Photo: Jacintha Castora Photography

Galapagos in the face of climate change: considerations for biodiversity and associated human well-being

Noémi d'Ozouville[1], Giuseppe Di Carlo[2], Fernando Ortiz[1], Free De Koning[1], Scott Henderson[1,2] and Emily Pidgeon[2]

[1]Conservation International – Ecuador, [2]Conservation International

Introduction

The Galapagos Archipelago provides a globally-unique 'field laboratory' for assessing the effects of climate change on biodiversity and a small local community. The species and ecosystems of Galapagos undergo cyclical climate shifts in accordance with the strength of El Niño seasons, which occur every two to eight years. Extremes in climate and oceanic conditions include rising sea levels and soaring sea surface temperatures. Some loss of biodiversity has apparently already occurred and future losses may be accelerated by the increasing impact of climate change upon the already stressed ecosystems (due to over-fishing, tourism, and invasive species). These losses will directly impact the local human communities as their livelihoods are primarily dependent on these threatened natural resources (Figure 1). Although local mitigation actions and increased local awareness programs about climate change should be encouraged as a general policy, such actions will not have an impact at a global scale. Attention must be directed to increasing the adaptation capacity of the local communities and, at the same time, reducing the vulnerability and increasing the resilience of the ecosystems. Responding to climate change should be used as an opportunity to bring together both biodiversity conservation and the health of the community through a unified adaptive management approach.

This article summarizes the results of the Galapagos Climate Change Vulnerability Assessment Workshop, held in Puerto Ayora,

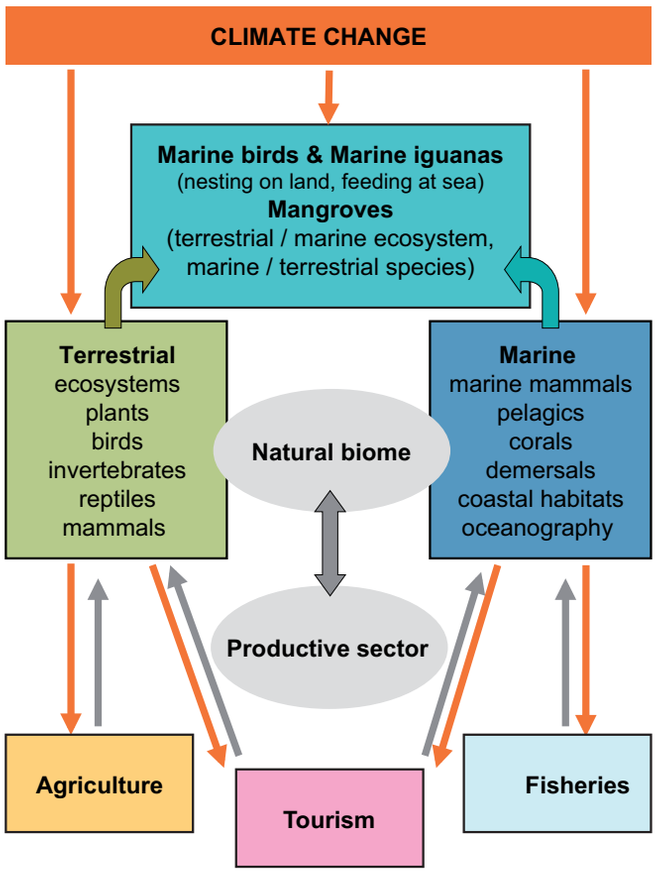

Figure 1. Theoretical diagram of potential impacts of climate change on Galapagos systems and interactions between the different components.

Galapagos, April 20-23, 2009. Over 70 participants attended the workshop, representing local, national, and international experts and scientists, local and national stakeholders, and representatives from the business sectors. The objectives of the workshop were: (i) assess existing local scientific, technical, and socioeconomic information on climate change; (ii) assess potential impacts of climate change on local ecosystems, biodiversity, and human well-being; and (iii) formulate response strategies, focusing primarily on adaptive management.

