Analyzing the Impact of Extreme Weather Events and Climate Change on the Galápagos Islands

Emily Dolhansky

Stockton University

Table of Contents

Approximately 600 miles off the coast of Ecuador lies a chain of volcanic islands with some of the greatest scientific significance in human history. The Galápagos Islands, an archipelago of 19 islands in total, range from a few hundred thousand years old to five million years old. They were formed as the Nazca tectonic plate slowly made its way across a hotspot deep within the Pacific Ocean, and they are still forming as the plate continues its journey (Galápagos Conservancy, 2016). The islands are best known as the origin for Charles Darwin's groundbreaking theory of evolution. After visiting four different islands, a young Darwin made observations about the differences in beak sizes among finches – these observations later became the inspiration behind natural selection. Since then the Galápagos Islands have become a symbol for scientific progress.

Today, the islands face pressures that threaten their vitality and the unique biodiversity they contain. Climate change is a prime example of a threat that is not easily remediated. The Intergovernmental Panel on Climate Change estimates that the islands will warm by about 3.6°F by the end of the 21st century (IPCC, 2014). This prediction is slightly above the global average since the islands are surrounded by ocean (IPCC, 2014). Climate change effects more than just ambient air temperature, though. Oceans will continue to warm up as they absorb heat from the atmosphere and respond to changes in air temperature. The rainy season on the Galápagos Islands will lengthen considerably. By the end of the 21st century, the sea level may rise by one meter and the ocean will become more acidic due to the carbon being absorbed from the atmosphere (CI & WWF, 2011). The culmination of all of these changes will produce a climate that more closely resembles the weather event known as El Niño. In order to prevent the collapse of not only the unique wildlife, but the human population that inhabits the islands, certain steps

must be taken to ensure that adaptation to climate change is possible. Without collaboration between organizations such as the Galápagos National Park Service, the Charles Darwin Foundation, the United Nations, and many more, several species may be faced with extinction before the end of the 21st century.

Overall, the Galápagos Islands have surprisingly low biodiversity. This is due to the fact that the islands formed 600 miles off the coast of Ecuador, and every species now found there either swam, flew, floated, or was accidentally introduced by man (Quasar Expeditions, 2016). Although the islands have a tropical climate, very few birds and terrestrial mammal species are considered native due to the difficulty of getting to the islands from the mainland. Despite the low biodiversity, the Galápagos Islands are considered home to some of the most unique species in the world. The iconic giant tortoise roams 10 of the 19 islands (Galápagos Conservancy, 2016). Galápagos marine iguanas are the only iguana species in the world to feed in the ocean. Galápagos penguins are capable of living in the tropical environment due to the cold currents surrounding the islands (Karnauskas, 2015).

The Galápagos Islands lay right at the heart of the Equatorial Undercurrent, putting them directly in the path of the weather event known as El Niño (Karnauskas, 2015). An El Niño usually occurs every 2-8 years, and during this time a cold ocean current known as the Humboldt is interrupted (CI & WWF, 2011). The Humboldt flows upwards from Antarctica to the west coast of South America, which is why the Galápagos Islands normally have mild weather (PBS, 2016). Instead of cold, nutrient rich waters, warm, nutrient poor waters are pushed towards the islands during an El Niño, drastically reducing the food supply in the surface waters (Karnauskas, 2015). The lack of upwelling (or the churning of cold water to deliver nutrients and

