



Adapting to Climate Change in the Galápagos Islands



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Every several years, El Niño conditions hit the Galápagos Islands and the archipelago gets a glimpse into its future:

Temperatures rise, rainfall increases, ocean currents shift, and much of the islands' wildlife struggles to cope with these conditions. During past strong El Niño years, the populations of some of the islands' most iconic species—including marine iguanas, sea lions, and penguins—plummeted by 50 percent or more. The response of these species to El Niño, can be used to understand the effects of climate change to the Galápagos. Current scenarios predict that the future Galápagos climate will bring similar but prolonged and more intense conditions of those caused by El Niño events by the end of the century.

In this scenario, it is critical to understand future climate conditions in the Galápagos, and to identify immediate adaptation strategies to ensure species and ecosystems can survive and continue to provide goods and services for the benefit of the people of the Galápagos.

To address the vulnerability of the Galápagos to climate change and climate adaptation needs, the government of Ecuador is now creating a national adaptation strategy, with special focus on the Galápagos Islands. This strategy will not only protect the islands' vital resources, but will also serve as a model of adaptation planning globally.

The Galápagos Climate

Some 600 miles off the coast of Ecuador, a volcanic hotspot in the Pacific Ocean created the Galápagos Islands, which today consist of 13 large islands and over 100 smaller islands, islets, and rocks. The islands' unique array of life is made possible by a complex mix of oceanic currents that bring both warm nutrient-rich and cold water to the islands. Warm currents allow mangrove forests, coral reefs, and other tropical marine environments to flourish. At the same time, a cold, deep-water current creates an upwelling system that fuels a productive food chain that culminates with animals such as sea lions, sharks, and penguins.

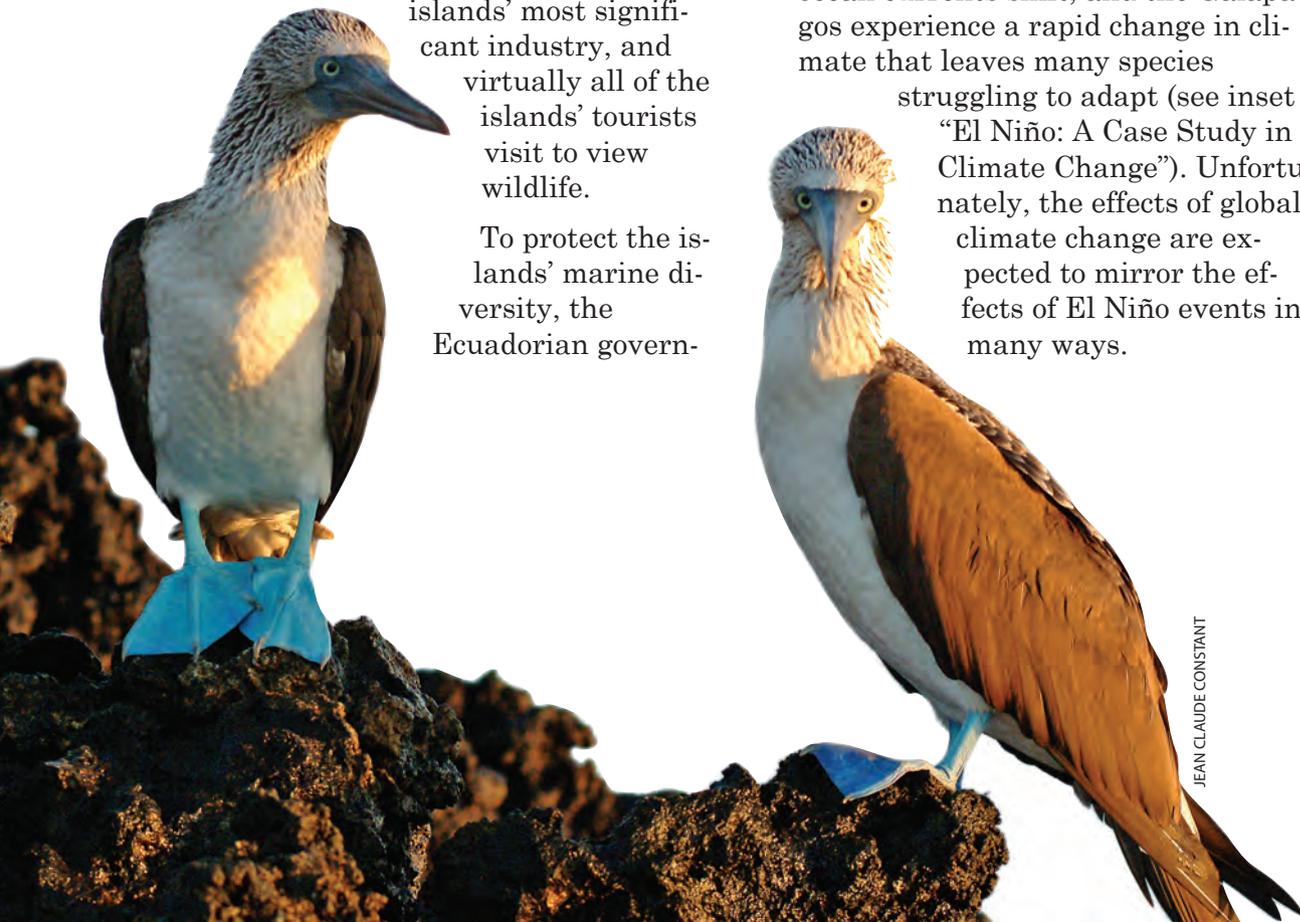
The islands also are home to a thriving—and growing—human population, almost all of whom depend on the islands' biodiversity for their economic security. Tourism is the islands' most significant industry, and virtually all of the islands' tourists visit to view wildlife.

