ADAPTACIÓN CAMBIO CLIMÁTICO
PACÍFICO ORIENTAL
San José - Costa Rica • 9 al 11 de Febrero 2009

CETACEANS & Other Marine Biodiversity of the Eastern Tropical Pacific

Options for Adapting to Climate Change

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of the Eastern Tropical Pacific
Options for Adapting to Climate Change

WWF Marine and Species Program for Latin America and the Caribbean

Sistema Nacional de Áreas de Conservación del Ministerio de Ambiente, Energía y Telecomunicaciones de Costa Rica (SINAC-MINAET)

Inter-American Institute for Global Change Research

International Fund for Animal Welfare (IFAW)

The Nature Conservancy (TNC)

Whale and Dolphin Conservation Society (WDCS)

Conservación Internacional (CI)

Fundación PROMAR

EcoAdapt

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Cite this document as:
Hoffman, JR, Fonseca, A, and C Drews (eds). 2009. Cetaceans and Other Marine Biodiversity of the Eastern Tropical Pacific: Options for Adapting to Climate Change. Report from a workshop held February 9-11, 2009. MINAET/WWF/EcoAdapt/CI/IFAW/TNC/WDCS/IAI/PROMAR, San Jose, Costa Rica

ISBN: 978-9968-825-37-5

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GLOSSARY OF ABBREVIATIONS

CI	Conservation International
COP	Conference of the Parties
ENSO	El Niño Southern Oscillation
ETP	Eastern Tropical Pacific
GOOS	Global Ocean Observing System
IAI	Inter-American Institute for Global Change Research
IFAW	International Fund for Animal Welfare
IWC	International Whaling Commission
MINAET	Ministry of Energy, Environment and Telecommunications of Costa Rica
PDO	Pacific Decadal Oscillation
TNC	The Nature Conservancy
WDCS	Whale and Dolphin Conservation Society
WWF	World Wide Fund for Nature/World Wildlife Fund

For better or worse, climate change is altering ecosystems and communities around the globe. There are two essential elements to reducing the negative effects of these changes: limiting the rate and extent of climate change itself (mitigation), and reducing the vulnerability of species, systems, and communities to actual and anticipated changes (adaptation). The need for adaptation action is clear: failure to address how policies and practices might be affected by climate change runs the risk of investing time, money, and political capital in plans that are at best irrelevant and at worst maladaptive. This is true for any sector or activity influenced by climatic conditions, be it resource management, development, or conservation.

In February 2009 experts gathered in Costa Rica to review the implications of climate change for the Eastern Tropical Pacific, and to develop actions to support the region's biodiversity and the services it provides in the face of this threat. Despite its rich biodiversity and critical role for a range of marine, migratory species, the Eastern Tropical Pacific has received surprisingly little focus as a region in relation to climate change. While the Global Ocean Observing System (GOOS) has regional alliances for the South Pacific, the Pacific Islands, the Caribbean, and the United States, including a coalition specific to the northwest Pacific, there is no such regional organization for the Eastern Tropical Pacific. This workshop served as a key step in creating regional awareness and discussion around climate change, and gave scientists and organizations engaged in relevant work a chance to talk together about this critical issue. More importantly, this is the first effort in the region to collate oceanographic and climate knowledge in the context of vulnerabilities and adaptation options for marine organisms. Although it did not aspire to be comprehensive, it will serve as a platform to stimulate further regional work towards adaptation of marine habitats to climate change.

The first part of this report presents a generally applicable framework for adaptation. Although this document is directed towards conservation practitioners and natural resource managers in the Eastern Tropical Pacific or concerned with cetaceans as a whole, these basic principles can be used by anyone.

The second section presents findings from the workshop itself, both from presentations and from working group discussions. Although there are relatively few studies on climate change and its biological implications in the Eastern Tropical Pacific, participants assessed both what information there is for this region and how more global studies might be applied here.

The final section provides possible options for putting adaptation into practice. The ideas here are not an agreed-upon prescription for action from the workshop: they illustrate an approach to generating a range of actions that might be taken following thoughtful deliberation of costs, risks, and benefits. This reflects the consensus of workshop participants that there needs to be a fundamental change in conservation philosophy extending from policy makers to local communities to reflect the realities and uncertainties of climate change. Some fairly extreme options were purposefully included to illustrate the full range of possibilities for further analysis and consideration. How much or how little action to take depends on what is at stake, how much it matters, and how dire the situation.

Perhaps the most common reason cited for not taking action to reduce vulnerability to climate change is that there is still so much uncertainty. In reality, there will always be uncertainty, and the magnitude of the problem demands action now. There are many options for moving forward in the face of uncertainty, including scenario planning, robust decision-making, and active adaptive management. Since climate change is an unprecedented and urgent challenge, it is essential to learn by doing and to experiment with innovative, out-of-the-box thinking. Possible costs and benefits of different adaptation options must be carefully assessed, including potential unintended consequences, but the costs of taking no action at all are becoming increasingly clear.

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Introduction

At COP59 of the International Whaling Commission (IWC) it was decided to hold a second workshop on the implications of climate change to cetaceans. Mark Simmonds (International Director of Science, WDCS) was appointedagreed to act as convener for this event. At COP60 it was decided that the Climate Change workshop would be held in Siena, Italy, end of February 2009. In consultation with Mark Simmonds, the Costa Rican government offered to host a preparatory workshop before that, in which an assessment of the status of cetaceans in the Eastern Pacific could be made along with discussion of their vulnerability to climate change and adaptation options. From this, a report could be generated to assist the IWC in its work on climate change, including input for the subsequent Siena meeting. Costa Rica also decided to expand the scope of this workshop to include a specific analysis of marine and coastal climate change scenarios in the Eastern Tropical Pacific that may help to shape the adaptation interventions in this region. The Ministry of Energy, Environment and Telecommunications of Costa Rica (MINAET), WDCS, EcoAdapt, PROMAR Foundation, IAI, TNC, CI, IFAW and WWF agreed to join efforts to make the workshop in Costa Rica a reality. While the emphasis on cetaceans was maintained, the scope of the workshop was expanded to include in the analysis other marine biodiversity of the region.

Workshop structure

The workshop consisted of a collaborative, scientific review of the impact of climate change on oceanographic conditions in the Eastern Pacific and their interpretation for the design of adaptation responses. This is of relevance to endangered species conservation (e.g. cetaceans, marine turtles, sharks, corals), fisheries management, nature tourism operators, marine protected area management, and other users. Through a series of presentations and panel discussions, day one focused on collating oceanographic scenarios of climate change in the Eastern Tropical Pacific. These were interpreted by working groups on day two, in the context of taxa specific vulnerability to climate change. On day three, an overview of adaptation options based on the outputs of days one and two was produced, the results and lessons exchanged and fine-tuned in plenary, and the next steps for the dissemination of workshop results were decided. The dynamic of the workshop followed, with some adjustments, the "Climate Camp" methodology, a learning experience on climate adaptation developed by WWF.

Adaptation: human actions that reduce or limit the vulnerability of a system to the negative consequences of climate change

Resistance: the ability of a system to resist negative effects of disturbance

Resilience: the ability of a system to bounce back from a disturbance

See Appendix B for more detailed definitions

Importance

Despite its rich biodiversity and critical role for a range of marine, migratory species, the Eastern Tropical Pacific has received surprisingly little focus as a region in relation to climate change. While the Global Ocean Observing System (GOOS) has regional alliances for the South Pacific, the Pacific Islands, the Caribbean, and the United States, including a coalition specific to the northwest Pacific, there is no such regional organization for the Eastern Tropical Pacific. This workshop served as a key step in creating regional awareness and discussion around climate change, and gave scientists and organizations engaged in relevant work a chance to talk together about this critical issue. More importantly, this is the first effort in the region to collate oceanographic and climate knowledge in the context of vulnerabilities and adaptation options for marine organisms. Although it did not aspire to be comprehensive, it will serve as a platform to stimulate further regional work towards adaptation of marine habitats to climate change. While cetaceans were a significant focus of the workshop, participants thought more broadly, addressing the questions:

What are the physical, chemical and ecological effects of climate change in this region?

What factors influence the vulnerability of species and habitats to climate change?

Part 1:

Adaptation in the ETP: General considerations and recommendations

For better or worse, climate change is affecting many elements of the world around us. We can incorporate this reality into our planning or we can ignore it, but the climatic changes currently underway will continue for centuries or perhaps millennia regardless of which path we choose, even in the best case scenarios. Species ranges will continue to shift, weather patterns and the timing of key ecological events will continue to change. If we fail to look at how our policies and practices might be affected by these changes, we run the risk of investing time, money, and political capital in plans that are at best irrelevant and at worst maladaptive. This is true for any sector or activity influenced by climatic conditions, be it resource management, development, or conservation.

Climate change is affecting many elements of the world around us

In response to threats posed by climate change, as in response to other threats, more and more managers, policy-makers, and others are considering how they might reduce the vulnerability of the programs, communities, species, or industries they care about. This is what in climate change circles is known as adaptation, or put simply: taking action to reduce the negative effects of climate change on the resource of interest.

Some people worry that it is not possible to take adaptation action now because there is still so much uncertainty, so much we do not know. In reality, there will always be uncertainty, and the magnitude of the problem demands action now. The wisest course is to take an active adaptive management approach in which we take action to reduce vulnerability based on existing information but establish research and monitoring programs that allow us to periodically evaluate and adjust management strategies. Since climate change is an unprecedented and urgent challenge, we need to learn by doing and resort to innovative, out-of-the-box thinking for the design of adaptation measures. We should, however, be mindful of the degrees of risk, certainty, and possible costs and pay-offs of different approaches.

Ecosystems, Resilience, and Adaptation

A quick perusal of the adaptation literature reveals a sometimes-bewildering array of terms, such as community-based adaptation, resilience-based adaptation, or ecosystem-based adaptation, as well as some debate about the definition of the term adaptation itself (see Appendix A). While it is easy to get caught up in definitional discussions, a more productive approach is to understand the philosophical differences underlying the varied terminology, and to move forward in a manner that best fits the ecological and sociopolitical reality of the projects in question.