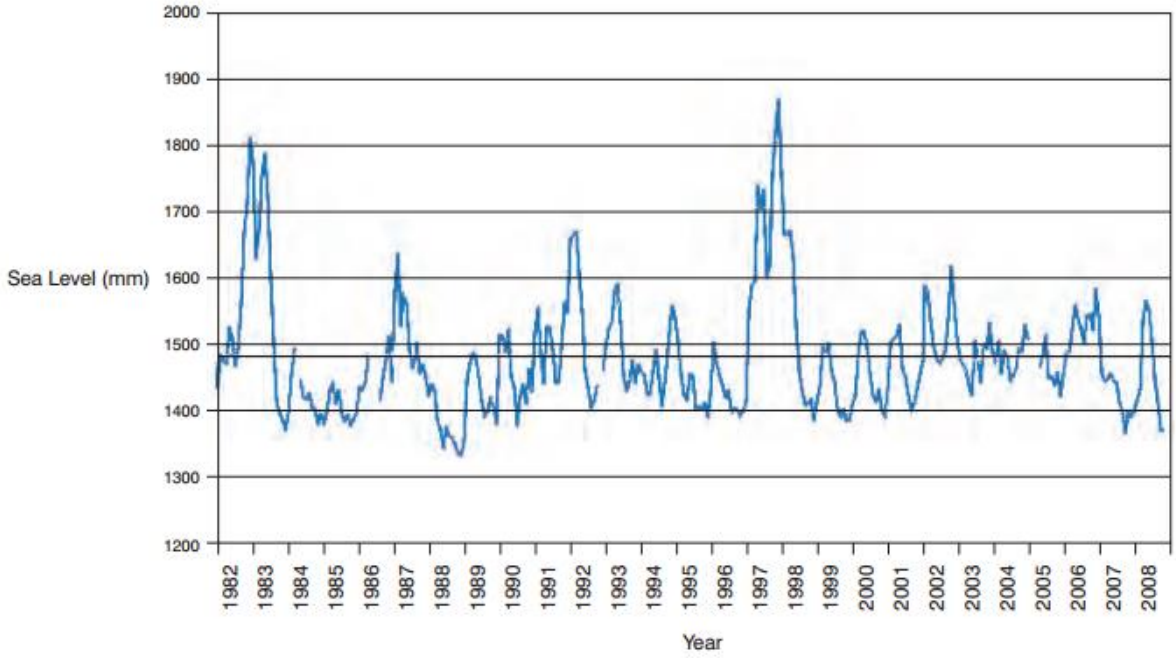
food) during these weather events has profound effects on the biodiversity of the Galápagos Islands.

Every single species is at risk due to the changing climate and potential for extreme weather events, such as El Niño, to become more frequent. Since El Niño causes many of the same problems that climate change does, scientists have used it as a tool for predicting what the future may hold for the Galápagos Islands (CI & WWF, 2011). Although the detrimental effects of El Niño events generally last for less than a year, they are useful in determining how species will be affected by long term climactic changes. For example, during the 1997-1998 El Niño (considered to be one of the most intense on record), the food chain between marine iguanas, sally lightfoot crabs, and fish was drastically altered due to a bottom-up effect (Vinueza et al., 2006). Food for marine iguanas and sally lightfoot crabs in the form of algae became scarce, and it was also difficult for them to graze due to the significant ocean swells. As a result, the marine iguana population declined by nearly 90% during this time (CI & WWF, 2011). Members of the iguana population that survived lost a significant amount of weight and had trouble reproducing (Vinueza et al., 2006). By studying El Niños and the subsequent effects they have on wildlife populations, scientists can predict how climate change may alter the islands and come up with conservation strategies based off what is observed.

El Niño has other effects on ocean-dwelling species and ocean ecosystems. Marine wildlife, such as the iguanas, generally suffers the most and it starts on the bottom most trophic level. Algae, krill, and sardines become less abundant due to the warmer waters and lack of nutrients (Galakiwi, 2015). Whales, sharks, and dolphins will actually leave the islands during an El Niño because of the lack of food (Anderson, 2003). Galápagos penguins have to swim further

and blue-footed boobies have to fly farther in order to find reliable food sources – this either causes the individual to die as a result of exhaustion, or stop reproducing (Galakiwi, 2015).