To protect the islands' marine diversity, the Ecuadorian govern-

ment has established the Galápagos Marine Reserve, a protected area that spans over 83,125 square miles of ocean surrounding the islands and is one of the largest marine reserves in the world. About 20 percent of the nearly 3,000 species that live in the reserve are endemic.

On land, the Galápagos also house a large number of endemic species that are well adapted to the islands' unique climate. Seasonal weather patterns in the islands shift between a cool season from June to December and a hot season from January to May. During the cool season, most of the limited moisture is generated from a misty fog called *garúa*. The hot season is also rainy.

Every several years, however, everything changes with the onset of El Niño conditions. Wind patterns and ocean currents shift, and the Galápagos experience a rapid change in climate that leaves many species struggling to adapt (see inset “El Niño: A Case Study in Climate Change”). Unfortunately, the effects of global climate change are expected to mirror the effects of El Niño events in many ways.



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Accelerating Threats

As it has in many other parts of the world, the explosive growth of human activity in the Galápagos has taken a toll on native wildlife. Pollution levels have risen dramatically, while native habitats are on the decline. Native *Scalesia pedunculata* forests in the island's humid zone, for example, have already been so severely reduced that only a few hundred hectares remain.

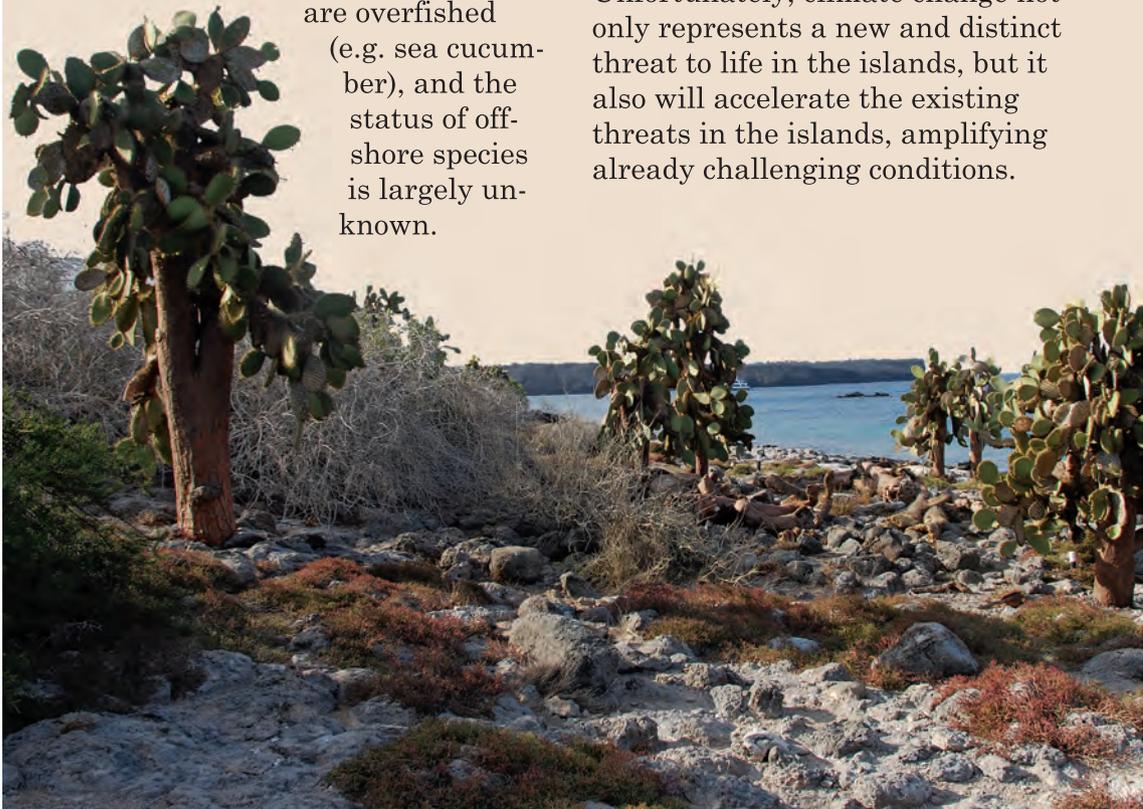
Threats are also continuing to increase in the ocean. Although the Galápagos Special Law, passed in 1998, limited fishing in the Galápagos Marine Reserve, enforcement of the law is weak, and overfishing has become a major threat. Almost all of the Galápagos commercially important coastal species

are overfished (e.g. sea cucumber), and the status of offshore species is largely unknown.

While these problems represent significant threats to the islands, perhaps the greatest threat to life in the Galápagos is introduced species. The growing number of tourists and residents in the islands, transported by boats and planes, inadvertently carry new species which outcompete endemic ones or alter the balance of the Galápagos ecosystems.

For example, invasive fire ants not only have displaced native insect species, but also have been observed attacking native wildlife such as sea turtle hatchlings. Today, nearly one-quarter of insects in the Galápagos are introduced, and invasive plant species on the islands now outnumber native species.

