Analysis of threats to Galápagos Marine Iguanas (*Amblyrhynchus cristatus*)

by

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Sarah Elizabeth Spangler for the degree of Bachelor of Arts in International Studies in Biology presented on June 5, 2015.

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ABSTRACT:

Galápagos marine iguana population sizes have been declining since first contact with humans. This decline has historically been attributed mainly to predation by invasive species, but additional human-caused threats exist today. My thesis conducts an analysis of the present threats to the species and determines which are the most severe. Modern threats include invasive species, the increasing presence of humans, the potential for foreign pathogens, and the effects of climate change. Specifically, the most severe threats are environmental contamination such as oil spills, oceanic changes due to climate change, and expected increases in the severity of El Niño events. Due to the difficulty of addressing climate change at the local level, conservation of this species should be focused on managing local human activity to prevent predation and chronic stress from other threats.

Bachelor of Arts in International Studies in Biology thesis of Sarah Elizabeth Spangler presented on June 5, 2015

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I understand that my thesis will become part of the collection of Oregon State University. My signature below authorizes release of my thesis to any reader upon request. I also affirm that the work represented in this thesis is my own work.

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Sarah Elizabeth Spangler, Author

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1 Background

1.1 Galápagos Marine Iguanas

The Marine Iguana (*Amblyrhynchus cristatus*) is one of the many endemic species of the Galápagos Islands, meaning that it is found nowhere else in the world. It is unique because it lives on land and forages for food in the ocean, making it the world's only sea-going lizard. There are seven subspecies in isolated populations on ten islands in the archipelago. Total population size is unknown, as surveys have never been conducted on the majority of these populations. However, populations that have been studied have seen steady population declines over the years. The Galápagos marine iguana was initially classified as "rare" from 1986 until 1996, when it was then classified as "vulnerable" by the International Union for Conservation of Nature (IUCN).

1.2 The IUCN Red List: A Means for Identifying Threats

The IUCN Red List is the predominant guiding force in establishing the degree to which a species is threatened. The categories for species at risk of extinction range from "least concern" to "extinct." The Galápagos Marine Iguana is classified as "Vulnerable" by the

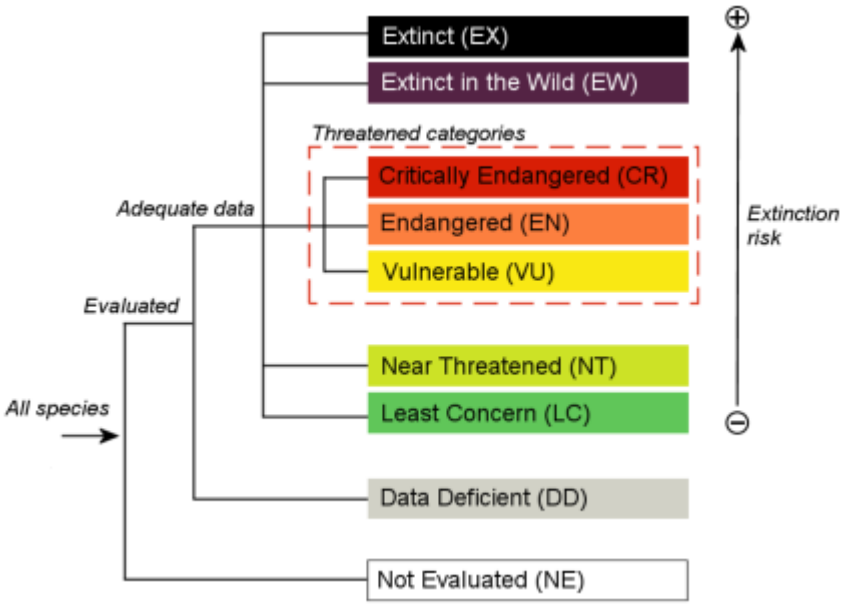

Figure 1. Levels of Classification for the IUCN Red List.

IUCN, meaning that it is “considered to be facing a high risk of extinction in the wild” (IUCN Red List Categories and Criteria Version 3.1, 2000). The classification of vulnerable is assigned based on criteria: having a small or decreasing population size, having a small or unstable geographic range, and/or having a statistical probability of extinction between 10-20% in the next 100 years (IUCN Red List Categories and Criteria Version 3.1, 2000). Marine iguanas are listed as more specifically as “Vulnerable B2ac(iv),” which means their status as vulnerable is because of their area of occupancy, which is less than 2000km^2. Marine iguanas have fragmented populations in fewer than 10 locations, and extreme fluctuation in the number of mature individuals (Nelson et al. 2004). These factors make them reproductively unstable and at a high risk of becoming endangered.

The IUCN website lists the threats to marine iguanas as: Invasive species, oil spills, climate change and severe weather (Nelson et al. 2004). While this information is useful for identifying threats, it does not tell conservationists which threats to the species are the most prominent and thus offers no way to prioritize conservative action. Further research must be conducted by scientists to determine what steps will be most effective in the protection of a species.

1.3 Exploration of Known Threats

Much has been written on the effects of the three threats listed: invasive species, oil spills and climate change. However, there are other factors that threaten the species such as increases in tourism, a growing residential population, and the potential for the introduction of foreign pathogens. The goal of this thesis is to examine the strength of

each of these threats individually, to discuss the possibility of compounding threats, and finally to identify those threats upon which to focus marine iguana conservation.

1.4 Global Concern Over Island Conservation

In recent years, global concern for the well-being of the Galápagos Islands as a whole has decreased. This is demonstrated by the decrease in deliberation over the Galápagos Islands by the World Heritage Committee since 2012, as shown in Figure 2 (UNESCO, 2014). The park was listed as a World Heritage Site in Danger in 2007 due to threats from invasive species, tourism and over-fishing. However, it was then removed from the Danger List in 2010 following progress in conservation, primarily in their treatment of invasive species (World Heritage Centre, 2010).