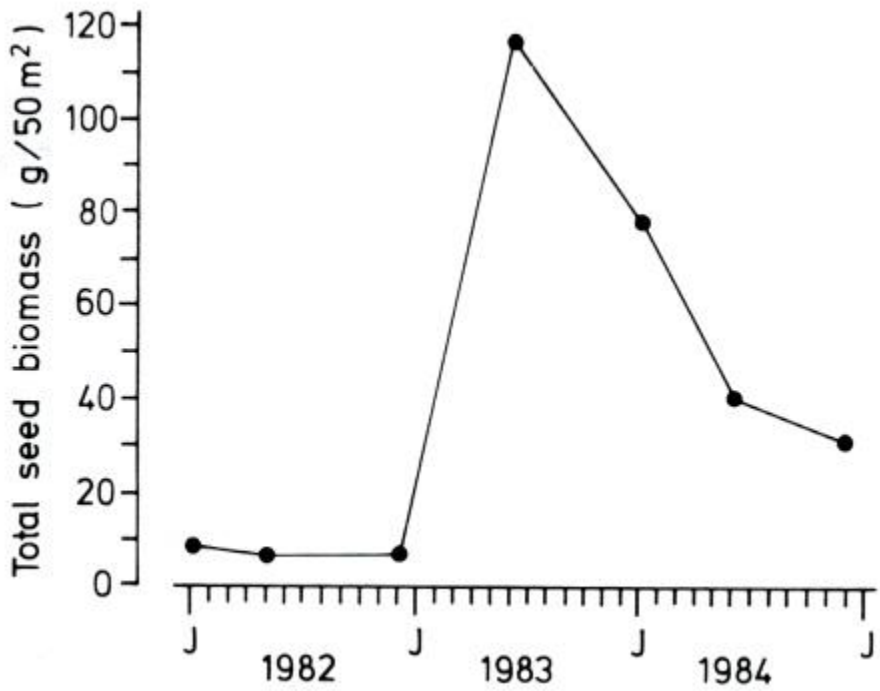
Figure 1. Sea Levels from 1982-2008 (University of Hawaii Sea Level Center)



Although marine life suffers during El Niño events, terrestrial life tends to thrive. Greater precipitation means plant and vegetation productivity is high, which causes insect populations to increase as well (CI & WWF, 2011). During the 1983 El Niño, seed crop was nearly 11 times greater than it was in 1982 due to the heavy rainfalls (Scope Environment, 2016). Finches, land iguanas, snakes, and Galápagos hawks all benefit from the abundant food source (Galakiwi, 2015). These species also tend to reproduce more during El Niños. Ground finches produced 3.5 times as many young during and after the 1983 event (Scope Environment, 2016). While it is tempting to claim El Niño events are beneficial to the islands' wildlife for these reasons,

scientists are doubtful that they have long term beneficial effects on terrestrial ecosystems, as many negative effects have also been observed.

Figure 2. Changes in total seed biomass (g/50m2) during the El Niño period (Scope Environment)



Species adapted to a drier environment have a hard time withstanding the increased rainfall; for example, the *Opuntia*, or prickly pear, cactus collapsed during the 1997-1998 El Niño because their shallow roots could not support the enormous weight of the water-logged leaves (CI & WWF, 2011). During the same El Niño, 36 giant tortoises drowned in ravines that had become flooded, and up to 80% of their eggs were lost due to fungal infections (Márquez et al., 2008). Like global climate change, El Niño events have short term effects that are beneficial to a handful of species. However, it is dangerous to assume these effects are beneficial in the long term, just like it is dangerous to assume that longer growing seasons due to climate change are sustainable. The Galápagos Islands have adapted to periodic El Niños over hundreds of

thousands to millions of years and life on the islands typically rebounds in a few years. However, if climate change continues as projected, El Niño events will become more frequent and more severe, such as the 1982-1983 and 1997-1998 events (CI & WWF, 2011). This climactic shift is not sustainable and may have devastating consequences for life on the islands.

Climate change has an even broader scope than El Niño events. Every aspect of the islands – from ocean life to land dwelling species and the human population – will be affected if the climate continues to change in such an accelerated manner. The consequences of climate change and what they may hold for the future of the Galápagos Islands are outlined below.

CLIMATE CHANGE AND MARINE LIFE

Scientists have come up with six changes that the oceans surrounding the Galápagos Islands will undergo based off current climate models and climate projections. The list is as follows: sea surface temperatures will warm, El Niño events will become more frequent, sea level will rise, precipitation will increase, ocean pH will lower (oceans will become more acidic), and upwelling will decrease (CI & WWF, 2011). Even if anthropogenic emissions were reduced dramatically, the ocean would continue to warm due to a lag in response time (the ocean heats up and cools down very slowly – the process of cooling would take decades) (CI & WWF, 2011). Due to the likelihood that the six aforementioned changes will continue to occur despite mitigation attempts, the focus for marine ecosystems has moved towards adaptation.