Galapagos and climate change

The Galapagos Archipelago is located within the Eastern Tropical Pacific. Key elements that characterize the Galapagos climate are: (i) the South-East tradewinds; (ii) the interaction of four warm and cool oceanic currents, including a strong subsurface current and areas of upwelling; and (iii) the climatic variability related to the El Niño Southern Oscillation (ENSO) phenomena.

Potential physical and chemical changes in the tropical Pacific Ocean resulting from global climate change will play a vital role in controlling future shifts in biology and ecosystem dynamics within Galapagos. The workshop reached a consensus that the most critical parameters will be an increase in the strength of ENSO events and a reduction in the strength of upwelling currents. Scientific studies predict that changes in water properties and circulation could impact nutrient supply, larval dispersal, and the distribution of habitat zones. Changes in wind and rainfall patterns will affect seasonality, growth patterns of vegetation, and breeding patterns and distribution of native and introduced wildlife.

The Galapagos Archipelago and the Galapagos Marine Reserve straddle two distinct El Niño (EN) Regions (Figure 2). EN Region 3, to the west of the archipelago, is influenced by the upwelling of the Equatorial Counter Current and the Cromwell Current, while EN Region 1+2 is influenced by the Humboldt Current. Predicting climate change impacts on the Galapagos at local and regional scales is difficult because of this complex setting and also due to the lack of long-term data. The currently available scenario modeling of the Intergovernmental Panel on Climate Change (IPCC) focuses primarily on the EN region 3.4, which extends west of Region 3, from 120ºW to 170ºW.