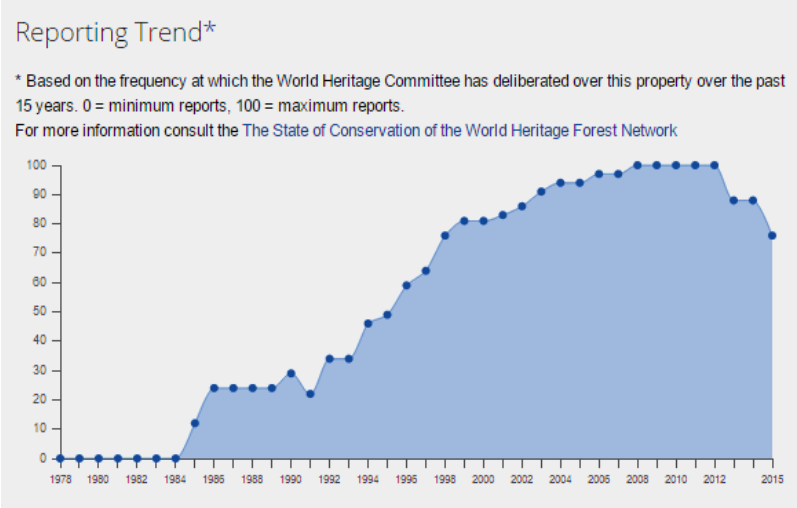

Figure 2. Reporting Trend for Concern over Galápagos Islands. *The relative frequency at which the World Heritage Committee deliberated over the Galápagos Islands*

The decline in concern for the well-being of the islands seems misguided given the increases in tourism and local populations, higher frequency of environmental contamination and worsening climate change situation. Continued deliberation about the health of Galápagos ecosystems is necessary for sustained protection of the islands' many threatened species.

2 LITERATURE REVIEW

2.1 INVASIVE SPECIES

2.1.1 Egg Predation

Invasive black rats (*Rattus rattus*) were first introduced on the islands sometime in the 17th or 18th century after contact with pirates and whalers, and brown rats (*Rattus norvegicus*) were introduced as late as the 1980's by human colonization (Rat Eradication on Pinzon, 2015). These species outcompete the native rice rats and prey on the eggs of many birds and reptiles. On islands that have invasive rats, some populations of marine iguanas are unable to successfully hatch their eggs. This creates marine iguana populations that are made up almost exclusively of adults (Berger et al. 2007). This age distribution is very unstable because while population size may be large, the small proportion of young iguanas indicate a lack of reproductive momentum for the population. This leads to smaller populations in future generations. Unable to hatch offspring, eventually these populations will approach zero as older iguanas are not replenished by hatchlings.

However, there are practical solutions to this problem that have shown to be effective. Invasive species are not present on all islands. On some of these islands, they were never introduced, so the threat has never existed. On other islands, invasive rats have been eradicated. This has occurred on several of the smaller islands and islets, the largest of them being Pinzon at 17km^2 (Rat Eradication on Pinzon, 2015). Eradication is completed via island-wide placement

of rat poison. Surveyors have yet to have encountered a rat yet on the island, and have reported tortoise eggs hatching on Pinzon for the first time in over 100 years. This gives hope to the possibility of rats being eradicated on all islands in the future.

2.1.2 Adult Predation

Galápagos marine iguanas have experienced very low levels of predation throughout their evolutionary history. They have no natural terrestrial predators (Vitousek et al. 2010), and show very low numbers of deaths from marine animals such as sharks or sea lions (Berger et al. 2007). They do have one natural aerial predator, the Galápagos hawk (*Buteo galapagoensis*) (Vitousek et al. 2010). However, the Galápagos hawk is not present on all islands, and predation rates are low on those islands it does inhabit, for two reasons. First, Galápagos hawks are unable to prey upon large adult iguanas. Second, Galápagos hawks prey on other small animals that are easier for them to capture and eat, so their predation efforts are not highly focused on marine iguanas (Berger et al. 2007). They are often able to prey upon adult iguanas who have been weakened by starvation or the costs of reproduction (Wikelski & Nelson, 2004).

Because of this relaxed predation, marine iguanas have acquired and retained very few anti-predator characteristics. Animals typically have both innate and learned anti-predator responses. In the case of marine iguanas, their evolutionary history has not given rise to a strong responses in either category.

Examples of lacking innate response are their inability to recognize unfamiliar animals as predators and their lack of a stress response to novel predators (Berger et al. 2007). Evolutionarily, this lack of a stress response may have been adaptive because flight is energetically expensive and perceiving benign animals as threats would waste energy. In most cases throughout their evolutionary history, mounting a large response to perceived predators would have used up energy that could have been used for other more beneficial activities such as foraging or reproduction. Flight from an established territory would also result in lower reproductive success for territorial males (Vitousek et al. 2010). For this reason, lack of the instinct to flee has likely been an adaptive trait in marine iguanas.

Behaviorally, marine iguanas show low levels of wariness to novel predators. When approached by humans and other unfamiliar animals, they wait until the animal is very close before fleeing, and their flight response is not powerful enough to successfully escape. Marine iguanas do show some signs of learned wariness, as most exhibit a slight stress response and flight behavior upon second attempts at capture by humans. However, the learned behaviors are not enough to protect the species against introduced predators because the events that facilitate that learning (i.e. first attack by predator) often lead to their death (Vitousek et al. 2010). The flight response they do exhibit on second contact is not strong enough, and does not occur early enough to escape the predator. For example, marine iguanas are easily captured even on subsequent attempts by humans. In nature, the opportunity to learn escape behaviors often does not

arise, as first contact with predators such as dogs and cats usually result in immediate death, or eventual death due to infected bites. By the time the iguanas have developed some behavioral response, it is likely too late and they are either dead or fatally wounded.

2.2 Increasing Human Presence

The Galápagos Islands is one of the few places in the world with no native human inhabitants. For the vast majority of their evolutionary history, the Galápagos wildlife has existed in isolation from human contact. This makes them particularly vulnerable to human presence, as they lack evolutionary and behavioral adaptations for coping with the impacts of humans.