There will always be uncertainty, and the magnitude of the problem demands action now

Resilience is the ability of a system to recover from a disturbance, while adaptation covers a broad suite of actions that limit a system's vulnerability. Thus resilience-based adaptation would include those actions geared towards decreasing vulnerability by increasing resilience in general, while adaptation as a whole might also include actions that directly address a particular element of climate change or its effects. An example of resilience-based adaptation for coastal erosion would be restoring coastal mangrove forests, while building seawalls would be a "hard" engineering rather than resilience-based strategy. Likewise, providing communities with sustainable livelihoods that are less vulnerable to climatic forces would be a resilience-based alternative to shipping in food and water to communities that have trouble surviving where they are.

While resilience-based adaptation is for many the preferred approach philosophically, there may be some situations in which resilience-based actions would be insufficient to prevent loss of ecosystems or communities of concern. For instance, faced with the potential death of all corals within a particular reserve, managers may opt for more extreme options such as putting shades over corals whenever a bleaching alert is issued, simply to keep at least some of their corals around.

Building on the concept of ecosystem-based management, a number of organizations have coined the term ecosystem-based adaptation for strategies that integrate a range of adaptation options and stakeholders. Such an approach emphasizes preserving and restoring ecosystems to support human as well as natural communities, and to promote ecosystem services beyond just biodiversity.

General Considerations

Given a desire to engage in climate-aware planning and action, what is the best way to go about it? This depends on the severity of effects predicted or already evident, the level of capacity and engagement, the sociopolitical setting, and the core values of the organizations and communities involved. Appendix A lists a number of existing adaptation documents. Of these, *Buying Time: A User's Manual For Building Resilience To Climate Change In Natural Systems* was particularly influential in framing the current document due to its focus on conservation and natural systems.

Using the Right Tools

A first step towards adaptation is to ask how climate change might affect existing policies, tools, and management strategies. Will they remain effective? Can they be adjusted to account for climate change? Will they lose relevance completely? As an example, consider current equations for maximum sustainable yield. Surplus production models for fisheries

*A first step **towards adaptation** is to ask how climate change might affect existing policies, tools, and management strategies*

determine the Maximum Sustainable Yield (MSY) using data on yield and effort for a particular species over a number of years. If climate change alters the population dynamics of the species of interest, say by changing death rates, age to maturity, or the carrying capacity of the environment for that species, past data on effort and yield may no longer be relevant. In contrast, MSY models that explicitly incorporate the species' rate of increase and the carrying capacity for that species would simply need to adjust values for those variables over time. However, if rate of population growth and carrying capacity become subject to dramatic fluctuations as a result of climate change (for instance, if food availability becomes less predictable as a result of oceanographic variability), all existing MSY models may become ineffective and a new approach would be needed.

Protect Adequate and Appropriate Space

Much resource management and conservation is currently done using a spatial framework, restricting where and when various human activities can take place. Because many species are changing ***where*** they feed, grow, or breed, and ***when*** they engage in key life history behaviors such as reproduction and migration, existing spatial restrictions may not adequately protect the resources and ecosystems for which they were designed. For instance, during particularly warm years salmon that traditionally return to Canada's Fraser River through US water along the south end of Vancouver Island instead travel north around the island, avoiding US waters (and therefore US fishing fleets) altogether. Likewise, investment in conservation or development along low-lying coastlines should be done with any eye towards sea level rise. How long will it be before fresh water aquifers and swamps become salty? Before an area is underwater? What level of investment is appropriate given the risks? In the face of climate change, spatial management strategies will need to incorporate such features as buffer zones and corridors to accommodate uncertainty and latitudinal range shifts. Identifying and protecting refugia, or areas less likely to change, is another important criterion for climate-smart spatial management. This might include, for instance, ensuring that resistant and resilient coral reef patches are well represented in marine protected area networks. There is already a suite of recommendations for the design of resilient marine protected areas (see e.g. CCSP 2008; IUCN 2008; West and Salm 2003).

Reduce non-climate stresses

Climate change is not the only threat faced by marine ecosystems and the communities and industries that rely on them. Pollution, habitat destruction, over-exploitation, invasive species, and more are already challenging us. Such threats, plus a status of severe depletion in some species, make marine and coastal ecosystems particularly vulnerable to climate change, a condition unlike such of millennia ago, when the same species and ecosystems were in much better shape and were able to withstand environmental changes resulting from climatic variability. Reducing non-climate stressors in general is thought to increase overall ecosystem resilience; when it comes to climate change adaptation, the key is to focus on those stressors that will interact negatively with climate change or its effects. Certain chemicals, for instance, make some animals more sensitive to heat or become more toxic at higher temperatures (e.g. Sokolova and Lannig 2008; Patra *et al.* 2007; Schiedek *et al.* 2007); clearly those pollutants would be important to target in areas expected to see an increase in maximum temperatures. Changes in rainfall patterns are expected to increase the nutrient loads in some coastal areas, increasing the risk of dead zones, and higher water temperatures in and of themselves can increase dead zone size and frequency. Thus more effort might need to be focused on reducing input of nutrients to at-risk areas. Rates of harvest that have been sustainable in the past may become unsustainable if climate change alters population growth rates. The precautionary principle suggests that we add "insurance factors" to regulations governing a variety of non-climate stressors to minimize the risk of marine systems we care about flipping to alternative stable states.

Manage for uncertainty

Climatic variability is a fact of life, but the long-term directional climate change we are currently experiencing is different. While not unprecedented in the history of the world, it is unprecedented in the history of modern humans, and there are therefore a great many unknowns as we look towards the future. To remain effective, management systems must be able to incorporate uncertainty and respond to new information and unforeseen circumstances in a timely fashion. Active adaptive management and scenario planning provide frameworks for how this can happen.

*To remain **effective**, management systems must be able to incorporate uncertainty and respond to new information and unforeseen circumstances in a timely fashion.*

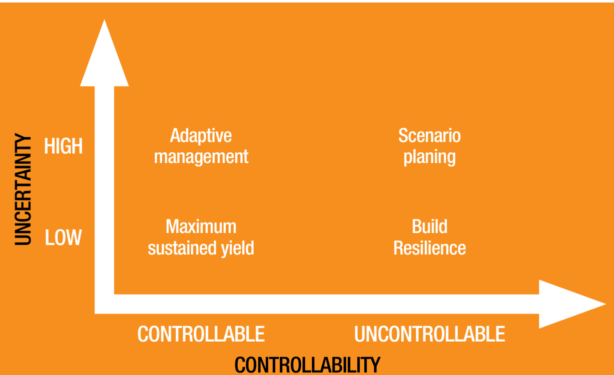
The process of adaptive management follows an iterative series of steps (Salafsky *et al.* 2001). First, define the goal or purpose of management. Then design an explicit model of how your system works, and develop a management plan that you think will maximize resilience and

minimize vulnerability. A critical next step is to develop a monitoring plan that allows you to test the assumptions of your model and evaluate the effectiveness of your plan. Once these elements are in place, implement your management and monitoring plan, analyze the data you collect, and adjust your model or plan as needed.

In some cases, not only will uncertainty be high, but the variables controlling the fate of the resources being managed may be beyond the manager's control. In these cases, combining quantitative and qualitative information to create alternative future scenarios may provide the best basis for management decisions. Even if incomplete, collecting and discussing the information necessary for building scenarios and making scenario-based decisions can help to create a shared understanding of possible risks and benefits of alternative course of action (Peterson *et al.* 2003).

Minimize the Rate and Extent of Climate Change

If we do not limit the rate and extent of global climate change, adaptation becomes less effective and more costly. Reducing global emissions of greenhouse gases, then, is fundamental to the success of adaptation plans. In some cases, there may also be management actions that reduce the rate or extent of local or regional climatic changes. For instance, planting native vegetation along sea turtle nesting beaches can maintain cooler sand temperatures, a strategy developed by WWF in Junquillal beach, a leatherback nesting site on the Pacific coast of Costa Rica. The loss of lowland forests in Costa Rica has contributed significantly to drier conditions in montane cloud forests such as Monte Verde; protecting and restoring lowland forests could limit this change.



The most appropriate management strategy depends on both the uncertainty and the controllability of the system in question. Maximum sustainable yield is appropriate when uncertainty is low and controllability is high, but when uncertainty is high either adaptive management or scenario planning becomes the better choice.

If we do not ***limit the rate and extent*** *of global climate change, adaptation becomes less effective and more costly.*

Workshop presentations reviewed the current state of knowledge about observed and projected climate change in the region and the implications for marine biodiversity, and working groups further refined this information. We briefly summarize physiochemical changes and the implications for particular species below; for further discussion, please see the summary papers by workshop participants in Appendix A. Although few of the effects listed below are unique to this region, we include them here to provide a context for the discussion of specific adaptation approaches.

Physiochemical changes

Temperature: the region has warmed by 0.2 – 1 degree C since 1900. Warming is expected to continue strongly in this region, although trends in sea surface temperature may be masked by ENSO and decadal oscillations. The oceans in this region have acted as sinks for atmospheric heat, and are expected to continue to do so.

Precipitation: while no significant trends in precipitation have been observed to date, precipitation is expected to increase in the tropical and subarctic Pacific, but to decrease in the subtropics.

Wind and storms: winds are increasing in the subarctic, but decreasing in the N. Pacific subtopics. Longshore winds and coastal upwelling have increased. It is likely that trade winds will weaken and westerlies will shift poleward, but changes in coastal upwelling are not expected. There has been no measured increase in cyclone activity in the eastern Pacific, and there is much uncertainty as regards projections of future storminess.

Sea level: Rising sea level on a global level is regionally and locally modulated by sedimentation, isostatic forces, and atmospheric pressure (e.g. large changes in sea level associated with El Niño). The effects of sea level rise will be modulated by changes in storminess as well as any adaptation measures taken along the coast.

Currents and stratification: there is no clear evidence for long-term ocean circulation changes, and high uncertainty surrounding predictions of future change. Thermal stratification has increased in the California Current, reducing primary productivity. Globally, stratification is expected to increase.

Coastal erosion and sedimentation: local increases in erosion and changes in sedimentation are already occurring. Increased erosion due to sea level rise is likely, and any changes in storm frequency, intensity, or amount of precipitation would likewise affect erosion, both due to waves and due to terrestrial runoff.

Climate Variability: There is no consensus on changes to ENSO itself, except that it is likely to continue to be the made mode of interannual variability in the region, followed by the PDO. Climate extremes caused by these interannual or decadal oscillations must be considered as added on to any long-term trends.