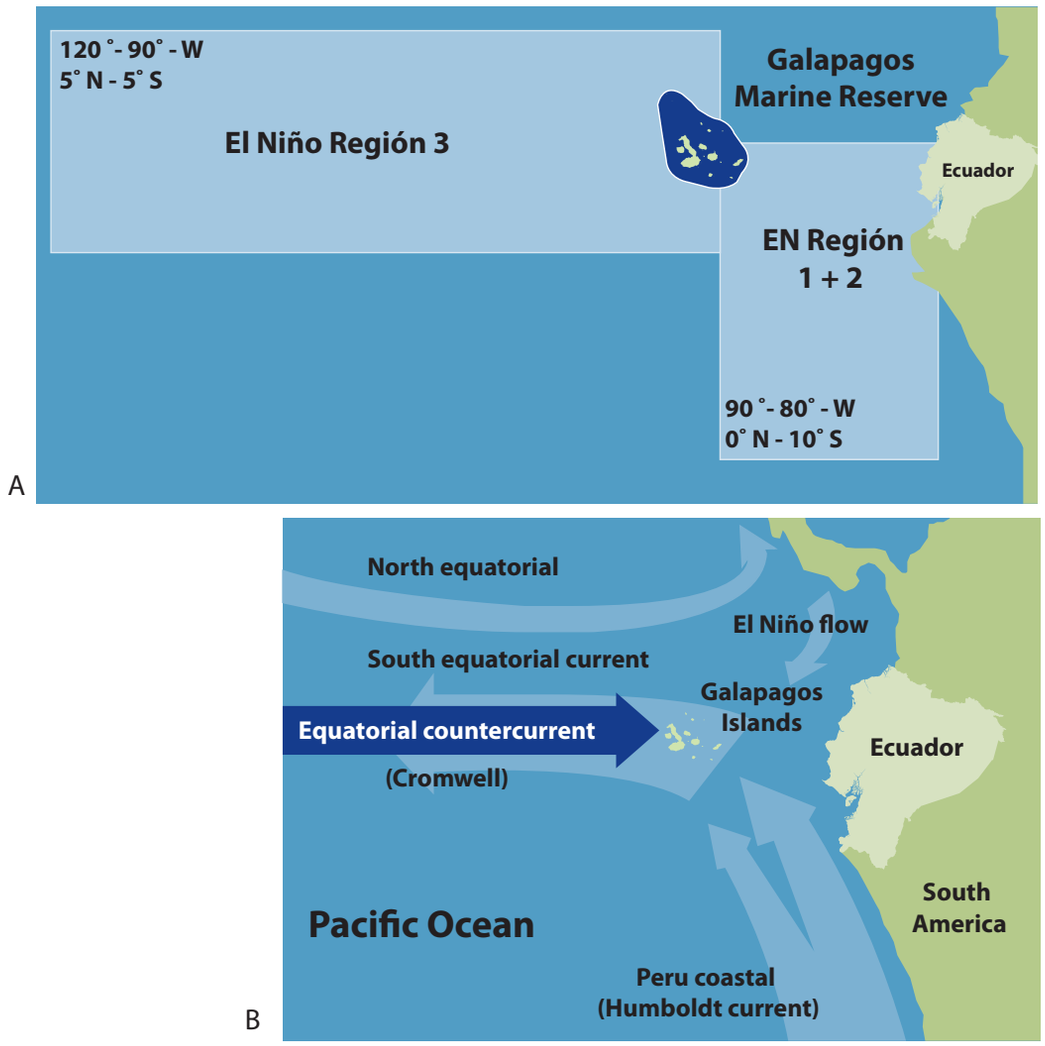

Figure 2. (A) Galapagos Archipelago in relation to the different El Niño Regions based on NOAA definitions (from CDF, 2009); (B) the oceanic currents that bathe the archipelago (www.galapagosexplorer.com). EN = El Niño.

Analysis of trends, modeling, and predictions

Long-term data sets are fundamental for determining trends in physical climate indicators, such as sea surface temperature (SST), sea level (SL), and precipitation. These data sets can then be used to carry out predictive modeling under given scenarios, such as those presented by the IPCC. Long-term climate data sets for Galapagos, with up to 55 years of data for some parameters, have recently been compiled and analyzed (Martinez, 2009; CDF, 2009). The data includes *in situ* observations and measurements, data collected during oceanographic cruises, and data obtained from satellite observation and from the scientific literature. Results of the analysis showed no definite trend in SST, SL, or precipitation in Galapagos over the last 40 years.

However, four interesting observations emerged from the analyzed data:

1. The extremes of SSTs (cool season and hot season) show a diverging trend.

2. Internal variability, including ENSO and Pacific Decadal Oscillation (PDO), dominates the analysis and masks any impact of external forces related to climate change (Figures 3 and 4).

3. Specific regions within Galapagos should be evaluated separately in terms of climate change impacts: western, central, and eastern.

4. The range in spatial and temporal variability in Galapagos due to ENSO and PDO, including SST and SL rise, is as great as the predicted changes under global climate change scenarios over longer time scales, suggesting that the local ecosystems have an inbuilt resilience to a certain degree of change.

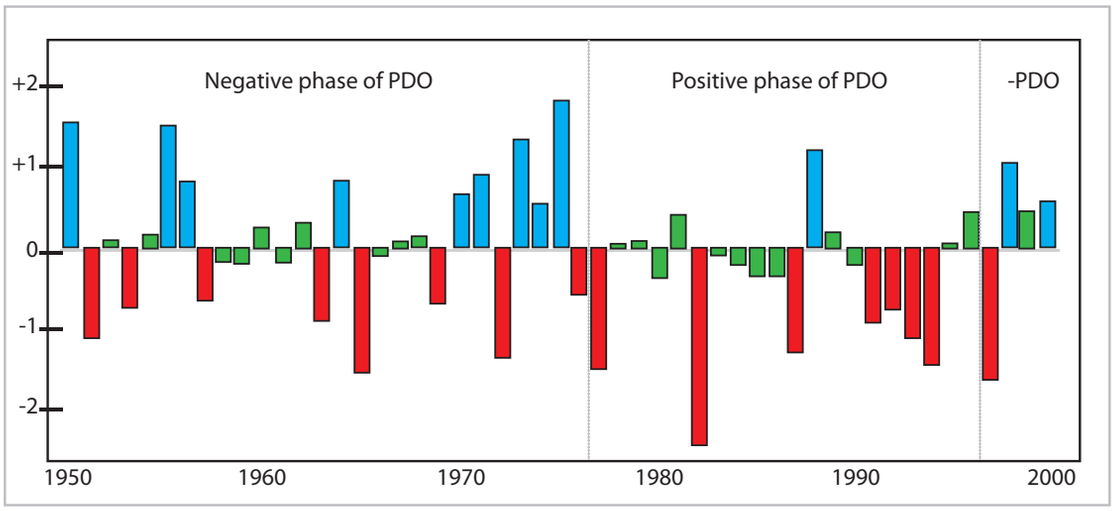

Figure 3. Time series of Southern Oscillation Index (SOI). El Niño events are colored red while La Niña's are blue. Green bars represent neutral years of SOI. Notice the decreased number of La Niña events during the positive phase of the Pacific Decadal Oscillation (PDO) (from Martinez, 2009).