The first recorded Western contact with the islands was in 1535 by Spanish bishop Fray Tomas de Berlanga (Markham, 1892). After discovery of the islands, whalers and pirates often visited to gather resources and food. The Galápagos Islands were annexed by Ecuador in 1832. Some of the islands were briefly populated in the 1800s and early 1900s, but the settlements did not last. Beginning in the 1920s, settlers came to the Galápagos and established themselves on Santa Cruz and San Cristobal. The population steadily began increasing, but at a much slower rate than observed today. In the past century, the number of residents has been increasing by as much as 6% per year, fueled by the opportunities introduced by the booming tourism industry (Galapagos Conservancy, 2015). Efforts to prevent excessive growth were made in 1998 with *The Galápagos Special Law of 1998*, but it was ineffective in controlling population due to loopholes and poor implementation. As illustrated in Figure 1, the

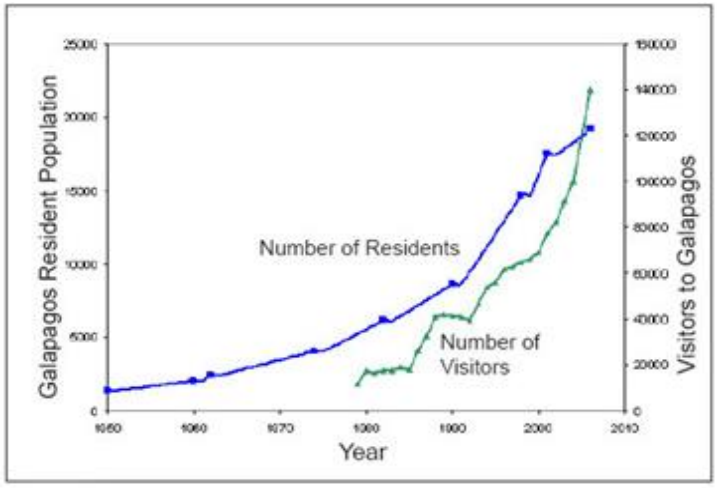

Figure 6. Number of residents and annual tourists in Galápagos Islands, 1950-2010. *Both number of residents and tourists have been increasing since the mid-1950s. Experts expect these numbers to continue to increase. Source: Galápagos Conservancy.*

number of residents in the Galápagos has grown from less than 5,000 in 1950 to over 25,000 currently with inhabitants on 5 out of the 18 main islands.

The islands first opened up to large scale tourism in the 1960s, just after becoming a national park. At first, most tourism was via cruise ships that were well-regulated. However, a rise in low-budget land-based tourist opportunities has opened up the market for people of all socioeconomic statuses. In 2014, the island saw 215,691 tourists, an increase of 6% from the year before. To meet the demands of increasing tourism, many entrepreneurs come to the islands and started their own low-budget tourist companies. Some of these small companies are unregulated and hire unofficial guides. This may prevent national park rules being enforced, reducing the effectiveness of restrictions on land use.

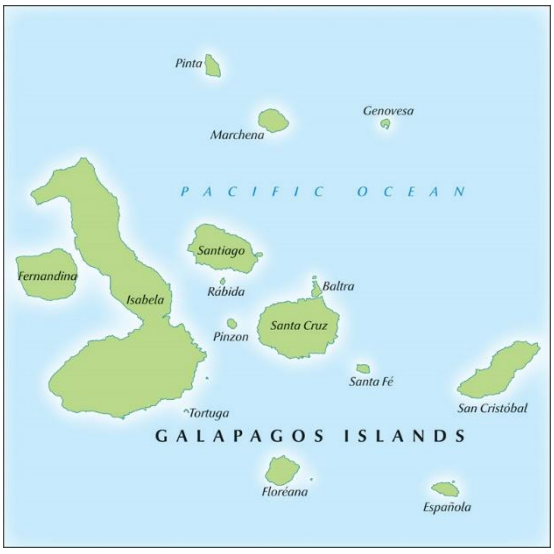

Figure 10. Map showing major islands of Galápagos. *The major islands, including the five inhabited islands (Isabela, Santa Cruz, Baltra, Floreana and San Cristobal), are shown.*

2.2.1 Direct Human Contact

Visitation of tourists to animal breeding grounds has been hypothesized to cause chronic stress in many animals. To test this, Romero & Wikelski (2002) measured the amount of corticosterone in the

blood of marine iguanas in sites near or far from heavily-trafficked tourist areas. Initial corticosterone levels and levels taken 30 minutes after capture were below levels expected in a chronically stressed population. They found that blood corticosterone levels in iguanas close to tourist trails returned to normal more quickly after capture than iguanas naïve to humans. The authors posit that the presence of tourists in breeding areas is not a source of chronic stress in iguanas, and that iguanas in these areas have dampened part of the stress response pathway. They claim that these are mixed results, as a weakened stress response is not necessarily beneficial. During periods of high stress, a stronger corticosterone response aids animals in efficient use of energy (Romero & Wikelski, 2002).

However, a later study by French et al. (2010) showed that tourism alters many physiological functions that contribute to an animal's survival. Factors examined included stress hormone levels and immune system responses during both breeding and non-breeding seasons at multiple sites. While there were no differences in baseline corticosterone levels among sites, iguanas at tourist sites showed elevated stress-induced corticosterone levels. This conflicts with the previously mentioned study, which indicates that stress responses in this species are plastic. The combined results indicate that while the specific effects are unclear, there is strong evidence that increased human presence has altered a complex system that could have many downstream effects (French et al. 2010).

The study by French et al. (2010) also observed marked effects on the immune response in marine iguanas in tourist sites. Iguanas in tourist sites show

suppressed wound healing and total hemolytic complement activity, both of which are indicative of stress-induced immunosuppression. Conversely, bacterial killing ability was not shown to be reduced in areas high in tourism. Based on these findings, the authors hypothesized that during non-stressful conditions, animals at tourist sites might not be significantly immuno-compromised compared to non-tourist sites. However, during times of acute or chronic stress, they likely have reduced immune defenses (French et al. 2010).

