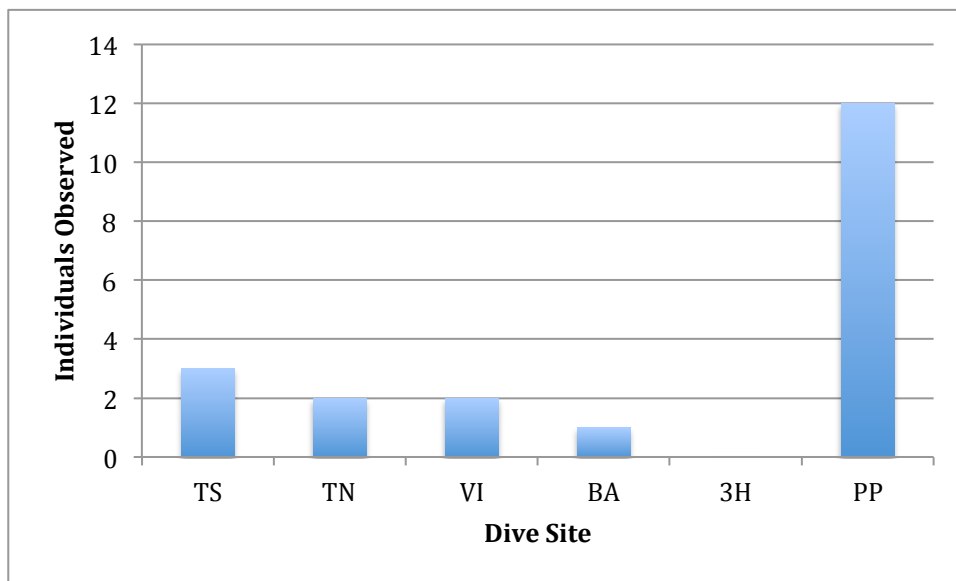


Figure 4. *E. imbricata* sightings off the dive boat during the six field visits

Table 2. Species observed and referenced

Chordata Tunicata	Abbreviation
<i>Rhopalaea birkelandi</i>	RB
Porifera	
<i>Haliclona sp</i>	Hsp
<i>Spirastrella sp</i>	Spi
<i>Mycale sp</i>	Msp
<i>Aplysina sp</i>	Apsp
<i>Axinella sp</i>	Axsp

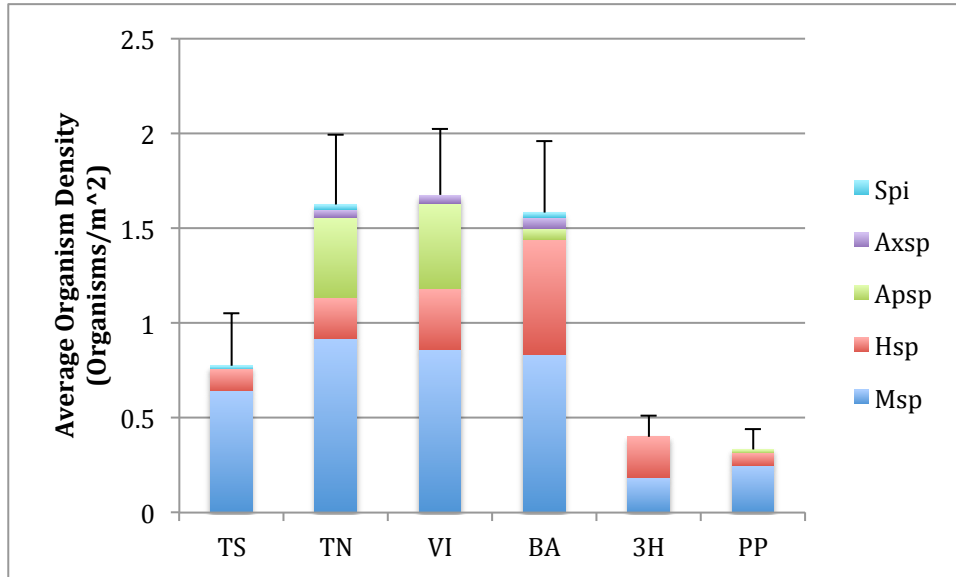


Figure 5: Average species per m<sup>2</sup> at each dive site from all six dives excluding *Rhopalaea birkelandi*