Unfortunately, climate change not only represents a new and distinct threat to life in the islands, but it also will accelerate the existing threats in the islands, amplifying already challenging conditions.



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What is likely to happen this century?

Higher Average Air Temperature:

The Intergovernmental Panel on Climate Change (IPCC) estimates that global average temperatures likely will increase 3.2 to 7.2°F (1.8-4.0°C) by the end of the 21st century (relative to the average temperature in the 1980s). Because the Galápagos are located at the Equator and surrounded by ocean, the islands likely will warm by at least the global average. Based on current commitments to warming, this almost certainly means a warming of at least 3.6°F (2°C).

Higher Sea Surface Temperature:

The temperature of the upper layers of the ocean is rising as the ocean absorbs the excess heat in the atmosphere. In 2009, the average global ocean surface temperature tied with 2002 and 2004 as the fourth warmest on record, at 0.48°C above the 20th century average. Waters surrounding the Galápagos are also expected to warm, both as a result of rising air temperatures and possible changes in ocean currents.

Increased Rainfall: Warming temperatures likely will result in an increase in rainfall in the Galápagos. The projected future pattern of rainfall in the Galápagos is similar to that seen in El Niño years. Data indicate that the islands' hot rainy season already has begun to gradually lengthen.

Sea Level Rise: Data indicate that the sea level in the islands could rise by approximately one meter by the end of the century. The net effect of sea level rise on each island is difficult to predict because volcanic activity is causing the land on some of the islands to rise (which would lower the impact of sea level rise) while land on other islands is subsiding (which would increase the impact of sea level rise). More research is needed to determine the overall potential impact of sea level rise on the Galápagos.

Ocean Acidification: About a third of the carbon dioxide that humans have added to the atmosphere has been taken up by the world's oceans, causing them to become more acidic. The IPCC estimates that by the end of the century, the ocean's average pH will drop 0.14 to 0.35 units. The process of ocean acidification impacts reef-building corals, with consequences for their growth and survival. This will likely cause a loss in biodiversity for the Galápagos.