2.2.2 Environmental Disasters

Increases in both residential and tourist demands for resources means higher numbers of cargo ships, airplanes and boat traffic on the islands. This leads to an increased risk of environmental impacts from pollution. With increasing local and tourist populations comes an increased need for imported goods. Resources are brought to the islands on cargo boats from the mainland. This includes food, consumer products, construction materials and fuel. The transportation of food and other toxic materials is of large concern because of the risk of spills in the event of an accident. The most severe incident in recent history was the 2001 grounding of the tanker Jessica. While initially it was categorized as a near-miss, this disaster resulted in a 62% mortality rate in marine iguanas on the island of Santa Fe in the following year (Wikelski et al. 2002). Scientists are not certain of exactly what effect the spill had on iguanas, though the leading hypothesis is that the oil killed bacteria in the gut of the iguanas, rendering them incapable of digestion. The iguanas on Santa Fe were found to be significantly more stressed than iguana on Genovesa, another island with similar geography and environmental conditions

that was not exposed to the spill. It is assumed that the lack of food stressed the iguanas and this contributed to the high mortality rate.

In January of this year, a freighter containing 1,400 tons of products including 13,000 gallons of fuel ran aground in Shipwreck Bay on San Cristobal. While no oil was spilled in this accident, Ecuador declared a state of emergency and immediately began removing fuel from the freighter to prevent a future spill. The government also sought to refloat the freighter, a costly project. Scientists argued that while there was no apparent damage to the island's ecosystem, there was a significant risk of the ship spilling some of its cargo, which included polluting chemicals (Alvaro, 2015). This accident is another example of a near-crisis in the Galápagos that could threaten the marine biodiversity of the islands. Further precautions must be taken to prevent accidents such as these from further damaging life in the Galápagos.

2.3 Foreign Pathogens

Reptiles are typically not highly susceptible to disease and parasites when compared to amphibians, who are noted as being a highly vulnerable group (Gibbons, et al., 2000). However, due to the isolation of marine iguanas from the mainland for millions of years, the species is likely to have a naïve immune system. Pathogenic viruses, bacteria and fungi have continued to evolve on the mainland and marine iguanas lack a genetic immune resistance to them. Should they be make their way to the islands, the impact could be deadly. Given the high tourist traffic, there exists a possibility for diseases to

be brought to the islands from not only the South American mainland, but around the world.

Currently, the most serious threat of disease comes from the black salt-marsh mosquito (*Aedes taeniorhynchus*). A study by Bataille et al. (2009) asserts that this species, which colonized the Galápagos Islands naturally over 200,000 years ago, could become a bridge-vector in the transmission of current and future diseases. Mosquitos normally feed on mammals and birds, but the absence of mammals on the islands has led this species of mosquitos to broaden its host range to include reptiles. In the study, 58% of the mosquitos analyzed had fed on reptile blood (47% on marine iguanas), compared to 41% on mammals, 16% on humans and 1% on birds (Bataille, et al., 2009). The main concern is that an introduction of the West Nile Virus (WNV) from the mainland could allow these mosquitos to spread the virus to each of the islands due to high levels of human traffic between the islands, which is concerning because WNV has a wide host range that includes birds, mammals and reptiles (Kilpatrick, et al., 2006). Since the black salt-marsh mosquito feeds on all three, it could cause disease in many island species.

The threat of other new diseases is been well documented as it is difficult to predict the arrival of foreign pathogens to an island. However, high tourist traffic and the existence of vectors such as the black salt-marsh mosquito suggest that there is potential for both the introduction of new pathogens to the islands, and the transfer of existing pathogens between species.

2.4 CLIMATE CHANGE

2.4.1 Changing Oceanic Environment

Given that marine iguanas do all of their feeding in the ocean, changes to ocean waters would have an effect on their available resources. Because they rely on gut microbes to digest their food, it is difficult for them to change food sources (Wikelski & Romero, 2003). During periods of starvation, marine iguanas rarely change their feeding behaviors. They sometimes will forage on brown algae when their preferred red and green algae are not available, but their gut microbes are unable to digest it efficiently, leading to less energy available for other behaviors such as reproduction (Romero, 2012).

Significant reductions in the available edible algae could occur if even slight changes to the chemical compositions of the ocean occur (Restrepo, et al., 2012). This could come from either a change in temperature or a change in acidity, but it is expected that the two will go hand-in-hand. A rise in ocean temperature or an increase in acidity could wipe out the green and red algae, leaving marine iguanas without their food source. Many iguanas could die of starvation, but the few that alter their feeding habits to include brown algae will do so at a cost (Wikelski & Romero, 2003). Digesting this alternative food source will likely not provide them with sufficient energy and nutrients, and they too will likely succumb to starvation.

Changes to the sea level could also negatively impact the iguanas. Marine iguanas dive into the ocean and feed on seaweed on the floor before returning to

the rocky shore to bask in the sun and regain their depleted energy (Wikelski & Nelson, 2004). If the sea levels rose, the location of this seaweed may change. If the distance between the shoreline and the algae increased, or if it shifted deeper into the water, marine iguanas would be unable to reach it, or would only be able to spend a short time foraging. Their limited swimming capabilities and difficulty maintaining temperature in water mean that even a slight increase in sea level could add a significant distance to their journey and push a lot of their food out of reach.

2.4.2 El Niño: Anthropogenic Effects on a Natural Phenomenon

Global climate change is specifically problematic when you consider that El Niño weather patterns are becoming more severe. With increasing duration and strength, El Niño events are expected to have devastating effects on marine iguana populations (Wikelski & Nelson, 2004). During El Niño events, the upper levels of the ocean become warmer and are lower in nutrients (Glynn, 1988). Because of this, most of the seaweed that marine iguanas feed on die, leaving them without enough food to sustain their populations. While some iguanas attempt to dive further in search of food, others shift their focus to eating other kinds of algae that are difficult or impossible for them to digest (Romero & Wikelski, 2001). The diving iguanas do not consume enough food to make up for the increased energy they spent in finding it, and the iguanas eating other food sources lack nutrients from incomplete digestion.