Salinity: Surface salinity has decreased, except in the subtropical South Pacific. Because of continued changes in the balance between precipitation and evaporation, salinity is expected to decrease further at high latitudes while increasing at low latitudes.

Carbonate saturation and pH: Globally, the average pH of the ocean has decreased by about 0.1 pH units from the pre-industrial period to the present and a further decline of 0.3-0.4 pH units could occur by 2100, and the calcium compensation depth has shoaled by roughly 200 m. These trends are expected to continue, and surface waters in the Southern Ocean and subarctic Pacific Ocean will likely become undersaturated within the next century, making calcification difficult for many organisms.

Oxygen: the oxygen minimum zone has expanded vertically in the ETP over the past 50 years. Because the mechanisms are not well-characterized, projections for the future are limited.

Noise transmission: Recent research suggests that ocean acidification may enhance noise transmission through marine waters.

Pollutants: Rising seas may flood landfills or other pollutant sources, releasing chemicals and debris into bays, estuaries, and other coastal zones. Changes in precipitation patterns may lead to increases in pollutant runoff from land, and melting glaciers may release stored chemicals as well (Blais *et al.* 2001). Both solubility and toxicity of many pollutants are affected by temperature and salinity.

Rising seas may flood landfills or other pollutant sources, releasing chemicals and debris into bays, estuaries, and other coastal zones

Estuaries: Changes in sedimentation rate, water temperature, pH, and salinity, storm frequency or intensity, and the input of organic material would all alter the physiochemical nature of estuaries.

Beaches: Sea level rise, changes in storm frequency or intensity, and altered wind and current patterns could all decrease beach area or change the profile, orientation, and distribution of beaches.

Biological implications

Plankton: Because primary productivity in this region is strongly linked to upwelling, any decrease in upwelling frequency or intensity would translate rapidly into decreased productivity. There will also be changes in overall abundance, and a likely shift from larger to smaller zooplankton. Changes in the timing of plankton blooms and zooplankton reproductive cycles are likely, with a possible mismatch between peak phytoplankton abundance and animal reproductive cycles. Species ranges will likely shift towards higher latitudes or deeper depths, along with an overall shift in species composition to favor those that are better-adapted to warmer, lower pH conditions. Harmful algal blooms may become more frequent.

Fish and fisheries: Climatic effects on reproduction and species composition are highly certain, as illustrated by dramatic shifts in response to shorter-term climate variability such as El Niño. Some species will benefit from warmer conditions while others will decline. Species ranges are likely to shift towards higher latitudes in response to warming, and the spread of diseases, parasites, and non-native invasive species may increase. Where climate change contributes to an increase in hypoxic zones, major mortality of fishes, crustaceans, and other organisms may result. Conflicts within the fishing community may increase as catch declines or as species ranges shift outside of areas where they have been harvested historically.

Cetaceans: The biggest effects on cetaceans are likely to come through effects on their food supply, and effects on reproduction are highly certain. Species displacement and decreases in survival are of medium certainty, and while there is the potential for significant effects on population, there is insufficient information at this point to feel confident making predictions of climate-related population declines. There is some likelihood of introduced diseases

Sharks: Indirect effects through prey and habitat are likely to be more important than direct effects, since sharks are fairly tolerant of changes in salinity, pH, and oxygen. Loss of mangroves to sea level rise or changes in terrestrial runoff would decrease nursery grounds, and loss of coral reefs and seagrass beds would reduce feeding opportunities for adults. Increasing strength or frequency of storms could lead to increased stranding and further loss of habitat.

Marine turtles: Increased temperature will decrease nestling survival and change the sex ratio of surviving hatchlings, and sea level rise will lead to loss of nesting beach habitat in areas where beaches are unable to shift landward because of topography or infrastructure. Increases in storm strength or frequency would further increase beach loss, and changes in patterns of wind and wave direction could cause beaches to pivot. Excess sedimentation onto nesting beaches can smother nests. At sea, altered temperature and current patterns may influence the distribution and migration of turtles. Diseases may become more prevalent due to changing water temperature and chemistry, and food may become scarcer.

Mangroves: Loss of mangrove forests; Changes in species composition in mangrove forests. This would affect biodiversity in associated communities

Coral reefs: Bleaching due to increased temperature, decreasing pH, increasing terrestrial runoff due to more intense rainfall events, or a combination of these is the primary climate-related threat to reefs. The runoff problem is exacerbated by deforestation and loss of coastal vegetation. Rising sea level can threaten reefs if the rate of rise is faster than the rate of accretion. Acidification combined with bleaching will decrease the rate of growth, increasing vulnerability to sea level rise.

Aquaculture: Higher air and water temperatures could increase problems with diseases in aquaculture operations as well as the occurrence of harmful algal blooms associated with aquacultural runoff. Changes in salinity due to increased evaporation or saltwater intrusion could affect the viability of coastal aquaculture ponds.

Indirect effects

Concern for conservation may decrease if coastal communities become more concerned with effects on their own livelihoods or communities.

Increasing demand for renewable energy may lead to increasing development of wind, wave, or tidal power generation in coastal waters. Adequate regulation to reduce effects on marine ecosystems and species of concern is essential, although clearly there is a conservation benefit to the reduction in greenhouse gas emissions associated with increased use of renewables.

People may shift livelihoods in response to physical or biological effects of climate change. For instance individuals or communities may shift from fishing to whale-watching, ecotourism, aquaculture, or farming if fishing becomes less reliable. Such shifts are not inherently good or bad, but must be considered in adaptation planning.

Movement of cetaceans into new areas may increase real or perceived competition with fisheries, leading to increased take.

Changing agriculture use of pesticides, fertilizer, and water would affect the quantity and chemical content of terrestrial runoff.

Workshop participants agreed that there needs to be a fundamental change in conservation philosophy extending from policy makers to local communities to reflect the realities and uncertainties of climate change. Adaptation actions can be taken at global, regional, or local levels, and stakeholders should act at the level most appropriate to their position and their needs. Improved overall governance in the marine environment could greatly enhance the effectiveness of adaptation efforts.

At the workshop, participants divided into five working groups to address impacts and adaptation options for cetaceans, fishes and plankton, marine and coastal ecosystems, endangered species, and the physiochemical environment. Each working group was asked to consider observed and expected changes, factors influencing the vulnerability of species or habitats to changes, and what actions might be taken to reduce vulnerability. We have organized this section of the report around climate change implications for key population functions and processes.

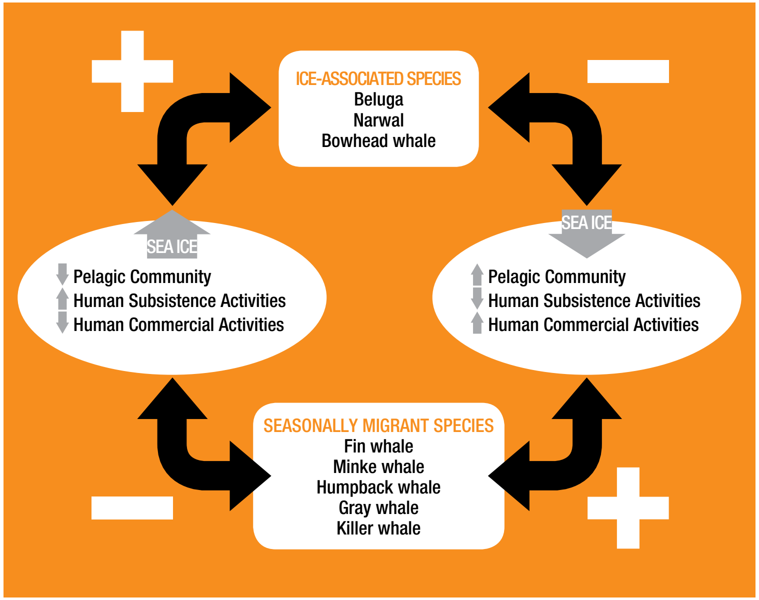
The adaptation ideas below are meant to stimulate creative thinking, and are not agreed-upon recommendations for actions from workshop participants. We have included some options that are fairly extreme to illustrate the full range of possibilities for further analysis and consideration of managers.

Although we do not specifically address mitigation here, limiting the rate and extent of climate change through reducing greenhouse gas emissions is essential. If such emissions are not limited, adaptation options become increasingly limited and expensive. The process of selecting among adaptation options should include a consideration of the unintended consequences of those options, including greenhouse gas emissions.

We hope the ideas here generate discussion amongst scientists, regulatory bodies, managers, and conservationists about how to best incorporate climate change into discussions about cetaceans and other species and habitats in the Eastern Tropical Pacific. Formulating concrete ideas allows a more realistic discussion of costs and benefits of various options, and of how they relate to the priorities of various parties involved.

NB: Specifc adaptation options described below are intended primarily to stimulate discussion and further analysis of their viability. As they stand, they do not represent definite recommendations by the editors, workshop participants, or WWF.

There needs to be a fundamental change in conservation philosophy extending from policy makers to local communities to reflect the realities and uncertainties of climate change



1. FOOD SUPPLY

Climate change may alter prey density, location, behavior, and type. Less specialized feeders such as fin or bowhead whales may be better able to adjust to changes in prey availability, while specialist feeders like blue whales are more vulnerable. While it is not always possible to attribute changes in prey availability to specific environmental changes, a role for climatic variability can often be inferred. For instance, it is unclear which oceanographic variables led to the sharp decline in amphipod populations in the Bering Sea between 1983 and 2000, but a climatic shift linked to warmer water and reduced currents almost certainly played a role (Moore *et al.* 2003). This decline in prey availability was correlated with the deaths of hundreds of grey whales that typically feed in this region. Workshop participants felt that food chain effects presented the most worrisome climate-related threat to cetaceans in this region.

Altered upwelling and current patterns. Upwelling brings nutrients from depth to the surface, promoting productivity, and many cetaceans and other marine animals favor upwelling areas for foraging. The Eastern Tropical Pacific's typically strong upwelling is due to the atmospheric Walker Circulation; when Walker Circulation weakens, El Niño conditions result. Although models disagree about how climate change will affect the frequency and amplitude of ENSO cycles, they agree that it will lead to generally weaker Walker Circulation, and thus more El Niño -like conditions in the ETP. It is unclear how climate change will affect the Costa Rica Dome, a region where the relatively shallow thermocline concentrates plankton and creates rich feeding grounds for many marine species, and rich fishing grounds for humans. In temperate regions, increased warming of surface water may lead to a more stable and stratified water column with less upwelling (summarized in Soto, 2002; Field *et al.*, 2001). Conversely, climate change may alter wind patterns in ways that increase offshore winds and thus upwelling (e.g. Snyder *et al.* 2003 for the California Coast). Models predict continued strong upwelling around Antarctic Peninsula, while areas around the Kerguelen Plateau will see weakened upwelling between 50 and 55 degrees south and somewhat more upwelling further south (Tynan and Russell 2008).