Several marine ecosystems are vulnerable in the face of global climate change and have become the center of adaptation efforts. In the past, coral reefs have flourished in the warm, tropical currents around northern islands such as Wolf and Darwin; cold-water coral reefs also

thrived in upwelling zones (CI & WWF, 2011). However, the ocean is expected to drop 0.4 units on the pH scale by the end of the 21st century (CI & WWF, 2011). This increase in acidity hinders calcium carbonate shells from forming, and this phenomenon is even more dramatic in the Galápagos Islands where upwelling brings CO_2 rich waters to the surface. As a result, coral reef production is expected to drop almost 50% by mid-century (CI & WWF, 2011). This will cause a decline in the fish populations that are dependent on coral reefs for hunting and reproducing habitats. To combat the decline, scientists suggest establishing "Restricted Access Zones" in areas where coral reefs are least affected by bleaching and El Niño events so that they may recover. Another suggestion is implementing artificial substrates to encourage the regrowth of coral reefs in areas that have been degraded (CI & WWF, 2011).

Another ecosystem that faces threats from climate change is the mangrove forest. The dense forest and root system provides habitat for several bird species including the mangrove finch, which is critically endangered, and acts as a buffer to ocean swells (CI & WWF, 2011). The mangrove forests will be most affected by sea level rise, which causes erosion and coastal flooding. As the sea continues to rise, the mangrove forests will shift upshore and inland (CI & WWF, 2011). Another threat to the mangrove forests are insects such as the cottony cushion scale and parasitic fruit flies, which thrive during heavy El Niño rainfalls (CI & WWF, 2011). To protect the forests from these threats, coastal development should be minimized and stricter guidelines for development should be created. Natural buffer zones behind mangrove stands should be implemented, so that migration can occur more easily as the sea rises. Finally, best management practices for fisheries that depend on the mangrove forests should be promoted to ensure sustainable harvesting is possible in the long term (CI & WWF, 2011).

Individual species are just as at risk due to climate change as whole ecosystems are. For example, Galápagos sea turtles suffer when algae levels are reduced. Algae is the turtle's main food source, and it will become scarcer as the oceans continue to warm. Warmer temperatures may also hinder egg development and cause embryos to die, and beach erosion makes nesting difficult (CI & WWF, 2011). Management recommendations are unique to each species, and in the case of sea turtles, beach protection will be the most effective.

CLIMATE CHANGE AND TERRESTRIAL LIFE

Terrestrial life on the Galápagos Islands evolved under unique climactic conditions. Even though the islands are located at the equator, the climate is relatively cool due to the ocean currents and winds that drive it (CI & WWF, 2011). While terrestrial organisms are hardy and have adapted to the variations in rainfall brought about by El Niño events, a change to the baseline climactic conditions would drastically affect terrestrial ecosystems. Two notable ecosystems are threatened by climate change: the arid zone and the humid zone.

The arid zone occurs at low elevations (80 to 200 meters or so above sea level) and is extremely dry and desert-like (WWF, 2016). Many xerophytic species of cacti, shrubs, and trees live in this zone and have adapted to conditions where water is scarce and the soils are dry. Many animals have also made this zone their home, and most of the islands' endemic species live there (CI & WWF, 2011). The arid zone thrives under periods of irregular rainfall during the hot-season and it may become threatened by the increased precipitation that climate change will cause. The increase in precipitation will also aid one of the greatest threats to terrestrial life: invasive species. Humans have been introducing species to the islands since they were discovered in 1535, and these introductions were both intentional and unintentional (Galápagos

Conservancy, 2016). While most of the large vertebrates, such as pigs, goats, and donkeys, have been eradicated from several of the islands, smaller species such as insects and plants are much harder to control.

If conditions in the arid zone become wetter, insects such as fire ants and ectoparasitic flies will flourish (Galápagos Conservancy, 2016). These insects feed on land iguana eggs and bird nestlings, and can also harm native plants as well. In addition to invasive species, native species might even move into the arid zone and cause competition for resources to increase (CI & WWF, 2011). To combat invasive insects, the feasibility of different biological control measures should be tested. In 2002, Australian ladybugs were released to combat the cottony cushion scale, which proved effective (Galápagos Conservancy, 2016). The driest areas of the arid zone should also be identified and managed accordingly so that arid zone species do not experience total habitat loss (CI & WWF, 2011).