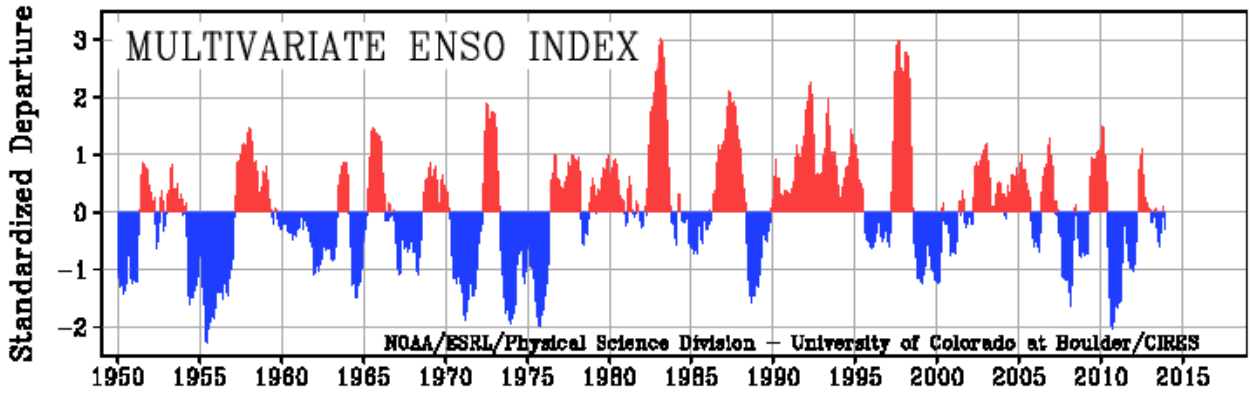

Figure 11. Incidence and Strength of ENSO events. The two most severe El Niño events, (82-83 and 97-98) coincide with mortality rates of up to 90%.

During El Niño events, these stressed iguana populations often see little to no reproduction, and may struggle to re-establish normal levels of reproduction in subsequent years if conditions do not improve significantly (Romero & Wikelski, 2001). Two recent, severe El Niño events, '82-'83 and '97-'98 saw losses of up to 90% of the population. These were extreme cases, but under the assumption that we will see more extreme years like this, this may become the norm. El Niño events usually occur every 3-7 years. However, severe El Niño events occurred more frequently during 1990s than usual and are expected to occur at a higher frequency in the future (Steinfartz, et al., 2007). Multiple extreme El Niño events back-to-back would mean that adult populations would plummet and reproduction would stall for several years, leaving them without a substantial younger generation to repopulate. This would create a lag on building up the adult population and would endanger the entire population's chances of being able to repopulate.

Since El Niño is a natural phenomenon that marine iguanas have endured throughout their evolutionary history, they do have some adaptations to survive it. Wikelski & Thom (2000) found that marine iguanas can become shorter by up to

almost 7cm during El Niño events. This decrease in length is thought to be a demineralization of bone caused by a lack of food during these times. By decreasing the amounts of tissue they need to maintain, they are able to reduce their food intake requirements and prevent high stress levels. During La Niña, when more food is available, their length increases again. Marine iguanas that are able to shrink and grow more are shown to survive longer during these conditions (Wikelski & Thom, 2000). This is an interesting adaptive mechanism that may help iguanas to adapt to the changing climate.

3 METHODS

3.1 DATA COLLECTION

First I analyzed the natural history of the iguanas in order to pinpoint certain aspects of their unique anatomy and physiology that may make them especially vulnerable. I referenced books and encyclopedias that covered marine iguanas in order to build a broad base of knowledge about their social, reproductive and feeding behaviors. I then located scientific journal articles by searching “Galápagos marine iguanas” or “*Amblyrhynchus cristatus”* plus other terms such as “behavior,” “characterization” or “natural history.” This allowed me to identify certain traits or ecological factors that might lower their survival or reproductive rates.

In order to examine the impact of each risk, I gathered background information on the mechanism for each risk, as well as the annual impact of each threat. I searched the Oregon State Library database using key search terms. I combined “Galápagos marine iguana” plus a risk such as “El Niño,” or “invasive species” and then added various other key terms such as “risk,” “endangered,” “conservation,” “threat,” etc.

3.2 THREAT LEVEL ASSESSMENT

After building a list of threats, I analyzed the relative severity each of these posed to the species and categorized them as either “mild,” “moderate,” or “severe” threat levels. I did this based on three categories: the percentage of deaths caused, the impact on stress levels, and the trajectory of the risk. In many cases, it was hard to quantify them based on hard numbers because there is no way to isolate each threat and examine its

impact in terms of population declines. However, studies conducted in areas with high incidence of a particular risk allowed me to estimate the potential for a particular threat to impact the species.

The percentages of deaths caused by each risk were taken directly from journal articles. If there was no mention of deaths, the risk was listed as “n/a.”

The stress levels of iguanas were estimated based on findings in scientific journals. Threats that were said to lead to very high stress levels were categorized as “severe,” those causing slightly elevated stress hormone levels were categorized as “moderate,” and those causing minimal rise in stress hormones were categorized as “mild.” If there was no mention of an effect on stress levels, the risk was listed as “n/a.”

I also took into account the trajectory of each risk. Some of these threats are estimated to increase in severity over time, whereas others are expected to lessen. For this reason, two threats that are currently impacting iguanas at an equal rate may be ranked differently depending on estimates for their expected future rise or decline in severity. Similarly, a threat that is currently very serious but is on track to become less severe in the near future may be ranked as “moderate” whereas a threat that is only a moderate problem currently but is forecasted to increase in severity in the near future may be ranked “severe.”