As a result of these changes, climate scientists predict that the future Galápagos climate, on average, is likely to be more like what is now described as El Niño conditions. Around this new average, variability could include larger extremes, with El Niño conditions that are much more frequent or intense than they are today.

El Niño: A Case Study on Climate Change

Large-scale, rapid changes in the Galápagos climate already occur periodically with the onset of El Niño conditions every 2–8 years, when wind patterns and ocean currents shift in the Pacific Ocean. Because El Niño brings many of the same changes that climate change could cause, scientists use it as one tool to help predict how climate change could affect the islands.

In the ocean, El Niño causes a sharp reduction in the cold-water upwelling in the western part of the islands. Warm waters replace productive cold waters that normally occur with the upwelling, and without the current's rich nutrients, the food chain quickly breaks down.

The El Niño events of 1982-1983 and 1997-1998 were the most intense on record, and the effects on marine species were staggering:

- marine iguana populations declined up to 90 percent
- sea lions declined by 50 percent
- fur seals lost nearly all young under three years
- penguins suffered population losses of more than 75 percent

- flightless cormorant numbers declined by nearly half
- blue-footed booby breeding colonies were entirely abandoned.

At the same time, El Niño causes a dramatic increase in precipitation on land. The increased rainfall boosts plant production, which in turn boosts the populations of insects and animals higher on the food chain, such as snakes. While the wet conditions and booming plant productivity may at first glance seem beneficial to the islands, the new conditions can be difficult for species adapted to the normally dry islands.



The excessive rains of El Niño caused the collapse of *Opuntia* cacti. Their roots, which are shallow and were anchored in loose mud because of the water, could not sustain the enormous weight of the cacti's canopies, which were overloaded with fluid. Another long-lived species, giant tortoises also suffered from the wet conditions. A giant tortoise that fell into a creek filled with water and died during the El Niño of 1997-1998 was reported, and many of the tortoises' nests became too wet to maintain their eggs at the correct temperature, causing a decline in reproduction.

In addition to threatening native species, the wetter conditions also help introduced species become established and flourish. Invasive

ants and wasps, for example, expand their ranges considerably during El Niño events.

Climate scientists are quick to point out that El Niño is not the same as climate change. El Niño effects are relatively short-lived, typically lasting a year or less, while climate change represents a longer-term, and more permanent, shift. But because the effects of El Niño are much the same as the effects projected under climate change, it's helpful to look to the impacts of El Niño for clues to how species might react to longer-term climatic changes.

Climate models suggest that El Niño events will continue, and could possibly become more frequent or intense, as climate change advances.



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Vulnerabilities in the Islands

Virtually every aspect of life in the Galápagos will be affected by climate change. Adapting to this new reality now will help minimize the costs of adaptation and maximize the benefits. The following tables provide examples of some of the ways that the islands' ecosystems, economic sectors, and key emblematic species are likely to be affected by climate change, and what can be done to help address their vulnerabilities.

Ecological Vulnerabilities of the Galápagos Islands

Terrestrial Ecosystem	Vulnerability	Key adaptation actions
The Humid Zone		
<p>The cold trade winds of the southwest reach the islands full of humidity. Upon reaching the islands, they rise and find warmer, drier air, which results in condensation in the form of garúa. This only affects the southeastern portions of the higher islands. The humid zone allows the development of agriculture in the inhabited islands and is the most biologically diverse habitat of the islands' terrestrial ecosystems.</p>	<p>Higher precipitation could threaten the humid zone by changing vegetation growth rates and forest structure. <i>Scalesia</i> forests reported high mortality, possibly due to the tree roots losing their ability to sustain the trees, because of excess water in the soil. Increasing temperatures will cause many species to shift their ranges to higher elevations. Species restricted to the very tops of mountains may have nowhere else to go.</p>	<p>Work with the agricultural sector to improve land management practices, with particular attention to limiting the expansion of non-native plants into native ecosystems. Identify and protect the "drier" areas of the humid zone, as these may become refuges for humid-zone species (such as <i>Scalesia pedunculata</i>) as the rest of the humid zone becomes wetter.</p>
The Arid Zone		
<p>Most of the islands' surface lies at relatively low elevations where fresh water is scarce, in what is referred to as the arid zone. The land here is almost like a desert, with plants and animals such as cacti and iguanas well adapted to life in these conditions. Most of the islands' endemic species are found here.</p>	<p>Increasing rainfall threatens arid-adapted species. Wetter conditions also may favor the establishment of more introduced species in this zone, which previously has been too dry for most new species to thrive. Even species native to the islands but not typically found in the arid zone might move into arid zones as they become wetter, creating species invasions and competition.</p>	<p>Limit invasive species introductions, and assist native species as they shift their ranges into areas that become more suitable. As in the humid zone, the driest areas of the arid zone may become refuges for typical arid-zone species. These areas should be identified and managed accordingly.</p>