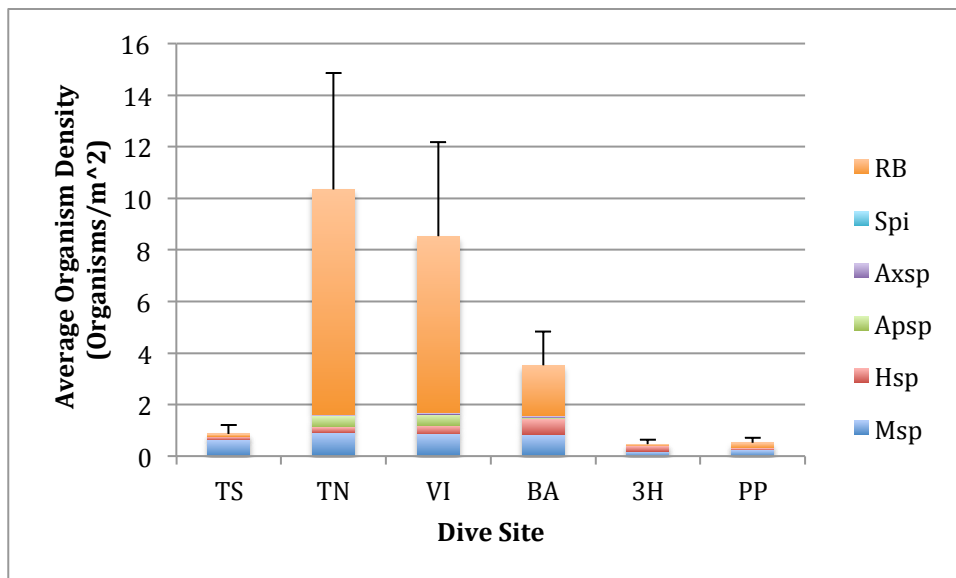


Figure 6: Average species per m<sup>2</sup> at each dive site from all six dives including *Rhopalaea birkelandi*

Between dives, I measured daily temperature and salinity changes along the 1.2 km nesting beach. Playa Tortuga is greatly affected by daily tides and the Río Térraba, so examining the effects of erosion, and daily temperature and salinity change could be vital in characterizing the nesting habitat of *L. olivacea*. As with the survey dives, continual monitoring of these areas is necessary in depicting an accurate representation of the processes taking place. Over a month period, I observed significant variability of temperature and salinity along the beach (Figure 7). I was unable to observe a sufficient number of nesting *L. olivacea* to determine a trend in nest location preference; however, Brenes plans to continue my research in the hopes of understanding if a preference exists between nest location and temperature and salinity or if any patterns can be observed.