Classifications for each threat in each of the three areas were then summarized in a table, and overall threat levels were assigned based on the following general criteria:

3.2.1 Mild Threats

Mild threats are those that generally cause a low number of deaths (<25% of a population), have little effect on stress levels, and/or are expected to become less serious in the future. Mild threats are currently well understood and are being adequately addressed.

3.2.2 Moderate Threat

Moderate threats are those that generally cause a moderate number of deaths (between 25-49% of a population), have a slight effect on stress levels, and/or are not expected to become more serious in the future. Moderate threats are not completely understood and/or are not being adequately addressed.

3.2.3 Severe Threats

Severe threats are those that generally cause a high number of deaths (above 50% of a population), have a significant effect on stress levels, and/or are expected to become more serious in the future. Severe threats are not completely understood and are not being adequately addressed.

4 RESULTS

Results from this study were compiled into Table 1. The table indicates the overall threat level assigned to each threat, as well as a breakdown of each of the three components.

		% Deaths Caused?	Chronic Stressor?	Estimated Trajectory?	Overall Threat Level
Invasive Species	Egg Predation	n/a*	n/a	Decreasing	Mild
	Adult Predation	27%	Mild	Decreasing	Mild
Increasing Human Presence	Direct Human Contact	n/a	Moderate	Increasing	Moderate
	Environmental Disasters	Up to 62%	Severe	Increasing	Severe
Foreign Pathogens	Foreign Pathogens	n/a	Moderate	Increasing	Moderate
Climate Change	Changing Ocean Environment	n/a	Severe	Increasing	Severe
	El Niño	Up to 90%	Severe	Increasing	Severe

Table 1. Relative risks of current threats to marine iguana populations.

** It is not possible to determine the percentage of deaths caused as this threat prevents births rather than causes deaths.*

4.1 MILD THREATS

4.1.1 Invasive Species

Invasive species pose a mild threat to marine iguanas. While egg predation is still common and numbers of deaths from cats and dogs are still up to 27% in affected areas, these threats are both containable and treatable. The existence of many unaffected islands, as well as islands that have effectively eradicated this threat indicate that this problem is being adequately addressed and its impact will decline in the future. Invasive species are a localized problem and do not affect

the archipelago in its entirety, meaning that while one population may experience drastic effects, others could be unaffected. While this example describes a severe threat to one population, it does not describe a threat to all populations, and thus not the entire species. Further, the effects of invasive species on marine iguanas are very well documented and studied. This in-depth understanding of the problem is important because a well understood threat is more manageable than one we know little about.

4.2 Moderate Threats

4.2.1 Direct Human Contact

Direct human contact is classified as a moderate threat due to the disturbing effects on stress levels and immune function in marine iguanas. Though data from studies conflicted in specific findings, multiple studies concluded that any alteration in these complex systems would likely have negative effects on multiple downstream pathways. More studies are needed to better understand the mechanism for the altered stress response, especially in anticipation of a continued rise in human populations on the islands.

4.2.2 Foreign Pathogens

Foreign pathogens are classified as a moderate threat due to the possibility for mass deaths to a population. While no deaths have been observed to date, the possibility of introduced pathogens will increase as more people travel to the islands, as the highest risk of introduction is via mosquitos in airplanes. Introduced pathogens may have the capacity to kill iguanas, but it is also likely that even if

they are not lethal, they will contribute to additional stress. This will further exacerbate mortality rates.

4.3 Severe Threats

The most severe threats to marine iguana populations are environmental disasters caused by meeting the growing needs of humans in the Galápagos, a changing ocean environment and increasing frequency of severe El Niño events caused by global climate change effects.

4.3.1 Environmental Disasters

Environmental disasters such as oil spills have been found to cause high numbers of deaths (up to 62% of a population). Stress levels in those populations subjected to environmental disasters are significantly higher than control populations under similar environmental conditions. Given the expected rise in both tourism and residential populations, the incidence of these types of accidents is likely to increase, causing more frequent harm to iguana populations.

4.3.2 Changing Ocean Environment

Changes in the chemical composition and temperature of the ocean, combined with expected sea level rises will alter the availability of marine iguanas' main food source. This will increase mortality rates and lead to chronically high stress levels. Experts expect to see the acidity, temperature and sea level of the oceans to rise substantially in the future, leading to pronounced effects on marine iguana livelihood.

4.3.3 El Niño

El Niño has the strongest correlation with high mortality rates (up to 90%). During severe El Niño events, stress levels in marine iguana populations are significantly higher than normal. Experts predict that El Niño events will occur more frequently and the damage will be more pronounced in the future. They also expect fewer La Niña years, which inhibits marine iguanas' natural means of replenishing population health and size following losses from an El Niño event.

5 Discussion

5.1 Compounding Threats

The purpose of this thesis is to discuss major threats to marine iguana populations and identify the most critical ones. However, to accurately portray the current threats to the species, the issue of compounding threats must also be addressed. In nature, none of the threats mentioned above exist in isolation. Therefore, we must take into consideration the effects when any of these threats occur simultaneously. This is the case on the five islands that are inhabited by humans; invasive species, human presence and climate change occur simultaneously to cause the highest mortality rates. As explained by Romero (2012), the cause for this is chronic stress. Normally, stress responses function to increase metabolic efficiency in the presence of a threat in order to ensure enough energy can be dedicated to overcoming or avoiding that threat. However, chronic stress (and thus, chronically high levels of corticosterone in the body) causes iguanas to ultimately succumb to starvation as they are unable to maintain their body condition for prolonged periods of high stress (Romero, 2012).