Ecological Vulnerabilities of the Galápagos Islands

Marine Ecosystem	Vulnerabilities	Key adaptation actions
Upwelling Zone		
<p>A dense, deep-water current carrying cold, nutrient-rich water across the Pacific hits the western Galápagos islands and abruptly wells up to the surface. The nutrients fuel a highly productive food chain that starts with microscopic plants and animals and continues through large predators such as sea lions, hammerhead sharks and penguins.</p>	<p>Upwelling areas could be reduced as a result of climate induced ocean warming. Past reductions in the upwelling associated with El Niño led to dramatic declines in productivity that extended from the bottom of the food chain through fish populations and up to marine cormorants, penguins, sea lions, marine iguanas, and other species. (See “El Niño: A Case Study in Climate Change” inset.)</p>	<p>Establish “No-Take Zones” in upwelling areas to monitor and control fishing pressure during periods of weakening of this phenomenon.</p>

Coral Reef Ecosystems

Warm, tropical currents create the conditions needed for coral reefs. Cold-water coral species also can be found in upwelling areas where temperatures are lower. Coral and rocky reefs create a subtidal fringe around the islands. Due to the unique oceanographic conditions of the Galápagos, coral formations are reduced and confined to areas in the Northern islands (i.e. Wolf and Darwin).

Coral reefs are threatened by rising ocean temperatures, ocean acidification, and human pressures. As temperatures rise, some cold-water corals could be replaced with warm-tolerant species. Acidification of the waters surrounding the islands is expected to limit coral growth. Past strong El Niño events have decimated coral populations: The 1982-83 El Niño led to an estimated 97 percent mortality of reef-building corals. El Niño events and declining fish populations also have contributed to the formation of sea urchin barrens.

Improve coordination and enforcement in marine protected areas in the Galápagos and coastal Ecuador to protect coral larvae after extreme El Niño events. Establish monitoring programs on coral reefs to document their responses to extreme events and help establish their capacity to adapt to climate change. Identify areas that are least affected by El-Niño-related bleaching events and establish “Restricted Access Zones” in these areas so that corals can recover without human stressors. Explore the feasibility of using artificial substrates and transplantation to reestablish coral communities in degraded areas.

Ecological Vulnerabilities of the Galápagos Islands

Marine Ecosystem	Vulnerabilities	Key adaptation actions
Mangrove Forest		
<p>Mangroves create a coastal transition from ocean to land. The trees' stilt-like roots create a nursery for many of the islands' most commercially important fish species. Overhead, the trees provide cover for a variety of birds, including the mangrove finch, a critically endangered species native to the islands' mangroves. The trees also slow or eliminate erosion from waves and storm surges, helping protect the islands' coastal developments.</p>	<p>Mangroves are threatened by the coastal flooding and erosion associated with sea level rise. Forests could shift inland as sea level rises, but those areas where the forests are bordered by human developments or other impediments could be lost.</p>	<p>Create and implement guidelines for coastal development to minimize its impacts on mangroves. These plans should include buffer zones behind current areas of mangroves to allow room for natural migration. These plans also should take into account the important role that mangroves could play in protecting the islands under climate change scenarios in which sea level rises and storm activity increases. Also, promote the use of best management practices to protect fisheries dependent on mangrove forests for part or all of the fishes' life cycle.</p>



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Vulnerabilities of Key Industries