Many cetaceans, including blue, humpback, fin, and sperm whales often feed in or around fronts and waterfront boundaries, features that promote high primary productivity or trap prey. In the southern hemisphere, many fronts are predicted to shift southward, which means that cetaceans heading south to summer feeding grounds might have to travel farther before reaching those feeding grounds. Models also predict a compression and reduction of fronts and boundaries associated with the southward shift, meaning that key foraging grounds would also be reduced and compressed (Tynan and Russell 2008).

Reduced pH. As the oceans absorb increasing amounts of carbon dioxide from the atmosphere, a series of chemical reactions causes the pH of marine waters to drop, a phenomenon known as ocean acidification. When pH drops below the saturation point for calcium carbonate, organisms may have difficulty secreting or maintaining calcium carbonate skeletons. This phenomenon is progressing most rapidly at high latitudes. The Southern Ocean's surface waters are likely to become undersaturated with respect to aragonite, one of two common forms of calcium carbonate, by the middle of this century. The effects could be wide-reaching, potentially leading to the loss of such important planktonic organisms as pteropods, coccolithophores (an important food item for some salmon which are in turn important for some whales), and even krill. Lower pH can also decrease the metabolic rate and activity level of epipelagic squid, a phenomenon that is exacerbated by higher temperatures (Rosa and Siebel 2008). The interaction of oxygen, temperature, and pH has the potential to restrict the range of these squid, with knock-on effects on sperm whales, other deep-diving whales and tuna-like fish species, which feed on squid.

Higher temperatures. Increasing water temperatures have already been linked to poleward range expansions of warmer-water species and range contraction of colder-water species. Species may respond directly to increased temperature, or indirectly through changes in predator, competitor, or prey species. For instance, during the 1982-1983 El Niño the squid on which short-finned pilot whales depended in southern California left the area likely due to higher water temperatures, and the short-finned pilot whales disappeared as well (Shane, 1995). Even when squid returned to the area, the short-finned pilot whale population did not. Risso's dolphins later moved into the area, taking advantage of the niche left by pilot whales. In the Bering Sea, warmer water has led to a shift away from lipid-rich amphipod species critical to the success of gray whales.

*When **pH drops** below the saturation point for calcium carbonate, organisms may have difficulty secreting or maintaining calcium carbonate skeletons*

Low-oxygen "dead" zones. Increased ocean temperatures, altered upwelling regimes, and changes in patterns of terrestrial runoff may lead to an increase in size and occurrence of "dead zones," areas where oxygen becomes so depleted that animals either leave or die. This could reduce food availability for cetaceans and other marine predators that feed in shallow coastal areas.

Loss of sea ice. While sea ice is not present in the ETP, some of the species that occur here seasonally spend part of the year in polar environments where sea ice may play an important role. The effects of sea ice loss on marine organisms will not be uniform across species or locations, although it is generally projected to lead to an overall reduction in the high productivity zones associated with the ice edge.

Loss of warm-water coral reefs. Coral reefs have seen massive losses around the globe to bleaching resulting from high water temperatures, or a combination of changes in water temperature, salinity, runoff, diseases, and overfishing. They are further challenged by decreased oceanic pH. Because they are key feeding grounds for many species, their loss could have repercussions far beyond the reef ecosystem.

Adaptation Options

I. Adjust fishing effort on prey species and in key feeding areas for cetaceans or other species of concern in response to predicted forage conditions, decreasing effort in years and locations where food limitation is likely to be problematic.

II. Focus protection on foraging areas where the factors contributing to high food availability are less likely to be affected by climate change. For instance, while upwelling along the eastern coast of the Pacific Ocean is largely wind-driven and thus vulnerable to climatic changes, upwelling along southeastern Madagascar is driven by bottom topography and major oceanographic currents, making it amenable to protection as a foraging refugium.

III. Consider spatial restriction on krill harvest to compensate for the compression and reduction of high-krill areas in the Southern Ocean. The changes in krill distribution and potential for increased conflict between krill harvesting and cetaceans is a prime example of why climate change must be considered in developing regulations for marine resources in the Southern Ocean.

IV. Provide supplemental food to vulnerable populations at risk of extinction during particularly bad years (expensive, high greenhouse gas emissions, and impractical in many areas).

V. Identify and protect areas most likely to maintain conditions that produce high concentrations of food, such as the Costa Rica Dome.

2. REPRODUCTIVE SUCCESS

Climate change will affect conditions on feeding, breeding, nesting (e.g. marine turtles and seabirds), calving, and nursery grounds, as well as affecting the dispersal of planktonic larvae. For cetaceans, sharks, and other large pelagics, the primary effect of climate change on reproductive success will likely occur as a result of changes in maternal condition, but it may also render some existing nursery and calving grounds unsuitable while creating favorable conditions in other areas. The degree to which animals can adjust to such changes by shifting activities to another location is unknown, but there are examples of breeding ground shifts in response to non-climatic factors. For instance, the southeastern Caribbean once hosted the largest aggregation of humpback whales in the North Atlantic. As an apparent response to intensive whaling in the region, humpback whales in this breeding range shifted their breeding aggregations to the North West Indies (Clapham *et al.*, 2007).

Sea level rise. Many species depend on coastal habitats such as beaches, mangrove forests, estuaries, bays, or lagoons for nesting, breeding, calving, and nursery grounds. As sea levels rise, these habitats will either shift landward with the rising water or disappear if natural or anthropogenic structures prevent the shift. Hence, their ability to shift landward depends on topography and degree of coastal development. For instance, an estuary backed by steep cliffs or extensive seawalls would shift to a deeper-water environment as sea level rose, while one backed by gently sloping topography and minimal development could maintain shallow-water habitat. Furthermore, both rising sea level and increasing storminess may cause the release of toxicants from coastal landfills, agricultural land, or other sources of pollutants into coastal waters, increasing the exposure of marine organisms to pollutants. This would be particularly problematic for early life stages, which are thought to be particularly vulnerable.

Water temperature. Water temperature anomalies are often linked to reproductive success in cetaceans. The calving

Developing a vulnerability index for cetaceans

Sensitivity or vulnerability indices can be useful tools for designing and assessing adaptation actions, as well as for identifying key research needs. Building on the work of Laidre *et al*. (2008), who developed sensitivity indicators for Arctic cetaceans, and the IUCN (Foden et al. 2008), which developed sensitivity indicators for birds, amphibians, and reef-building corals, Mark Simmonds presented workshop participants with a draft set of sensitivity indicators for cetaceans as a whole. Indicators included population characteristics such as genetic variability, geographic distribution, and reproductive rates as well as physical and ecosystem-level changes. These indicators were discussed and further work is planned to elaborate them.

output of southern right whales breeding in Argentina, for instance, declines markedly in response to warm water anomalies in the females' feeding grounds around South Georgia Island (Leaper *et al.* 2006). Likewise, warm water anomalies around the Galapagos Islands have been linked to reduced reproductive success in associated sperm whale populations (Whitehead 1997 as cited in Learmonth *et al.* 2006).

Oceanographic variability. Reproductive success is strongly linked to maternal nutritional status. Increasing variability in oceanographic conditions leading to greater variability in food availability may increase the time between pregnancies for individual females, and decrease calf survival. This has been documented for the highly endangered North Atlantic right whales, which feed almost exclusively in an oceanographic transition zone between cold sub-polar waters influenced by Labrador Current and warmer temperate waters influenced by Gulf Stream. Multiyear declines in calving rates between 1993 and 2001 were linked with climatic shifts and steep declines in the availability of *Calanus finmarchicus*, the primary prey of North Atlantic right whales (Greene *et al.*, 2003). Similarly, high interannual variation in jellyfish availability has been associated with the long internesting intervals of leatherback turtles in the Eastern Pacific (Saba *et al.* 2007).

Adaptation Options

I. Adjust population projections and associated conservation/harvest plans to accommodate a decreased rate of population growth. For instance, conservation efforts for North Atlantic right whale historically focus on female mortality, but climate change may increase the importance of calving rates to conservation success.

II. In areas where topography would allow key nesting, calving or nursery habitat to shift landward with rising sea level, restrict development so as not to obstruct the natural process.

III. Clean up potential sources of toxicants landward of key calving or nursery areas.

IV. Restore coastal vegetation to provide habitat for and shade for shore-nesting birds and marine turtle nests

3. CHANGES IN DISTRIBUTION, RANGE, AND MIGRATION

Numerous marine species, from snails to whales, are expanding their ranges towards the poles. The past two decades have seen an increase in the number of warmer-water dolphin species expanding into the waters around Scotland. The common bottlenose dolphin expanded its range north into central California during the 1982-1983 El Niño event, and has remained there since. Grey whales, once uncommon in the Beaufort Sea, now occur in the tens to hundreds, and occasionally even overwinter in the Arctic (Stafford *et al.* 2007).

Changes in the timing of migration have been documented for many species, including fishes, birds, and some cetaceans. Some are responding to changes in the timing of plankton blooms, others to changing temperature regimes. In some cases, the distance between foraging and breeding grounds may increase: in the Southern Ocean, migratory cetaceans will have to travel about 3-5 degrees of latitude farther to reach Southern Ocean fronts where they forage (Tynan and Russell 2008)

Adaptation Options

I. Develop protection schemes that can accommodate changes in distribution rather than relying on fixed protected areas (e.g. increasing overall land- and seascape permeability).

II. Anticipate shifts in range and distribution, and manage areas into which species of concern may move in such a way that they will be capable of supporting those species.

III. Where species may have difficulty tracking suitable habitat on their own, transport individuals into new regions (assisted migration).