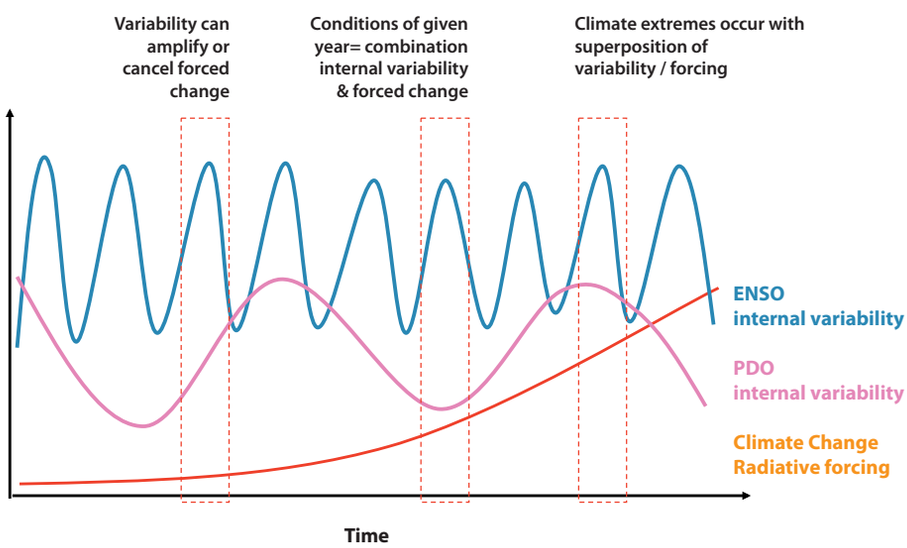

Figure 4. Diagrammatic representation of additive and subtractive combinations of different signals affecting the Galapagos climate.

Global climate change models tend to show a decrease in tropical atmospheric and oceanic circulation (Vecchi and Soden, 2007), resulting in an increase in precipitation and a decrease in upwelling. A predictive model has been run for Galapagos using the IPCC AR4 SRES A1B Emission Scenario. However, the interpretation and validity of the results are limited, as only one scenario has been used to date (Xie *et al.*, 2009).

Internal variability within the Galapagos system (resulting from ENSO or PDO cyclic events or annual seasonal changes at a smaller scale) occurs alongside external influences, such as the positive trend in radiative forcing related to global warming and climate change (Figure 4). At certain times, the magnitude from the different signals may combine in ways that mask a rising trend while at other times the combination of signals may exacerbate peak intensities giving rise to potentially disastrous climatic extremes. It should be noted that the relative magnitude of ENSO is probably much greater than that of the PDO in the Eastern Tropical Pacific.

Experts participating in the Vulnerability Assessment workshop reached consensus on several key points regarding physical oceanography changes in Galapagos, which include both climatic and non-climatic changes (Table 1).

Table 1. Summary of likely physical oceanography changes in Galapagos agreed to in the Vulnerability Assessment workshop.

Physical phenomena	Likely change	Other observation
El Niño / La Niña	Continued variability, some intense	
Sea Level Rise	More likely than not	No current trend
Ocean acidification	Likely problem	Already high due to presence of upwelling zone
Region SST	Surface ocean warming	
Local SST	Warming more likely than not	
Upwelling	Reduction more likely than not	Especially from Equatorial undercurrent
Precipitation	Increase more likely than not	

Climate impacts on marine ecosystems

The marine ecosystems of Galapagos are characterized by having a natural resilience to abrupt changes in temperature and sea level at certain temporal scales. However, as these changes intensify (becoming more frequent, abrupt, and sustained), their impact on the ecosystems, already stressed by overuse, overfishing, contamination, invasive species, and fragmentation, could be disastrous.