The humid zone is the second terrestrial ecosystem that faces threats from climate change. This zone exists above the arid zone at elevations of 300+ meters. During the dry season, garua fog forms which shrouds this zone in humidity (WWF, 2016). As a result, the vegetation is lush and tropical. Ferns, sedges, Sphagnum mosses, orchids, and large trees dominate this zone (WWF, 2016). The humid zone is the most biologically diverse and on islands that are inhabited by humans, it has been used for agriculture (CI & WWF, 2011). As with the arid zone, an increase in precipitation will have negative effects on humid areas. Higher precipitation will alter vegetation growth rates, and certain species are not adapted to withstand excess water in the soil. For example, *Scalesia* forests experienced high mortality when their roots could no longer sustain the trees due to waterlogged soils (CI & WWF, 2011).

While climate change may be responsible for some of the changes currently occurring in the humid zone, the agriculture sector is just as guilty and conservation strategies include working with farmers to improve their land management practices. Conservationists suggest teaching farmers to limit the introduction of non-native vegetation into native areas (CI & WWF, 2011). Another strategy is to identify "drier" areas within the humid zone and protect them, so that species such as *Scalesia* will have a place to migrate if other parts of the humid zone become too wet (CI & WWF, 2011).

CLIMATE CHANGE AND THE HUMAN POPULATION/HUMAN INDUSTRY

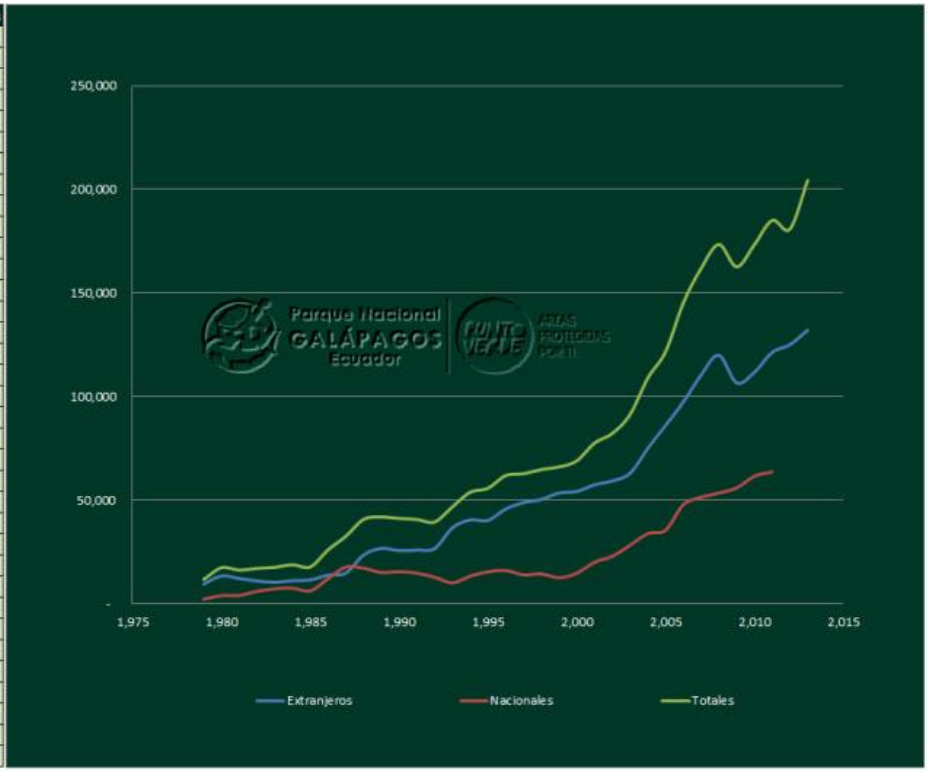
Climate change affects more than just the natural environment and the wildlife that lives within it. Approximately 25,000 people live in the Galápagos Islands and many of them depend on the tourism and fishing industry. Both of these industries rely on the natural environment, and climate change may threaten their viability in the near future (CI & WWF, 2011).