4. HEALTH AND SURVIVAL

Health reflects a complex set of factors, including immune status, body condition, toxicant exposure, the presence, transmissibility and pathogenicity of pathogens, and various interacting environmental conditions. Climatic conditions can affect all of these. Many pathogens do better in warmer conditions, for instance, and organisms subjected to changing temperature or salinity may become stressed, reducing immune function and body condition. For species whose ranges or feeding grounds shrink, density-dependent transmission of diseases may increase.

Harmful algal blooms. Warmer temperatures and potential increases in terrestrial runoff in some areas may lead to an increased incidence of harmful algal blooms, and there appear to be an increasing number of marine mammal and coral die-offs linked to harmful algal blooms (Gulland and Hall 2007). Die-offs associated with algal toxins have been documented for a number of dolphin and whale species, in some cases affecting hundreds of individuals.

Shifting ranges. Disease-causing organisms and parasites may expand their range as water temperatures increase. In some cases, this range expansion of parasites and diseases may result from the movement of cetaceans themselves. For instance, cetacean morbillivirus (CMV), which has caused massive mortality events, appears to be endemic in some cetacean populations but not in others (Van Bressem *et al.* 2001). Populations that lack humoral immunity to CMV are vulnerable to outbreaks.

Toxicants. Climate change may affect toxicant exposure of marine organisms in many ways (reviewed in Schiedek *et al.* 2007). Altered precipitation and run-off patterns may change pollutant input into coastal waters. Changes in human behavior in response to climate change, for instance increased shipping in formerly ice-covered area, may likewise increase chemical inputs in some areas. For species and locations for which food availability declines, there may be more frequent mobilization of fat stores, and thus more frequent uptake of toxicants that have accumulated in the fat.

Adaptation Options

I. Vaccinate at-risk populations for diseases.

II. Provide captive or *in situ* care for unhealthy individuals in populations with particularly low numbers.

III. Reduce nutrient inputs likely to trigger harmful algal blooms in areas where species of interest or their prey congregate.

IV. Prevent animals from feeding in areas where harmful algal blooms have rendered prey items dangerous.

V. Protect multiple populations within each species as insurance against the loss of one population to disease or stress, and to increase the chances that some individuals will be resistant.

VI. Identify and put stronger restrictions on contaminants likely to increase susceptibility to disease or higher temperatures.

VII. Identify pollutants whose toxicity increases with increasing temperature or changing salinity, and adjust water quality criteria accordingly. This may be more relevant to ectothermic than endothermic animals.

VIII. Regulate fishing to maintain populations of species essential to the health of others, such as grazers on coral reefs.

IX. Restore coastal and riverine wetlands and vegetation to decrease harmful terrestrial run-off and maintain cooler air and water temperatures.

5. EVOLUTIONARY POTENTIAL

Within species there are often two or more genetically distinct groups that differ in a number of ways, including behavior, resource use, thermal tolerance, etc. Genetic diversity within and among populations may be a key element to the long-term survival of species in the face of climate change, as it increases the chance that some individuals will have genes that make them better-adapted to future climate conditions. To maximize species' resilience, it is essential that human activity not close off evolutionary options.

An example of how loss of distinct populations may have increased the vulnerability of some cetacean species to climate change is the case of blue and humpback whales around South Georgia Island. While this region once supported thriving populations of these two species, they were hunted to local extinction in the early 20th century. Despite the presence of abundant krill, these species have not recolonized the area, suggesting that the cultural memory of this feeding ground may have been lost (Clapham *et al.* 2007). This loss may become significant, as South Georgia Island is one area where krill populations do not appear linked to sea ice.

Adaptation Options

I. Identify and conserve genetically distinct lineages.

II. Identify and prioritize populations that appear adapted to conditions likely to become more common as climate change progresses.

6. SPECIES WITH LIMITED RANGES

Range-restricted species are more vulnerable to climate change, so deserve special mention here. Vaquita and the several species of river dolphins are faced with distinct challenges. Non-migratory populations of otherwise migratory species, such as the humpback whales in the northern Indian Ocean or the fin whales in the Mediterranean, may also be at increased risk. For these species, it is critical to reduce the rate and extent of climate change and to minimize all non-climate stressors, as adaptation options are more limited.

Summary and Key Recommendations

While the uncertainty cited by many workshop participants is most certainly real, it should not be an impediment to action. The output of the workshop demonstrates the breath of adaptation avenues that can be identified, even in the absence of complete knowledge. There will always be uncertainty, so we must learn to act, to set policy, to plan in the face of uncertainty while working to reduce uncertainty where we can. From the discussions at the workshop and the principles and ideas described in this document, we can make a number of general recommendations to reduce vulnerability to climate change in the ETP and for species found there:

- The primary adaptation actions (after addressing climate change itself) are to reduce non-climate stressors, and to develop spatial management schemes that protect key feeding, breeding, and migration areas based on plausible future as well as current conditions.

- Within the context of climate change vulnerability assessment and adaptation, prioritize and conduct research to fill key information gaps. This should include improved monitoring of relevant biological, oceanographic, and climatic variables, as long-term data sets are essential for understanding ecosystem function and change as well as for adjusting management practices for enhanced effectiveness. Relevant research and monitoring within the ETP should be coordinated through a regional GOOS, as well as by establishing climate change working groups in the relevant national, regional, or international organizations for species, places, and processes of concern.

- Support and build capacity for adaptation to climate change in the region among government agencies, academic institutions, conservation leaders and non-governmental organizations.

- Insert adaptation measures in national and regional policies and planning tools, and increase enforcement of existing laws and regulations that would enhance the success of adaptation measures.

- Begin enacting adaptation projects and systematize and disseminate lessons learnt.

The connections and working groups developed at this workshop will hopefully serve as the beginning of a growing network of individuals and organizations interested in climate change adaptation in the Eastern Tropical Pacific. Indeed, discussions on vulnerability indicators from this workshop are ongoing. A coordinated effort calling on the range of creativity and insight present at this workshop and beyond will be essential in the fight against climate change.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Part 2:

Adaptation in the ETP: Specifics about climate, biology and adaptation

Sea Level and Surface Sea Temperature variation in the tropical Intra-Americas Sea.

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For the physical oceanographer, sea level and surface water temperature are two of the most relevant variables in marine climate control. Their evolution over time shows a close relationship, which makes them of fundamental interest when determining their possible impact on the living marine resource.

Few studies about the behavior of these variables over time have been done for our region; nevertheless, some quantification of their temporal variation has been carried out by foreign and local scientists. Thus, our intention is to present a quantified illustration of that behavior in regional and Costa Rican waters to enhance comprehension of the effects detected in recent times on the living coastal and marine resources in the various ocean and sea systems on our planet.

Temporal variations in relative sea level (RSL) have a direct relationship with the other variables in this equation: $RSL= H_T + H_P + H_W + H_E + H_S + H_C + H_G + R$. These variables refer to astronomical effects (H_T), atmospheric pressure (H_P), wind (H_W), water volume (H_E), changes in water temperature and salinity (H_S), oceanic circulation (H_C), tectonics and other geological changes (H_G) and background noise (R). The term H_S is what concerns us in this case, given its relationship to RSL and air temperature.

The RSL trend is rising on average globally, consistent with rising temperatures and CO_2, but with exceptions in some parts of the planet due to the differentiated combination of other phenomena at those sites. What is not clear is whether the increase of CO_2 and other gases has been responsible for those growing trends since the start of the industrial era.

In any event, and independently of the cause of the increasing values for these variables, the rising trends of air temperature, SST and RSL are clear and reason enough for the interest in controlling change in specific sites of our region. Figures 1 and 2 show the tendency for change in RSL in the tropical Intra-Americas Sea, and in particular, the nearly generalized trend in this variable that is rising at a rate of 1 to 5 mm/year. With this in mind, one of the authors of this article participated in a study on the impact of RSL on Central America in the mid-1990s for one of the most vulnerable sites in Costa Rica, Puntarenas (Figure 3).

Studies such as these, given the evidence for change in those variables of impact, an outcome of the accentuation of climate change in the last decades of the Holocene, turn out to be highly useful for decision makers in the different nations of the planet. Even so, we should make the following considerations:

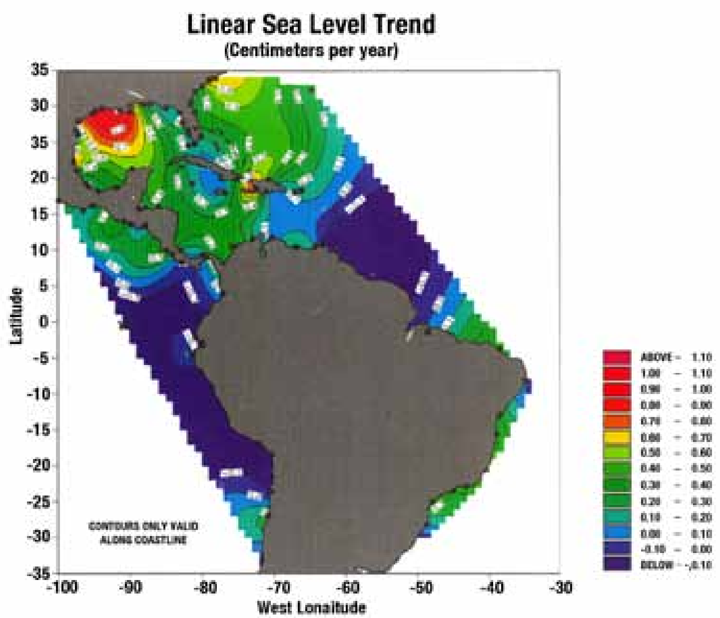

Figure 1. Relative sea level variation in the Wider Caribbean. From Maul, G (ed) 1993.

I. Many of the models for forecasting future climate include assumptions, uncertainties and omissions that need correction, which is why an analysis of the corresponding time sequences is essential.

II. Available hourly and daily temporal sequences of the variables of interest over periods of 20 years or more that are reliable are rare and this significantly increases error in estimates of trends derived from shorter temporal series; for this reason it is imperative that institutional measures are taken to allow the proper maintenance of recording instruments. Only in this way can decisions regarding the possible consequences of climate change be figured out appropriately.