5.2 El Niño: Cause or Catalyst?

We see that the highest mortality rates are correlated with severe El Niño events. However, the species has been exposed to these cycles for all of their evolutionary history, and have evolved adaptations to cope with these natural cycles. One example is the ability of marine iguanas to grow and shrink in response to nutrient availability (Wikelski & Thom, 2000). During El Niño events when food is scarce, marine iguanas can shrink by up to 20%, decreasing the amount of energy they must dedicate to

maintaining tissues. This decreases the amount of food they require, allowing them to survive famine (Wikelski & Thom, 2000). Studies show that in the years following an El Niño event, algae availability returns to normal, allowing iguanas to replace lost fat reserves and restore good body condition (Wikelski & Nelson, 2004). Marine iguanas also alter reproductive behaviors by reproducing annually rather than every other year, reproducing at a younger age, and laying more eggs per clutch. These factors allow losses of up to 50% to be replenished within four years (Wikelski & Nelson, 2004). Even populations with losses of up to 90% can bounce back during plentiful La Niña periods when algae is abundant.

Due to the adaptive ability of marine iguana populations to survive and rebound from El Niño events, it might be a better strategy to focus on preventing concurrent threats, especially those introduced recently in evolutionary history. Specifically these include high stressors such as oil spills and human disturbance, which should be minimized to prevent high mortality rates. Marine iguanas do not possess adaptive traits to withstand these newer threats, and the stress they cause severely impacts survivability.

Additional stressors will reduce a population's recruitment ability. For instance, if a strong El Niño event coincides with an oil spill, the combined stress levels are likely to lead to very high mortality rates. In the following years, when populations should recover and begin recruitment, a chronic stressor such as high amounts of human contact could keep stress levels high and prevent improvements in body condition. If an additional threat of egg predation is present, any attempts at egg-laying may be thwarted as the majority of clutches are destroyed by invasive species. The few that do

hatch may fall prey to nonnative predators such as feral dogs and cats. This example of concurrent threats is the reality on the inhabited islands.

This example illustrates that El Niño is more of a catalyst to high mortality rates than a cause itself. In the absence of additional threats, marine iguanas can survive even strong El Niño events. Indeed, they have been doing so throughout their evolutionary history. While El Niño events are expected to become more frequent and more intense in the future, it is possible that marine iguanas will continue to evolve to adapt to these natural cycles. In this way, it is not the El Niño events themselves that are a severe threat to this species. El Niño instead acts as a catalyst, raising baseline stress levels and amplifying the impact of other stressors. Romero (2012) states that "any stressors in addition to the food loss will immediately push corticosterone into Homeostatic Overload, further decrease stored energy, and hasten death. The best chance to survive is to avoid any added stressors or to minimize the response to those that occur" (Romero, 2012). This shifts the focus of conservation onto threats other than El Niño.

5.3 Conservation: Next Steps

5.3.1 Minor Threats: Continue Current Efforts

Out of the three categories of threats defined in this thesis, the majority of conservation efforts should be dedicated to moderate and severe threats. Mild threats such as egg and adult predation are already very well understood and are being dealt with relatively well. Programs to spay and neuter stray dogs and cats will slowly decrease feral populations (Darwin Animal Doctors, 2015). The Fund for the Control of Invasive Species in Galápagos (FEIG), a $15.6 million

endowment, will ensure that funds to continue efforts at preventing the spread of invasive species will be available for as long as they are needed (Galapagos National Park, 2011). With continued interest in and funding for the eradication of rats for the purpose of tortoise conservation, little extra effort is needed to address this problem.

5.3.2 Moderate Threats: Seek Further Knowledge

The next steps for addressing moderate threats is to gain a better understanding of the exact impact they will have on marine iguana populations. In regards to foreign pathogens, there is little known about the susceptibility of marine iguanas to certain pathogens like WNV. More research on the direct effect of these potential pathogens on marine iguanas specifically will shed light on exactly how susceptible the species is. Continued diligence in fumigation of passenger planes will reduce the risk of migration of disease-carrying mosquitos. However, increased security on cargo ships and private planes is necessary, as well as fumigation on tourist boats travelling between islands.

As for the effects of direct contact between humans and marine iguanas, more studies are required to clarify what the actual effects are on stress hormones. A better understanding of the impact tourism is having on marine iguana populations will allow the Galápagos National Park to make adjustments to tourism regulations to better protect the species.

5.3.3 Severe Threats: Problem-Solving on an International Scale

The remaining threats are best dealt with on a global scale. Global climate change, which is the underlying cause of changes to the ocean and the expected increase in severity of El Niño events, cannot be reversed by action taken in the Galápagos Islands alone. Rather, international action must be taken to prevent these threats from increasing. Again, the best method for weakening the catalytic ability of El Niño events is to reduce the impacts of other stressors.

Next steps for reducing the risk of environmental contamination include creating and enforcing stricter regulations for tourists and residents. Placing a cap on annual tourists to the islands, and enforcing *The Galápagos Special Law of 1998* will curb the increasing demand for goods on the islands. This will reduce the potential for environmental disasters to occur. Tourism can be more heavily regulated during severe El Niño events to minimize stress levels and mortality rates. Further steps in moving towards sustainable food, water, transportation and energy sources in the Galápagos Islands will decrease the Islands' dependence on goods from the mainland. This will further decrease the necessity for frequent traffic of cargo ships and oil tankers.

5.4 Overarching Challenges to Conservation

Cost will prove to be a barrier to conservation of marine iguanas. Programs to eradicate invasive species can cost millions or billions of dollars (Rat Eradication on Pinzon, 2015). However, prevention is almost always less costly than reintroducing a population. This is especially pertinent to this species because breeding programs for

marine iguanas do not currently appear to be a realistic possibility. Scientists have not yet been able to breed them in captivity. Many iguanas have been taken into captivity in zoos around the world, but none have successfully reproduced (Wikelski & Nelson, 2004). Marine iguanas are difficult to keep in captivity due to their unique marine-and-terrestrial lifestyle. In the wild, they live in dense colonies, which may be necessary to prompt breeding in captivity. The difficulty of sustaining this type of population in captivity is high due to their marine-and-terrestrial lifestyle. Marine iguanas are the only endemic Galápagos species that we are unable to breed in captivity (Wikelski & Nelson, 2004). For these reasons, preventing the necessity for breeding programs should be highly prioritized.