Most tourists travel to the Galápagos Islands for nature related reasons. The unique biodiversity and scientific significance make it a popular destination: over 200,000 tourists fly into Puerto Ayora each year (Parque Nacional Galápagos, 2014). The species that tourists usually expect to see are charismatic megafauna such as giant tortoises, sea lions, and blue-footed boobies. These species also happen to be most at risk from climate change; if they were to go extinct, the tourism industry would take a major hit (CI & WWF, 2011). Most tourists are international and spend more money than local tourists. In 2013, 132,199 tourists were international as opposed to 72,276 who came from the Ecuador mainland (Parque Nacional Galápagos, 2014). Funds from tourists aid conservation efforts – therefore, if the tourism

industry on the islands started to fade, the ecosystems that are protected with that money will only further decline.

Figure 3. Galápagos Park Visitors from 1979 to 2013

Años	Extranjeros	Nacionales	Totales
1,979	9,539	2,226	11,765
1,980	13,465	3,980	17,445
1,981	12,229	4,036	16,265
1,982	11,056	6,067	17,123
1,983	10,402	7,254	17,656
1,984	11,231	7,627	18,858
1,985	11,561	6,279	17,840
1,986	13,897	12,126	26,023
1,987	14,826	17,769	32,595
1,988	23,553	17,192	40,745
1,989	26,766	15,133	41,899
1,990	25,643	15,549	41,192
1,991	25,931	14,815	40,746
1,992	26,655	12,855	39,510
1,993	36,682	10,136	46,818
1,994	40,468	13,357	53,825
1,995	40,303	15,483	55,786
1,996	45,782	16,113	61,895
1,997	48,830	13,979	62,809
1,998	50,351	14,440	64,791
1,999	53,469	12,602	66,071
2,000	54,210	14,779	68,989
2,001	57,474	20,106	77,580
2,002	59,297	22,945	82,242
2,003	63,010	28,346	91,356
2,004	75,072	33,876	108,948
2,005	86,103	35,586	121,689
2,006	97,393	47,840	145,233
2,007	110,444	51,406	161,850
2,008	119,951	53,468	173,419
2,009	106,646	55,964	162,610
2,010	111,723	61,574	173,297
2,011	121,328	63,700	185,028
2,012	125,059	55,772	180,831
2,013	132,119	72,276	204,395



In a survey of 400 Galápagos tourists, 81.3% of respondents said wildlife was very important to their visit and they may not have come otherwise. The top three species that tourists hoped to see were tortoises, sea turtles, and marine iguanas – all of which declined during El Niño events and might decline further in the face of climate change (CI & WWF, 2011). However, even with the decline of several key species, tourism continues to thrive in the Galápagos. Those employed by the tourism industry have adapted to climate change because of transferable skills, reliable economic resources, and a network of people that are able to give support in times of hardship (CI & WWF, 2011). Since tourism in the Galápagos Islands has

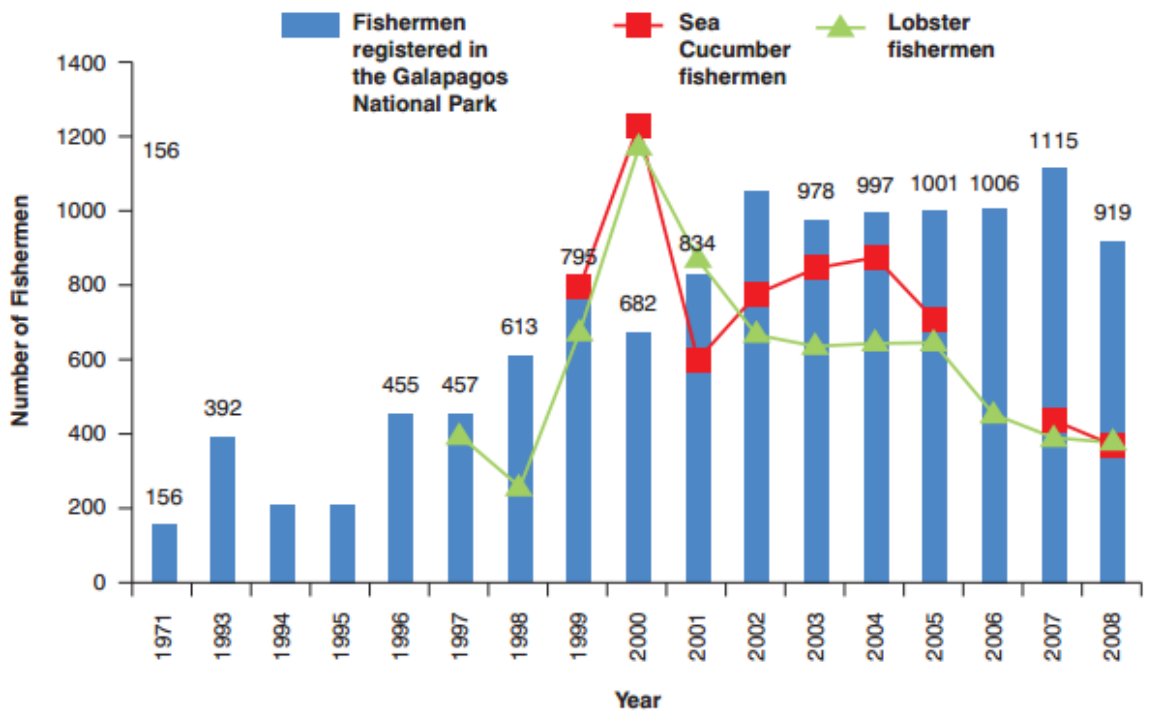
shifted towards more general nature tours, many tourists are unaware of species decline and will continue to visit the islands even if they do not see some of the species they were hoping to (CI & WWF, 2011).