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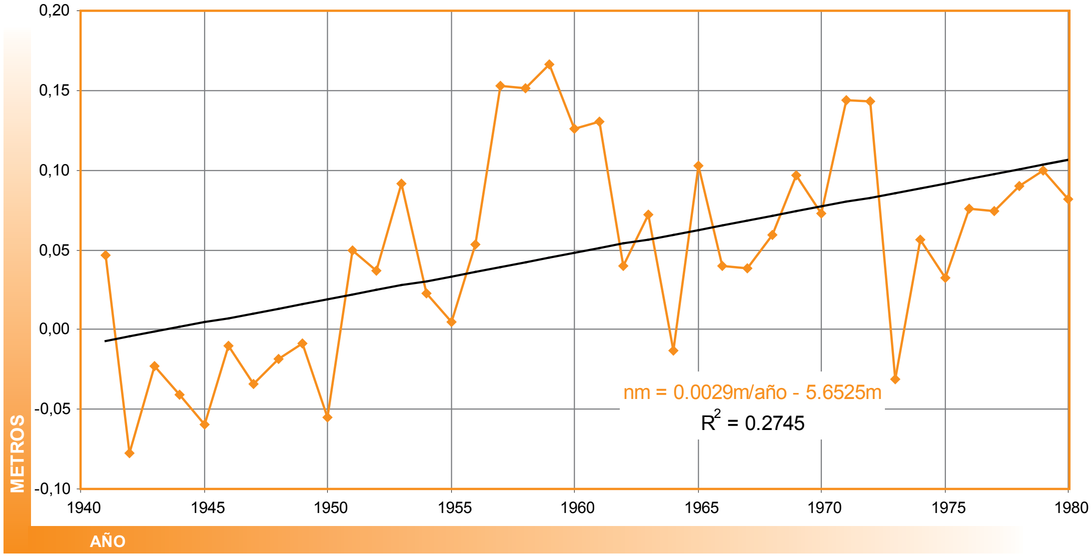

Figure 2. Relative sea level variation trend in Puntarenas for 1940-1980. Data from Permanent Service for Mean Sea Level, Proudman Oceanographic Laboratory.

Figure 3. City of Puntarenas: change in sea level relative to the continental surface for a relative sea level rise of 30 cm (blue) and 1 m (red). From Instituto Meteorológico Nacional de Costa Rica

Climate Change and ENSO in the Eastern Pacific

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According to the Fourth IPCC Assessment Report Chapter 5 (Bindoff *et al.*, 2007) some of the main trends observed in the oceans are: the sea surface temperature (SST) increment of 1.5º C since 1960, warming evidenced until 3.000 m depth, the acidification of upper water with a pH variation of 8.2 to 8.1 during the last 50 years and increase of global sea level of 19.5 cm since 1870.

In addition to these elements, the increment of extreme modifications such as the change of coastal morphology by erosion and flooding has been observed; low lands salinization and the subsequent negative impact in the biodiversity associated to species displacement, modification of natural habitat, and displacement of species distribution areas. Other important multiple effects are the eutrophication increase, coral reef bleaching, mangroves affectation combined with anthropogenic pressures on the marine environment such as contamination, overfishing, urbanization processes and coastal erosion.

One of the unsolved questions is what is the relationship between climate change and El Niño/la Niña Southern Oscillation (ENSO). There are not scientific consensus on this matter, however, at present, there is considerable understanding of what are the main modes of variability in the Pacific Ocean, the inter-annual mode (ENSO), one related with the decadal variability and another of low frequency which could be related to global warming (Latif *et al.*, 1997). Modulation of ENSO by the Pacific Decadal Oscillation (PDO) significantly modifies regional tele-connections around the Pacific Basin (Fig. 1; Power *et al.*, 1999b; Salinger *et al.*, 2001), and affects the evolution of the global mean climate (Trenberth *et al.*, 2007). For the last four decades, the tropical oceans warmed at the fastest rate while the extra-tropical North Pacific and the Northwestern North Atlantic have been cooling at the slowest rate (Lau and Weng, 1999). This factor influenced the intensity of ENSO events when the warm phases of an inter-annual signal, a decadal-interdecadal oscillation and a steady warming trend since 1955 were superposed (Latif *et al.*, 1997; Chavez *et al.*, 2008).

However in terms of Climate change impacts, to some extent the existent variability in the Eastern Pacific has registered extreme warm temperature during last strong El Niño such as 1982-1983 and 1997-1998 events. These perturbations caused severe impact in the marine ecosystems although after some time, they gradually stabilized in some of the cases. After 10 years of last strong El Niño, some of the species could probably get more resilient to SST increase and get adapted to them. One other important element is the overlapping of PDO and ENSO phases. At this moment within the PDO cold phase, ENSO variability could be attenuated in terms of warming and enhanced in terms of cooling, this probably could continue over the next 5-10 years. The main concern about the SST will be the moment when PDO, ENSO and global warming will be in the same phase and the level of expected SST anomalies could be extremely severe and surpass the currently gained resilience of marine ecosystems.

One relevant issue to be considered and highlighted to motivate Governments for action in the ocean and marine areas is the continuous acidification process. The pH has already changed by 0.1 in surface waters due to absorption of anthropogenic CO_2, equivalent to a 30% increase in acidity and threatens marine ecosystems where corals are a key element in their functioning. Several derived questions about the future biogeochemistry of the ocean are still open.

Climate change is a highly visible issue. The available scenarios projected to 2080 or 2100 have been good for awareness and international political positioning but the inherent uncertainty is extremely high. The time scale of projections is not compatible with the time scale of planners and national/local governments and is not being included in the public policies in most of the countries along the Eastern Pacific. According to the information compiled by the Ibero American Network of Climate Change, climate impacts in the ocean and marine areas have not been given the desired priority (Fig. 2). Coastal and oceanographic impacts related with climate change are not well understood yet and require a regional approach and more complex coordination.

Some adaptation strategies could be suggested:

- To provide a clearer picture of the oceanography in the region to Governments, as result of a historical analysis.
- To enhance the marine research related to long term changes in the regional ocean circulation during the last decades.
- To improve regional modeling capacities in order to adjust the current global models outcomes in the ocean
- The foster the dialogue between scientific and operational marine institutions with Governmental authorities to put this issue on the political and economical agenda of the Eastern Pacific countries.

From the oceanographic perspective and with a pragmatic approach, some proposals could be:

- To make the necessary coordination efforts to integrate ocean data and products in the Eastern Pacific.
- To enhance oceanographic research focused on Ocean Circulation and modeling in the Eastern Pacific.
- To promote the regional expected impacts along the Eastern Pacific at political level.

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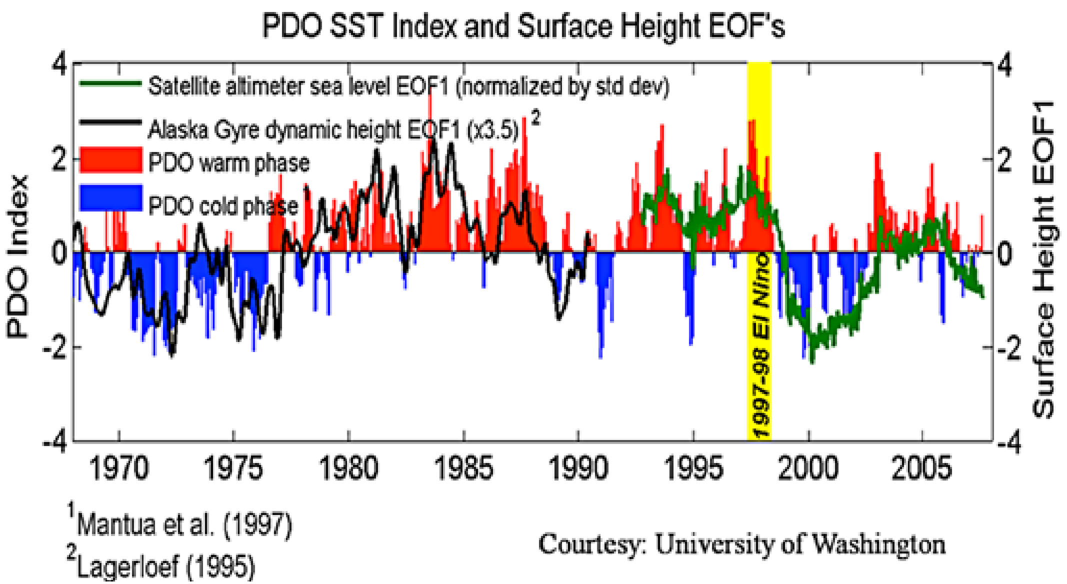
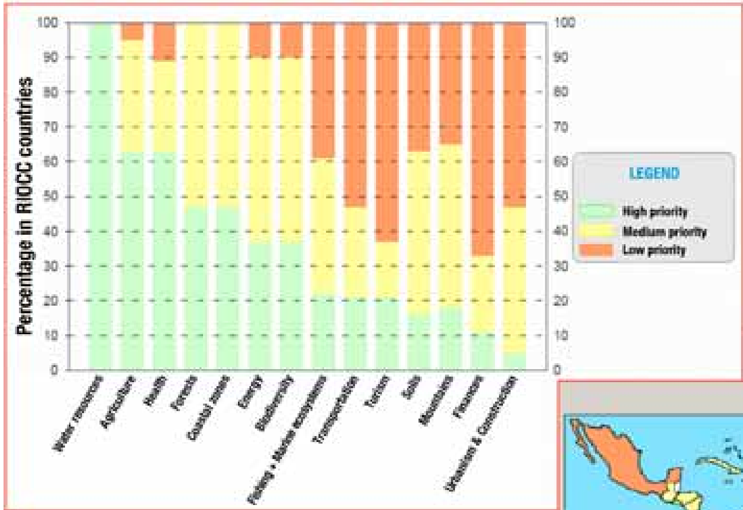


Courtesy: University of Washington

Sumary of Governmental Priorities in Ibero-America



Oceanographic variables affected by climate change - scenarios for the Eastern Pacific

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The first tools developed for making projections and explorations of future climate were General Circulation Models (GCM). For the considerations of change in climate, these models were reinforced with socioeconomic scenarios that hypothesized diverse intensities in the use of fossil fuels and the behavior associated with societies. Coupling these models with General Circulation (coupling because they simulate the ocean-atmosphere interaction) was able to resolve the larger patterns of rising temperature projected for the entire planet if concentrations of Greenhouse Effect Gases (GEG) vary over time. The need to obtain more localized information for these global climate projections stimulated the development of regional models and statistical techniques that can "downscale" the results from the GCM to smaller scales.