Industry	Vulnerabilities	Key adaptation actions
Tourism		
<p>Tourism is the most significant economic activity in the Galápagos, accounting for over 75 percent of the islands' economy, and employing some 40 percent of the islands' inhabitants. Tourism in the islands is almost exclusively nature-based. According to a recent survey of Galápagos tourists, over 80 percent of tourists consider wildlife very important to their decision to visit the islands.</p>	<p>Climate change is expected to threaten all of the species that research shows are most important to tourists (see "Key Species" table). Severe declines in these species could lead to either a reduction in tourism or a shift from nature-based tourism to more mass-market, resort-based tourism. Such a shift would further threaten wildlife species, as this style of tourism likely would require additional urban development and natural resources and result in increased habitat loss and pollution.</p>	<p>Protect emblematic species that support nature tourism (see "Key Species" table) to ensure the sustainability of the islands' tourism-based economy. Regulate tourist access in vulnerable areas or during the breeding seasons of sensitive species. Adopt sustainable ecotourism approaches—including infrastructure development, freshwater conservation, and waste management—to protect species and habitats.</p>
Fishing		
<p>Although the fishing industry is not nearly as economically influential as the tourism industry—fishing generates \$5 to \$6 million annually, an amount that represents less than 4 percent of the islands' total economic activity—it is nevertheless a vital part of Galápagos society. Fishermen in the islands harvest sea cucumbers, lobsters, grouper (locally called <i>bacalao</i>), and several other species within the Galápagos Marine Reserve's coastal waters, and also target large offshore species such as yellowfin tuna and wahoo. The fish catches within the islands supply local inhabitants and tourists with fresh seafood and also are exported to the world market.</p>	<p>Rising ocean temperatures could reduce the abundance of already-overfished cold-water fish while increasing the abundance of warm-water fish. Changes in upwelling also could reduce the abundance of many fish species.</p>	<p>Strengthen fisheries management to reduce pressure on marine resources and increase ecosystem resilience to climate change. In anticipation of a shift from coastal to offshore fishing, regulate offshore fisheries, including establishing "No-Take Zones" where needed. Ensure access to credit for fishermen upgrading equipment to shift from coastal to offshore fishing. Improve educational opportunities for fishers leaving the fishing industry so they can better compete for jobs in the tourism and service sectors.</p>

Vulnerabilities of Key Species

Species	Vulnerabilities	Key adaptation actions
Giant tortoises	 <p>During the El Niño of 1997-98, tortoises were washed away by floodwaters in the creeks. Higher temperatures could trigger altitudinal migrations and could reduce nesting success. Increases in invasive insect species such as fire ants could lead to increases in predation on hatchlings, reducing hatchling survival.</p>	<p>Maintain vegetation along creeks so that tortoises are not washed away during high rainfalls. Control invasive species such as fire ants. Consider beach shading to regulate nest temperatures and maintain hatchling sex ratios.</p>

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Sea Turtle



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Sea turtles are most threatened by reductions in algae, their main food source. Higher temperatures could interfere with egg development, favoring the development of females or causing embryos to die. Beach flooding and erosion from El Niño and sea level rise are another significant threat. Green sea turtle nesting declined sharply during the 1982-83 El Niño.

Protect nesting beaches. Provide shade in nesting sites to help maintain sex ratios.



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Vulnerabilities of Key Species

Species	Vulnerabilities	Key adaptation actions
Marine Iguana	 <p>Marine iguanas are most threatened by a reduction in algae, but also are threatened by rising air temperatures that interfere with egg development, and beach erosion and flooding that could prevent nesting. During the 1997-98 El Niño, marine iguana populations suffered 90 percent mortality. Changes in air temperature could interfere with iguanas' ability to regulate their body temperature while on land.</p>	<p>In other parts of the world, native plant species are being planted to help shade beaches and provide refuge to species and their eggs. As air temperatures rise, marine iguanas in Galápagos might also require shading from artificial shelters or native plants to lower their body temperatures and protect their eggs.</p>

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Blue-Footed Booby

	<p>During El Niño events, boobies have abandoned breeding colonies and increased migrations outside the Galápagos Marine Reserve in search of food. Flooding associated with future El Niño events and sea level rise could cause nest losses. Reductions in upwelling could cause severe declines in prey items.</p>	<p>Regulate fisheries' catches of key booby prey species during El Niño years. As sea-surface temperatures increase, permanent closures of some fisheries may be necessary.</p>
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Vulnerabilities of Key Species