Reduced localized upwelling will result in decreased nutrient input into surface waters with major consequences at all trophic levels, especially top predators (sharks, penguins, pelagic fish, whales, and sea lions). This could also lead to significant long-term decreases in fisheries, already observed during strong El Niño events.

Sea level rise will affect species that nest on beaches, such as sea turtles and marine iguanas, through coastal erosion and flooding. Coastal nesting species will also suffer greater losses if the current stress by introduced predators, such as rats and cats, is not reduced. Although current trends for sea level rise in Galapagos are not yet significant, swell surges, locally know as *aguajes*, will likely cause the greatest impact. Housing infrastructure along the coast, such as along Academy Bay in Puerto Ayora, will be at risk.

Increasing sea temperatures across the archipelago may result in warm-water-tolerant corals displacing cold-water species and the migration of more tropical Pacific fish species into the northern waters of Galapagos. In addition, extreme or sustained El Niño events may cause local coral extinctions through bleaching and put even greater pressure on the larger pelagic fish.

Overall, climate change will impact many of Galapagos marine species. Among marine megafauna, fur seals appear to be the most vulnerable to increased variability related to climate change, while scavengers (e.g., lava gulls) seem to benefit from periods of warming. Organisms that reproduce all year, such as sea cucumbers *(Isostichopus fuscus*), are less vulnerable than species whose reproductive season is limited to a specific time of year, such as lobsters. However this only holds true for those species not dependent on cold-water spawning conditions or areas. In general, cold-water corals and upwelling systems will likely be the communities most vulnerable to climate change, including in particular the northern region surrounding Wolf and Darwin Islands and the western archipelago (Isabela and Fernandina).

Climate impacts on terrestrial ecosystems

In an attempt to understand the impact of climate change on the complex terrestrial ecosystems of the Galapagos Islands, these were divided primarily into the arid zone and the humid zone. Precipitation, more so than temperature, is predicted to be the main factor impacting these ecosystems. Although the humid zone on the inhabited islands has been largely modified by land-use changes related to agriculture, this zone is considered more resistant to change than the arid zone because it is dependent on cold season humidity and *garúa* and less dependent on hot season rainfall. However, if El Niño events intensify and sea temperatures are persistently higher, it is likely that *garúa*

precipitation will disappear and heavy rainfall will increase. On the other hand, the arid zone is more vulnerable because changes in hot season precipitation can have drastic consequences on the flora and fauna assemblages. This zone, which until now has been inhospitable to most invasive species, could become hospitable under different climatic conditions.

Two examples of native terrestrial ecosystems especially susceptible to increased precipitation, as observed during extreme El Niño events, are the Scalesia forest in the humid zone and the Opuntia forest in the arid zone. In both cases, the die-back in these dominant species negatively impacted the many species dependent on them.

An increase in both the number and distribution of invasive species and diseases is a major concern in many of the different climate change scenarios, especially if El Niño events become more frequent or intense. Many of the invasive species are better adapted to respond to the associated changes of wetter, warmer conditions and may have an even greater impact on native and endemic species and habitats. For example, *Wasmania* fire ants and *Polistes* wasps increased their ranges considerably during past El Niños. Growth and spread of guayaba (*Psidium guajava*), an invasive fruiting tree, as well as blackberry (*Rubus niveus*) and lantana (*Lantana camara*), are enhanced by increased rainfall during El Niño events.

Climate impacts on human well-being

As marine and terrestrial ecosystems become affected by climate change, direct repercussions will be felt within the human society, from both economic and quality of life perspectives. The three primary economic sectors of Galapagos (tourism, fisheries, and agriculture) depend upon the natural resources and current climatic conditions. Global climate change will likely result in negative impacts on the unique flora and fauna of Galapagos potentially resulting in at least local extinctions, on the commercial marine resources, and on the soil, water, and climatic conditions of the windward slopes of the inhabited islands. An increase in the distribution and abundance of invasive species, including diseases, will not only affect the unique flora and fauna of Galapagos, but also agriculture and human health. All of this will have negative economic repercussions within Galapagos society and potentially for Ecuador. It is important to strategically strengthen each economic sector so that it is more resilient, including potential shifts in the types of tourism offered, fishing methodologies used, and types of crops grown.