When research on climate change was beginning, the models were mainly used to simulate continental climates. The reason is obvious: the first consideration is for the human species. As the panorama of change has progressed, modifications to the scope of the models have been necessary along with the development of specific tools to explore the effects of change on other systems, such as marine systems. Therefore, knowledge about future climate behavior over the oceans and the response of water masses to those changes is a topic that is relatively new. Added to this, the enormous diversity and mobility of species as well as the ecological niches and their interactions complicate analyses of the vulnerability of the system to the climate and its variability and change.

In accord with the most recent conceptualization of the term Climate Change (IPCC 2007), we are coming to the beginning of a ***certain climate change*** as a result of human activities. Why certain? Because the levels of concentration of greenhouse effect gases (GEG) currently found in the atmosphere cannot generate a reaction other than generalized warming of the planet. This global warming has already begun, it is detectable in many parts of the world, it is progressive, it will last for more than a century until reaching radiative equilibrium, and it is already producing effects on the climate of many zones (oceans included).

However, in accord with the projections of the IPCC (2007), there are some probabilities that within the certain change that will take place in this century, ***abrupt climate changes*** will occur that are rapid variations of some climatic component as an outcome of global warming and whose time scale is in decades. In other words, according to the models available, we do not expect the complete dismantling of the polar ice caps, the disappearance of the Greenland ice cap, or even a significant variation in the thermohaline circulation of the oceans in the short or medium term. Even though the results of these projections give low probabilities for abrupt changes, the increase in GEG and the current climatic perturbations engender concerns for greater changes that might develop more rapidly than projected. For example, the current melting rate of the Arctic and Greenland has alerted the scientific community about the effects of the contribution of fresh water into the Labrador current and its implications for the dynamics of Thermohaline Circulation (OMM 2000).

Putting eventual abrupt changes aside, there are alterations documented that, under similar conditions, have produced those that would be expected under climate change scenarios (for example, during El Niño phases) and, even more concerning, changes in oceanic variables that are now being recorded.

One of these variations is ocean pH as a consequence of the absorption of environmental CO_2. Atmospheric CO_2 can be absorbed by the ocean in two ways. The first way is by means of the autotrophic mass that uses solar radiation and atmospheric carbon for photosynthetic processes. However, part of this CO_2 is rapidly returned to the atmosphere. The rest can be deposited in the sea bottom where it remains captured, in all practicality, for hundreds of years. Another means of CO_2 absorption is by dissolution in sea water, producing carbonic acid that lowers ocean pH. This acidification threatens the lives of many species of corals, plankton and a group of mollusks that are among the preferred foods of whales (Royal Society 2005). The acidification of the seas and oceans has been monitored and the trend is growing. The greatest contribution of CO_2 to ocean water is from precipitation. Scenarios of change in future climate revealed by the most recent report of the IPCC (2007) show areas of the Equatorial Pacific where there are high probabilities of significant increases in annual rainfall.

Another oceanic variable that has changed strongly is sea level. With increasing temperatures due to thermic expansion, sea level begins to rise by centimeters on the coast. The Equatorial Pacific is one of the better covered zones in oceanographic and atmospheric observation networks because it is where the ENSO (El Niño Southern Oscillation) phenomenon develops. In accord with these observations, the surface temperature of this basin has increased 0.5°C since1950, the year observations began (Watkins, 2005). See Figure 1. This kind of evidence along with the extensive documentation of coastal erosion as a phenomenon associated with the rise in sea level due to climate change are visible signs of an important change in the oceanic level.

Associated with the thermic expansion of the ocean, reduction in density occurs as a result of changes in the salinity of the seas. One of the engines of vertical water movements is the difference in concentration and temperature. The gradients allow the flow of nutrient-rich cold currents toward the surface, displacing less dense warmer waters. Nutrient upwelling, energy distribution and biological richness can be variables affected by an increase in temperature that deepening of the thermocline, displacement of waters rich in nutrients and migration of species would cause. During warm ENSO events, where the surface temperature of the Eastern Pacific can increase up to two degrees above the normal value, these kinds of variations have been observed to affect not only the fishing but also the marine composition of the waters. Warm-water species have emigrated and appeared in these zones, altering the delicate equilibrium of coastal ecosystems even more.

These are some of the variations observed and documented in recent years that can be associated with a planetary warming phenomenon. The water-land-atmosphere observation network should be enhanced so that it may continue to monitor signs that would indicate where the changes due to atmospheric imbalance are going. The ocean is both a receptor and generator of changes, given its ties to the atmosphere. Therefore, the first step toward adaptation is to estimate, as accurately as possible, the effects of change on the climate and the vulnerability of the systems; otherwise, we will be trying to adapt communities to a threat that we have not finished getting to know.

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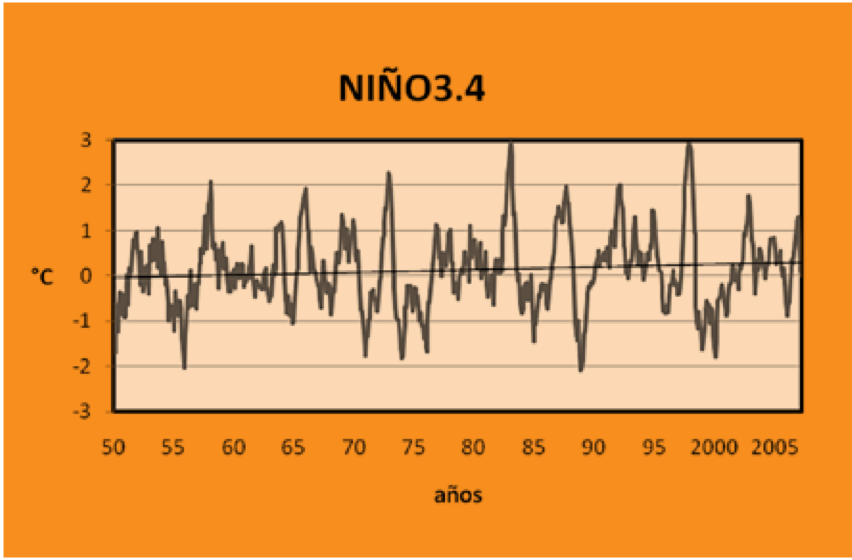

Figure 1. Anomalies and trends in surface temperature of the equatorial basin of the Pacific Ocean, in the Niño region 3.4.

The influence of oceanographic processes on top predator (sea turtle, seabird, marine mammal) distribution

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Oceanic top predators depend on patchy food resources that are determined by complex food-web dynamics, by local oceanographic forcing, and by the natural cycles of climate-driven variability. Because they are long-lived, top predators are well adapted to these sources of variability over evolutionary time scales. However, because of human pressures on their populations, either from direct exploitation or from habitat degradation, several species face serious conservation issues and their ability to cope with anthropogenic climate change may be compromised. Therefore, it is important to gain a detailed understanding of top predator distribution and habitat use in relation to the underlying oceanographic processes, as this knowledge will be valuable in predicting their response under potential climate change scenarios.

Our understanding of the movements and distribution of top predators in relation to environmental variability has seen significant progress in recent years thanks to advances in miniaturized electronic tag technology. Just as crucial has been the availability of high-resolution oceanographic data collected by a constellation of Earth-monitoring satellites (Palacios *et al.*, 2006), which have allowed us to analyze the animals' movements in the context of the local environmental conditions. Under the Tagging of Pacific Pelagics Program (TOPP; Block, 2005), over 2,000 electronic tags have now been deployed on over 20 species of tunas, sharks, turtles, seabirds, seals, and whales in the North Pacific Ocean (http://www.topp.org/). Examples of these studies include leatherback turtles (Fig. 1), Hawaiian albatrosses (Fig. 2), and blue whales (Fig. 3). These studies have revealed unique and persistent migration corridors and foraging destinations through dynamic oceanographic features such as currents, fronts, and eddies that were previously unknown.

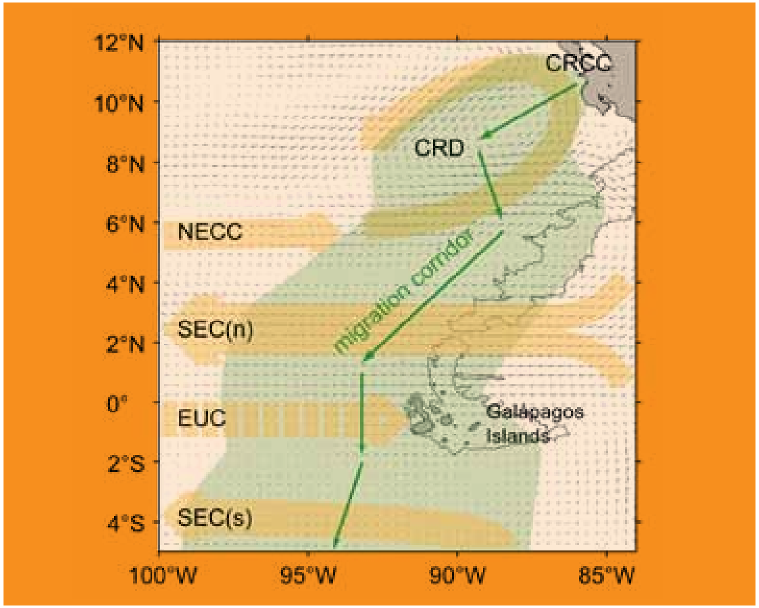

Figure 1. The migration corridor (green swath) of female eastern Pacific leatherback sea turtles, from their nesting site at at Playa Grande, Costa Rica, through the equatorial current system (yellow arrows) (from Shillinger et al., 2008).

Meta-analyses of historical databases can also yield important new insights into the global patterns of top predator distribution. In a recent study combining information in the published literature with a global sea-surface temperature database, we found that the location of all known humpback whale breeding grounds was consistently associated with a particular temperature range (21-28°C), such that the migration distance between the high-latitude foraging grounds and the low-latitude breeding grounds for all populations was dictated by the particular temperature regime in each ocean basin (Fig. 4). Because of this temperature dependence during the breeding phase of their migrations, humpback whales may be particularly susceptible to climate change, and this information will be useful in understanding the potential impact of different climate change scenarios on humpback whale populations.