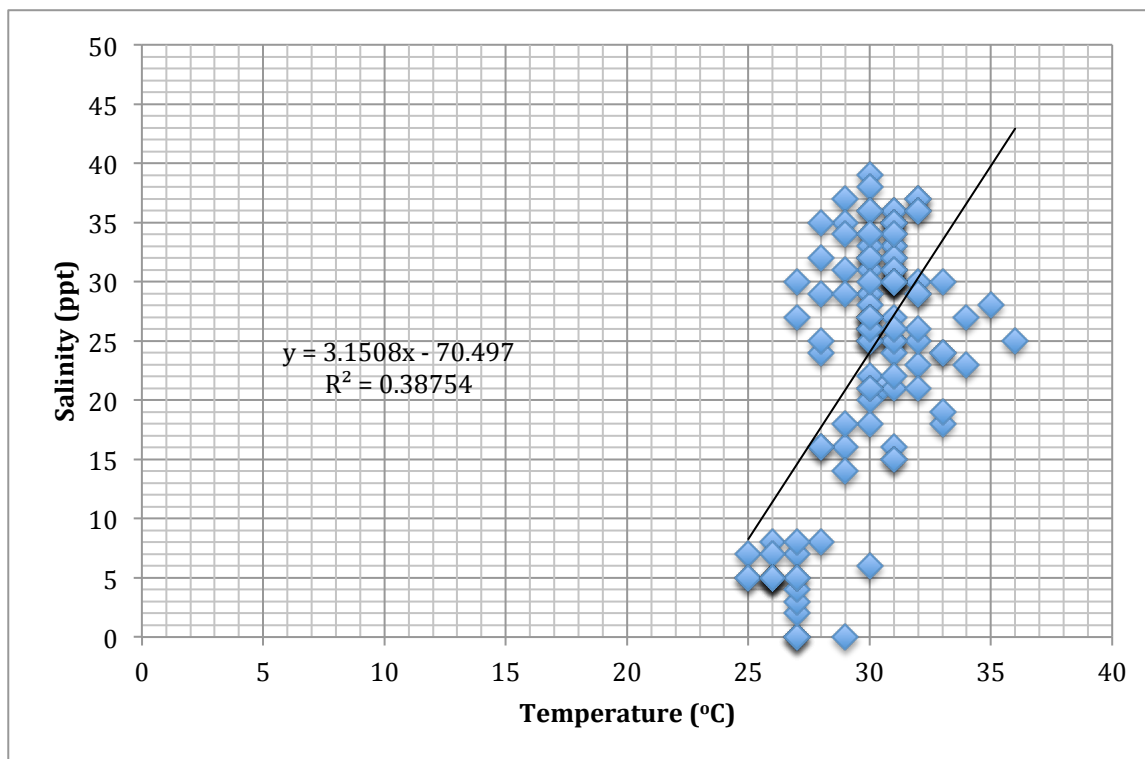


Figure 7: Plot of salinity vs. temperature from June and July 2015 along 1.2 km beach at 7 isolated locations



Along with salinity and temperature changes, I observed firsthand the effects of sea level rising as the beach eroded up to 5 meters over a two-month period. This greatly reduces the nesting space availability and forces the turtles to either nest in the intertidal zone, which leads to waterlogging, or forces them to dig at the 1m wall created by tidal erosion (Figure 9). In some areas, vegetation prevents any inland movement, which reduces the nesting area availability. Brenes is working with a team to monitor the erosion along the beach and for now, continually transplant nests to a protected rookery.



Figure 9: 1 m tall erosion slope and debris from the Río Térraba at Playa Tortuga

### **Current Research in Atlantic Populations**

Examining firsthand two distinct geographic locations, both the Atlantic and the Pacific, allowed me to gain a more global interpretation of the effects of climate change and other anthropogenic factors on disconnected sea turtle populations. I am able to compare and contrast



differing stressors, turtle responses, and human influence of the two distinct areas in order to better understand on a global scale, the current and potential future status of sea turtle populations as a whole.

Comparable to the Reserve Playa Tortuga, many non-profit organizations exist to help rehabilitate and study stranded and injured sea turtles in New England. While some of the local New England organizations focus solely on rehabilitating the animals, others have a strong focus toward conservation and research. In December, I attended a talk about Cape Cod efforts in sea turtle conservation, given by Robert Prescott of the Wellfleet Wildlife Sanctuary of the Massachusetts Audubon Society. He stated that last year, Cape Cod Bay trapped 1179 cold stunned sea turtles, including Kemp's ridley, loggerhead, and green sea turtle species. Many local organizations, including Massachusetts Audubon's Wellfleet Wildlife Sanctuary, National Marine Life Center, the Boston Aquarium, and more participated in rehabilitating the turtles with a combined 83.5% success rate. Conservation efforts and tools are evolving with our increasing technological advancements and knowledge of climate change. Adaptive responses to threatened sea turtle populations, coupled with a co-evolution of conservation efforts and public awareness of the seven endangered species of sea turtles, may potentially allow for the survival of these species in the future.

The majority of the stranded turtles were juvenile Kemp's ridley, *Lepidochelys kempii*, of "dinner plate" size. Many researchers are currently working toward understanding the cause of the strandings and are looking toward the rapid warming of the Gulf of Maine as a major cause. Kate Shaffer of the National Marine Life Center describes that although a vast majority of the rescued stunned turtles survives, some unfortunate juveniles are too weak and die of pneumonia, or succumb to fatal boat strikes or carapace damage from wave action along the rocky intertidal

zone. The Wellfleet Wildlife Sanctuary examines the carcasses of the stunned turtles that did not survive and through the necropsies, identifies cause of death and parasite abundance. They hope that through these necropsies, performed by volunteers, researchers will gain a deeper understanding of the stranding events and note any observable patterns.

Many of the reports on current and future statuses of sea turtle species seem to indicate an unpromising future; however, conservation efforts have dramatically increased over the past 30 years, and the trend continues upward (Figure 10).

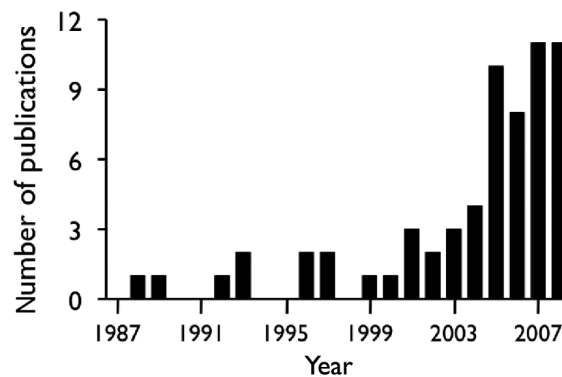


Figure 10. Increase in interest in marine turtles and climate change. Number of published studies per year (resulting from ISI Web of Science search, 28 January 2009) containing the search terms ‘marine turtles OR sea turtles’ and ‘climate change OR global warming’ in the title, abstract or entire article (Hawkes *et al.*, 2009).