To help combat costs, tourism reform could help to boost the economy in the Galápagos Islands. Currently only 15.5% of tourism revenue stays there due to international travel agencies (Epler et al. 2007). Restructuring the tourism industry to keep tourism dollars local would bring in more funds to the National Park to address these issues. Tourism reform should be prioritized because it reduces the impact of threats caused directly by tourism, while simultaneously providing funds to address other threats.

However, an increase in funding to the Galápagos Islands does not ensure that conservation efforts will be focused heavily on marine iguanas. Other iconic species such as giant tortoises and blue-footed boobies will likely take precedence as they are main tourist attractions. However, since many Galápagos species share common threats, conservation of one species is likely to aid in the conservation of others. Tortoises and iguanas are both threatened by invasive species, for example.

5.5 LIMITATIONS

While the methods used in this thesis are not the most intensive, they are a time- and cost-effective means to determine the most relevant and serious threats to marine iguanas. This study presents a qualitative analysis of the various threats and identifies target areas for conservation and future study. The qualitative data presented in this study provides a starting point for conservative action, as well as more expensive and time-consuming data collection.

Future studies could conduct a more quantitative analysis of the seriousness of certain threats, and mathematical models could be used to calculate statistics that would allow the threats to be more precisely measured. This would allow each threat to be assigned its own unique threat level, rather than a group or range, and would allow conservationists to better prioritize based on threat level. In this thesis, there is no way to scientifically prioritize on severe threat over another. Realistically, these threats are likely not identical in scale and could be further broken down.

A more quantitative approach could be taken with the assessment of each of the three components of threat level. An issue with the estimated percentages of deaths caused for each threat is that the numbers are not standardized and cannot be directly compared. The numbers are taken from different populations in different locations during different years. It is very hard to do a direct comparison when there are so many different variables; the data given merely serves as a vague estimation. While it is near impossible to calculate the individual risks in such a way that that would minimize unknown variables and compounding threats, more accurate data would likely result in more reasonable comparison.

Specificity could also be increased in the analysis of chronic stress. Rather than assigning different stressors to qualitative groups, stress levels could be measured quantitatively and compared to a control to give a clearer picture of the impact of different threats on stress hormones. Further, for some threats, no data on stress levels had been collected. Third, numerical estimations of the trajectory of these risks would give even more concrete numbers for comparison. Rather than stating that a threat would increase, decrease or stay the same, a researcher could give the rate of increase or decrease. This would ensure that threats that are increasing more quickly are prioritized over threats that may be increasing at a very slow rate.

Another limitation is that this thesis presents the threats as occurring uniformly across the species. This is problematic because this species exists in many relatively isolated populations, many of which are exposed to different threats. Perhaps a more useful analysis of threats would look at each population individually and determine the most significant threats to that population, rather than the entire species in general. Then each population could have a personalized plan for conservation. This would allow for better preservation of the diversity seen between different populations.

Finally, since the main language of the Galápagos Islands is Spanish, it is important to acknowledge that only English sources were used in the writing of this thesis. It is possible that valuable sources were skipped over due to the language barrier. Additional insight could be gained through the inclusion of Spanish sources.

5.6 Future Study

Many of the limitations mentioned could prompt further studies to be done to minimize the margin of error in the determination of the four threats. However, there is always the potential for new risks to be discovered or introduced. Continued study of the Galápagos Islands as a whole would be beneficial to remain aware of the threats to biodiversity. As global climate change continues to alter ecosystems across the Earth, migration of animals or shifting biomes could cause new species to find their way to the islands, or for island species to migrate elsewhere. This would create a host of new issues for marine iguanas.

Future studies in the apparent altered stress pathways in marine iguanas exposed to tourists could give insight into whether these changes will have negative consequences on marine iguana populations. Similarly, more data on the susceptibility of marine iguanas to diseases will give a more accurate understanding of the relative threat those diseases may pose. Once we have an understanding of these two issues, we can give more informed estimations of the risks they pose and determine what steps may need to be taken to address them.

The Galápagos Conservancy (2015) reported unusually high numbers of marine iguana deaths in the fall of 2013 on Santa Cruz and Floreana Islands. The cause for these deaths was unknown, and although analyses have been conducted on the afflicted populations, no clear results have been produced. Stomach contents of the dead iguanas contained undigested algae, and lesions were found in their inflamed digestive tracts, as well as the tongue. Tests have been conducted in laboratories across the United States, with no further explanations. It appears that an inability to secure

additional funding is hindering an explanation as to cause of death (Investigating Marine Iguana Mortality, 2015).

Incidents such as this give reason to believe that other unknown factors put marine iguanas at risk for further population decline. As stated previously, unknown threats are arguably more dangerous because we have no understanding of what is causing deaths and thus no way to prevent them. The continued confusion surrounding these deaths should prompt more observations and study. Unfortunately, acquiring funding to continue exploration of this issue appears to be difficult and has halted further studies from being done in the past two years. It could be argued that the lack of funding for these studies is acting as an additional threat to marine iguanas.

6 CONCLUSION

This study finds that the highest mortality rates in marine iguanas are found when multiple threats occur simultaneously. The most profound influence on stress levels is the occurrence of El Niño events. The pairing of one or more stressors with a strong El Niño event gives rise to a much higher mortality rate than any single threat individually. Since marine iguanas likely have the capacity to survive even the strongest El Niño events given that they are not stressed by other factors such as environmental disasters or high tourist traffic, the main focus should be on these other threats. This study recommends a continuation of invasive species management, better control of growing local populations, and stricter regulations on the tourism industry (specifically in the prevention of environmental disasters and unregulated tour excursions). Further study in the physiological effects of threats such as contact with humans and contaminants to gut microbes, and the potential for different diseases to infect marine iguanas are essential in understanding how to better protect these animals in the wild. Further, experimenting with different husbandry methods would ensure the survival of the species should they become more critically endangered, since scientists have yet to successfully breed marine iguanas in captivity.

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