Even though the tourism industry is currently stable, WWF and Conservation International have come up with strategies to ensure it remains sustainable moving forward. Conservation efforts should be aimed at key species, such as giant tortoises and sea lions, and the ecosystems they live in. In addition, business strategies should be devised that can address the uncertainty of climate change and help the Galápagos Islands maintain their reputation as a unique destination even if key species show decline (CI & WWF, 2011). Overall, more sustainable practices should be applied to the industry and educating individuals employed by the tourism sector on the effects of climate change is a step in the right direction.

Although only 3.55% of Galápagos residents are employed by the fishing industry, their livelihood will become threatened if climate change continues to have adverse effects on marine populations (CI & WWF, 2011). The demand for fish and other marine life increases as tourism increases, and most of the species being consumed are overfished as is. Species that are most vulnerable to overfishing and climate change alike are sea cucumbers, spiny green and red lobsters, and near-coastal demersal fish (CI & WWF, 2011). Efforts to conserve sea cucumber populations have been extremely effective. Between 2008 and 2009, only 368 fishermen harvested sea cucumbers because of the strict catch per unit effort that was implemented (CI & WWF, 2011). Spiny lobster numbers have also increased due to conservation efforts by the Galápagos National Park. Since coastal demersal fish (mostly grouper) populations have been overexploited, fishermen have started fishing further and further off-shore. If grouper

populations were to further decline, a moderate portion of fishermen would be negatively affected (CI & WWF, 2011). All three of these species are at risk due to ocean warming.

Figure 4. Numbers of registered fishermen in Galápagos National Park and active fishermen in the sea cucumber and lobster fisheries (CI & WWF)



To protect the fishing industry, sustainable harvesting guidelines need to be created, especially for the demersal fish in coastal zones. Other areas, such as seamounts and the mangrove forest, must also be protected because of the marine life that is being exploited there (CI & WWF, 2011). Overall, efforts should be made to educate fishermen, who have the lowest level of education on the islands. With higher education levels, fishermen can seek out other livelihoods in case the fishing industry ever collapses or becomes economically unviable (CI & WWF, 2011).

Throughout this paper, the effects that weather events and climate change will have on the Galápagos Islands have been analyzed. Although there is a certain level of uncertainty regarding climate change, El Niño events help illustrate how ecosystems might respond to dramatic climactic shifts. Research efforts must continue in vulnerable ecosystems, and organizations such as the Galápagos Conservancy and the Charles Darwin Foundation are in the midst of raising funds for such purposes. Although it is likely too late for climate change mitigation in the Galápagos Islands, the development of "Climate Smart" management practices that involve local decision makers and stakeholders are being introduced that aim to reduce human pressures and help the islands adapt (Galápagos Conservancy, 2016). The Galápagos Islands are undoubtedly one of the most unique ecosystems in the world; looking forward, it is imperative that they are managed properly and protected extensively in the face of a changing climate.

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