This suggests that there is hope for understanding and potentially helping to solve many of the problems sea turtles are facing and will face in the future with predicted climate change.

Understanding the problems is the first step; humans should acknowledge our global impact and work toward conservation efforts to help alleviate and prevent the anthropogenic effects and global climate change consequences. Though managing migratory species is difficult as they frequently cross country borders, there is the potential to establish local management plans and marine protected areas, and to reduce anthropogenic development and deterioration of nesting beaches. The key to combatting climate change effects is adaptive management plans in which

experimental strategies are tested and subsequently altered by a team of stakeholders (De Leo and Levin 1997). Through adaptive management plans, conservationists can not only strive to solve ecosystem degradation but furthermore understand the processes involved and adapt to the ever-changing conditions.

## **Conclusions**

The current state of global sea turtle populations is threatened by climate change and human development, emissions, and exploitation. Global climate change, which is causing sea level to rise significantly and sand and air temperatures to increase drastically, is currently threatening nesting habitat availability and hatchling sex ratio balance. Humans greatly impact both the vital marine and terrestrial environments of foraging and nesting sea turtles through ocean acidification, development, and over exploitation; all seven sea turtle species are threatened and some populations fare worse than others due to a lack of temporal and spatial refugia. Conservation and management relies on present and future research and understanding of anthropogenic and climate change effects on marine and coastal habitats.

As sea turtles are reptiles, hatchling sex is determined during the incubation process in the nests within coastal sand. Clutches of about 80 to 130 eggs rely on sand temperatures of about 29°C for a relatively unbiased sex ratio. If the nests are inundated with saltwater from spring tides, the eggs will drown causing a 100% mortality rate. With global climate change projected to cause increased sand and air temperatures, sea level rise, and consequently higher variability of spring and storm tides, sea turtle recruitment will be significantly altered with a high female bias and smaller fledgling populations. Humans are exacerbating the issue by

increasing coastal development; this prevents inland migration of nesting females and limits nesting habitat to low-lying near shore sands at higher risk.

Ocean acidification, a product of human carbon dioxide emissions, is causing a dramatic reduction in coral calcification in tropical reef systems. These foraging habitats will be further compromised by seawater temperature increase, and a reduction in reef area and stability could greatly limit prey availability for many species of sea turtle. Furthermore, human fisheries pose a threat to turtle populations as large portions of adult and juvenile populations die as bycatch. Though some species have shown historic resilience to temperature and habitat change, the current and projected rates of climate change as well as the consequences of anthropogenic pressure may be too great to allow for population adaptation.

While in Costa Rica, I was able to observe the present state of *E. imbricata* and *L. olivacea* foraging and nesting along the Pacific Coast. I witnessed bleaching events, gathered information on nesting beach temperature, erosion, and salinity, and recorded sponge and tunicate prey availability as baseline information for the Reserva Playa Tortuga conservation efforts. My two areas of interest are currently and will be greatly affected by sea level rise, temperature increase, and bleaching events. It is vital in establishing conservation plans to monitor these sites and establish a record of observable data. Understanding the current status of these populations could allow conservationists to more accurately predict and help prevent future population reduction.

Other organizations, like the Massachusetts Audubon Society and the National Marine Life Center, are working hard to understand some of the problems affecting local *L. kempii* populations. Mass strandings and cold stunning events are threatening the migratory juvenile population; conservationists and researchers are working together to understand the cause –

speculated as global warming – and are helping to rehabilitate thousands of juveniles to alleviate the stress on the population. An increased awareness for these populations will hopefully encourage future conservation efforts and increase the populations' resilience to projected climate change.

Though sea turtle research has drastically increased in the last decades, all seven species are still endangered and consequently threatened by climate and anthropogenic factors. Human progress and beach development decreases available nesting sites, and the steady state of global warming poses imminent threats to population sex ratios and even hatchling survival. Furthermore, human exploitation through fisheries and illegal hunting exacerbates all climate change-related effects. To continue researching this trend, further studies must be conducted to understand the exact effects altered sex ratio will have on population composition and size. If populations exhibit resilience and adaptability in nesting site location and evolutionary response to climate change, some populations of various species may survive. If we continue the trend of high global emissions; however, the population's adaptation and resilience may not be fast or strong enough to cope with the current rates of global climate change, increased temperature, sea level rise, and human development.

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