Quality of life, including health, infrastructure, and vital resources (water, energy, waste management), among others, will be negatively impacted as global climate change intensifies, unless necessary precautions are taken. Higher temperatures and increased precipitation (almost certain to continue) will result in increased dispersal of mosquitoes, vectors for serious diseases, and the risk of epidemics such as dengue (already present in Galapagos) and eventually yellow fever and malaria (not yet present in the islands). The current conditions in the communities of Galapagos, including poor healthcare, sanitation, water quality, and little to no urban planning, will exacerbate these risks. Urban planning strategies to ensure improved construction methods, especially along the coastal corridor, must be initiated. These must include planning for flash floods in both inland and coastal towns and higher sea levels. Watershed management and water quality controls must be implemented in the near future to avoid potential disaster.

A last consideration regarding the impacts of climate change on human well-being in Galapagos is that migration pressure from the mainland could increase to unprecedented levels if the climate change impacts on the mainland (for example flooding of lowlands in coastal areas and desertification in the *páramo*) generate a large number of "environmental refugees." Historically, waves of human migration to Galapagos have resulted from local disasters in continental Ecuador. Currently this can be seen in the current migration from the Tungurahua province due to on-going volcanic eruptions.

Recommendations and adaptive management

The aim of the workshop was to generate recommendations and lines of action that will lead to adaptive management decisions to help prepare Galapagos ecosystems and Galapagos society to confront climate change (Table 2). These recommendations fall under two general goals:

- Build inter-institutional support and engage all stakeholders

- Increase ecosystem resilience to meet changing climatic conditions.

Table 2. Summary of key recommendations proposed by the Vulnerability Assessment Workshop and related lines of actions or adaptive management.

Recommendations	Lines of action/Adaptive management
Establish an inter-institutional monitoring and early-warning system to detect impacts of climate change in Galapagos.	• Generate joint databases and baseline data on oceanographic and climatic conditions. • Fill in data gaps in knowledge of physical processes (such as cool season weather dynamics).
Protect endangered species nesting sites to improve population resilience.	• Create more penguin nesting areas with artificial nesting boxes. • Increase shading of nesting beaches for marine iguanas and turtles through natural or artificial means.
Support the recommendations of the fisheries management chapter within the GMR Management Plan to create and implement fisheries regulations for open water species.	• Encourage a sustainable shift from coastal to open water fisheries. • Develop a "climate smart" marine protected area in terms of its management.
Prevent and control an increase in number and dispersal of introduced and invasive species that may result from climate change.	• Strengthen the quarantine systems: single docking harbor in Guayaquil, fumigation of cargo boats, and control of boat lights.
Promote reforestation and restoration of key ecosystem functions and ecological connectivity.	• Provide local support to agricultural sectors. • Involve community in watershed based management.
Improve social resilience through urban planning and watershed management.	• Support climate-smart urban development and planning. • Create incentives for rainwater harvesting and freshwater management.

Conclusions

The oceanic setting of Galapagos at the confluence of warm and cold water currents has given rise to the unique ecosystems and biodiversity that we know today. This same setting means that the impacts of climate change will be different here than anywhere else in the world. It is critical that the people of Galapagos prepare for these potential changes. As our ecosystems are stressed locally and our planet globally, both native and invasive species may not respond as they have in the past, due to even greater climatic extremes, increased variability, and long-term impacts. Our livelihoods will be heavily impacted not only by the physical implications of climate change but also the repercussions on the natural resources we depend on. In addition, the local community, Ecuador, and the world have a responsibility to ensure the future survival of the Galapagos World Heritage Site.

As a concluding result of the workshop, a Santa Cruz Declaration was unanimously supported by local and national authorities (Ministry of Environment, Galapagos National Park, National Oceanographic Institute, AGROCALIDAD-SICGAL, and the Municipality of Santa Cruz) as a commitment to ongoing involvement in the process of understanding the consequences of climate change and the roles of the local communities and managers to take global warming into account in decision-making processes.

This declaration and other useful resources relating to this article can be found at:

http://marineclimatechange.com/Marine_Climate_Change_Workshops/Galapagos.html