Species	Vulnerabilities	Key adaptation actions
<p>Penguin</p>  <p>LEE POSTON / WWF</p>	<p>Past strong El Niño events have caused mortalities of up to 77 percent, with dramatic declines of prey species and reduced breeding success. Reduced upwelling could cause severe declines in prey items, and flooding associated with sea level rise or future El Niño events could cause nest losses. Higher temperatures and rainfall could favor pathogens such as <i>Plasmodium</i>.</p>	<p>Artificial nesting burrows have been used for similar species of penguins in other parts of the world, and consideration should be given to whether these might help Galápagos penguins cope with rising temperatures and nest flooding. Regulations limiting catches of penguin prey species may need to be considered in some years. Control introduced mosquitoes which are vectors for the avian malaria impacting penguin populations.</p>
<p>Sea Lion</p>  <p>LEE POSTON / WWF</p>	<p>Sea lions are especially sensitive to a weakening of the western upwelling. During past strong El Niño events when the upwelling dwindled, sea lion populations declined by up to 50 percent, and up to 90 percent of pups died. Populations can take up to 10 years to recover from strong El Niño events.</p>	<p>Use fisheries regulations to limit catches of sea lions' prey species during El Niño years.</p>
<p>Land Iguanas</p>  <p>EUNICE PARK / WWF</p>	<p>Changes in air temperature could interfere with iguanas' ability to regulate their body temperature. Changes in rainfall distribution and amounts could reduce nesting success and hatchling survival. The spread of introduced insects such as fire ants could further threaten nesting success and hatchling survival.</p>	<p>Like other reptiles in the islands, land iguanas may require shading from plants or artificial structures to provide thermal refuge. Control the spread of the invasive fire ant.</p>

Key recommendations for adapting to climate change impacts

The extent of losses to the diversity of life in the Galápagos, and, in turn, to the people who depend on those resources, will depend on how quickly and strategically the islands prepare for the coming changes. Climate change has already altered the balance of the oceans with serious and irreversible consequences for marine ecosystems and the services they provide. Therefore, it becomes imperative to take actions to increase the adaptive capacity of coastal marine ecosystems and the people that depend on them. Adapting is the only solution to ensure ecosystems and human societies can survive and maintain their wellbeing when exposed to climate change impacts. Adaptation planning in the Galápagos should consider the following broad principles that reflect the unique economic and ecological conditions in the islands.

Protect especially vulnerable species and ecosystems

Strengthen management measures to reduce existing pressures on marine resources, increase ecosystem resilience and integrate the management of coastal marine resources and continental protected areas with that of Galápagos. Protect climate vulnerable species, such as those that depend on the coastal zone for nesting and breeding.

Protect emblematic species to sustain tourism

Species such as giant tortoises, Galápagos penguins, and blue-footed boobies draw tourists that not only support thousands of Galápagos families, but also help fund local governments and conservation work in the islands. Protecting these species with actions that address the specific threats each face would have far-reaching economic and conservation benefits.



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Strengthen the quarantine system to limit the introduction of invasive species

Regulate cargo access from the mainland to limit introduction of pests and invasive species. Adopt clean-cargo protocols in ports that service the islands, and develop better procedures to detect and respond to pests on arriving vessels.

Improve management of coastal and offshore-water fisheries

Improve management of fisheries and establish offshore no-take zones to anticipate shifts in fishing pressure as climate change will induce coastal fish stocks to move away from coastal waters due to increase in ocean temperature and increasing fishing pressure.



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Promote climate research and establish climate-response monitoring protocols

Establish a monitoring and early warning system to detect the impacts of climate change on the ecosystems and species of the Galápagos. Promote research to fill in gaps on how species and ecosystems may respond to climate change and to enable managers to take adaptation actions.



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Adopt a sustainable eco-tourism approach and coastal development

Promote the use of freshwater conservation, waste management and boat operations to avoid loss of species (sea turtles) and habitat (e.g. mangroves, coral reefs). Implement guidelines and best practices for coastal and foreshore development planning that take into account the potential for increased storm activity, salt water intrusion, and other climate change impacts. Improve and retrofit existing infrastructure to make sure they can sustain climate impacts.

Improve education opportunities and promote community awareness

Education and awareness are key strategies to increase language and communication capacity that will enable people in the Galápagos to occupy jobs in the tourism and service sectors or by providing credit lines to allow a shift from coastal to offshore fishing, which requires sturdier, better-equipped boats. Outreach programs can help create awareness and engage communities on climate.



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Building upon a strong foundation of science, partnership and field demonstration, CI empowers societies to responsibly and sustainably care for nature, our global biodiversity, for the well-being of humanity.

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