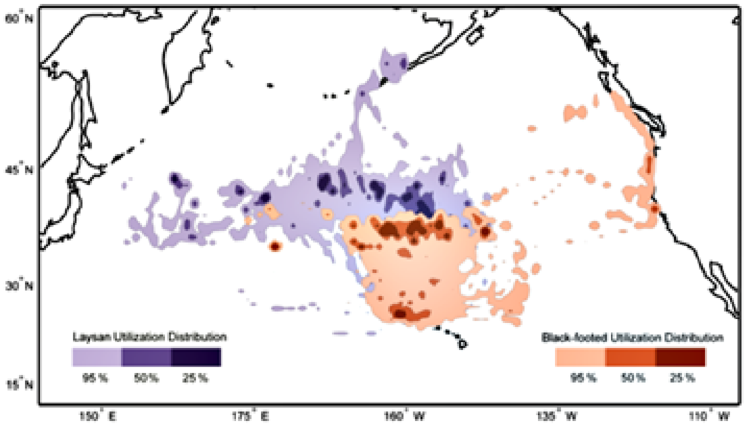

Figure 2. The different oceanic habitats of Laysan and black-footed albatrosses in the North Pacific based on data from animals tagged in Hawaii (from Kappes et al., in press).

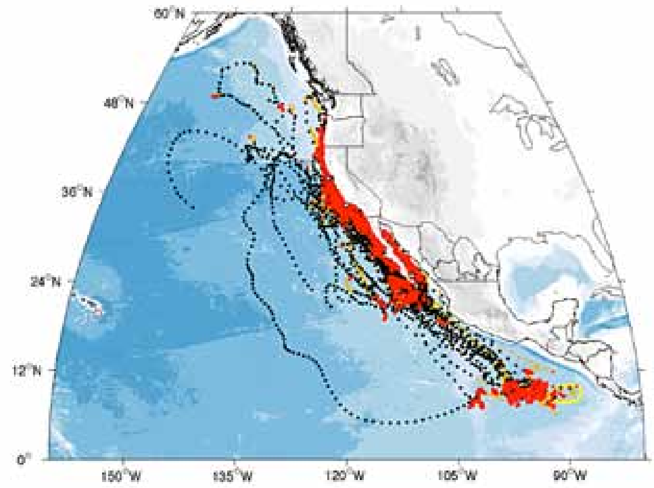

Figure 3. The migratory (black circles) and foraging (red circles) movements of eastern North Pacific blue whales from long-term satellite tracking studies (from Bailey et al., submitted).

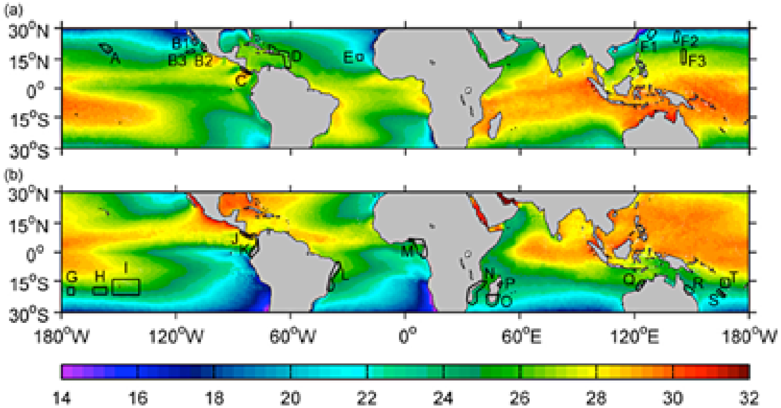

Figure 4. The worldwide distribution of all known humpback whale breeding areas (black polygons, labeled A-F and G-T) in relation to sea-surface temperature (°C) in the northern (a) and southern (b) hemisphere, respectively (from Rasmussen et al., 2007).

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Impacts of climate change on Eastern Pacific fisheries

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Climate change can impact the pattern of marine biodiversity through changes in species' distributions. However, projections on global and regional climate change impacts on ocean biodiversity and fisheries potential have not been performed so far. The major aims of this study are to assess the potential global and regional impacts of climate change on marine ecosystems and fisheries.

We predict the responses of marine fishes and invertebrates to climate change scenarios by developing a dynamic bio-climate envelope model, defined as a set of physical and biological conditions that are suitable to a given species. Using information from the global databases and species distribution maps of the Sea Around Us Project, FishBase and SealifeBase, we predict distribution shifts by evaluating changes in bio-climate envelopes, larval dispersal patterns, adult movements and population dynamics under climate change scenarios. Examinations of the developed bio-climate envelope model, and the resultant predicted distributions, indicate that the model provides reasonable and robust predictions of future distributions (Cheung *et al.* 2008a). Using this dynamic bio-climate envelope model, we project changes in distributions of 1066 species of exploited marine fishes and invertebrates from 2005 to 2050. The projections are based on climate change predictions from the NOAA/GFDL's Coupled Model (CM 2.1). We predict that marine fishes and invertebrates would shift their distribution ranges towards the poles under climate change. Globally, the median rate of shift in range limits is 45-59 km per decade. Our results show that such changes in distribution would lead to numerous local extinctions in the sub-polar regions, the tropics and semi-enclosed seas. Simultaneously, species invasion is projected to be most intense in the Arctic and the Southern Ocean. Together, they result in dramatic species turnovers of over 60% of the present biodiversity, implying ecological disturbances that potentially disrupt ecosystem services (Cheung *et al.* in press).

We also predict the effects of climate change on global fisheries potential. We have developed a statistical model that relates current fisheries potential to bio-geographic and life history attributes of exploited fishes and invertebrates. This statistical model has high explanatory power and is applicable to a wide range of species (Cheung *et al.* 2008b). Using predicted changes in species distributions under climate change scenarios, we apply the statistical model to project changes in potential catch globally for the 1066 species of marine fishes and invertebrates from 2005 to 2055. We show that climate change may lead to large scale re-distribution of global catch potential, with large increase in high latitude regions and a drop of in the tropics. Moreover, maximum catch potential declines considerably in the southward margins of semi-enclosed seas while it increases in poleward tips of continental shelf margins. Such changes are most apparent in the Pacific Ocean.

Regionally, in the Eastern Pacific Ocean, we predict high rate of local extinction, particularly along the continental shelf from southern Mexico to Colombia. Simultaneously, higher rate of species invasion occurs in deeper water and in higher latitudinal regions. Such shift in species distributions, together with changes in ocean primary productivity, leads to a net decrease in catch potential in many areas of the Eastern Pacific Ocean. Simultaneously, catch potential may increase in higher latitude. Composition of species in the catch is also predicted to change. Over-fishing and depletion of exploited populations exacerbate the impacts of reduced catch potential in these regions. Many highly impacted areas are developing countries with insufficient capacity to adapt to these changes. Our study suggests that it is important to consider the potential implications of climate change when designing fisheries management and marine conservation policies.

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Ecology and populations of cetaceans of the Eastern Tropical Pacific

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The Eastern Tropical Pacific (ETP) covers a vast area in the tropical American region of the Pacific Ocean. It is in the area between the northern coast of Peru and the southern coast of the United States (California) and encompasses at least 140º of west longitude. It completely includes the Pacific coasts of Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia and Ecuador.

The ETP is under the direct influence of the Equatorial Current (including its north and south components) and the Equatorial Countercurrent (including its north and south components), as well as local/regional currents of major importance (e.g. the Coastal Current of the Costa Rica Zone). It is also subject to the effects of the Intertropical Convergence Zone (ICZ). One of the main biological and oceanographic characteristics of this region of the Pacific is the presence of the Costa Rica Thermic Dome, a large area (±35,000 km² and ±400 m of depth) where the thermocline is very superficial, fostering massive upwellings and converting the dome into a highly productive oceanic area with large concentrations of plankton, a situation that is not very common in tropical waters (Wyrtki 1964, 1967; Hofmann *et al.* 1981, Gavidia 1983, Umatani & Yamagata 1991, Fiedler 2002).

A total of 43 species of cetaceans have been reported for the ETP. Curiously, only 23.2% of these species are exclusively pan-tropical, while 34.9% are species that are regularly found at the northern or southern margins of the ETP. Some 18.6% of these species are common in the tropics and in temperate or cold waters, 16.3% are cosmopolitan and a relevant 7.0% are endemic to the ETP (*Mesoplodon perrini, Mesoplodon peruvianus* and *Phocoena sinus*) (Reyes *et al.* 1991, Jefferson *et al.* 1994, Reyes *et al.* 1995, Pitman *et al.* 1987, 1988, 1999, Pitman & Lynn 2001, Rodríguez-Fonseca 2001, Daleabout *et al.*2002, Van Helden *et al.* 2002, Daleabout *et al.* 2003, May-Collado *et al.* 2005). Although there is a tendency for these species to be more oceanic, there is an important number of typically coastal species, as well as some species with both coastal and oceanic populations. Given the variable area and surface of the continental shelf in the ETP region (Brenes *et al.* 1995), in some parts it is common to observe oceanic species near the coast (Rodríguez-Fonseca 2001).

Studies have been done for some species that show they have particular ecological requirements that often determine their distribution in the ETP. For example, the blue whale (*Balaenoptera musculus*) has a distribution clearly associated with the Costa Rican Dome and the coast of the peninsula of Baja California, even at different times of the year (Reilly &Thayer 1990, Fiedler 2002). In other species, water temperature determines certain distribution patterns as for some species of dolphins: the spotted (*Stenella attenuata*) and the spinner dolphin (*Stenella longirostris*) seek the warmer waters of the region while the striped dolphin (*Stenella coeruleoalba*) and common dolphin (*Delphinus delphis*) show preferences for waters where the thermocline is more superficial and therefore, the water is fresher. These patterns can even vary seasonally (Reilly 1990, Reilly & Fiedler 1994). Finally, as for other marine regions of the planet, some species are regularly found in the open sea (oceanic waters) due to their preference for squid and other deepwater prey (Jefferson *et al.* 1994).

Population studies of cetaceans have been made for either the entire ETP or just for the Exclusive Economic Zones (EEZ) of the countries of the region or other, more specific areas; however, there have been disparities in the species evaluated and there are also some species of the ETP for which there are no population estimates of any kind. In general terms, it can be said that among the smaller species (less than 4 m), the common dolphin is the most abundant species, as well as the most abundant cetacean species. Among medium-size species (4 to 12 m), the short-finned pilot whale (*Globicephala macrorhynchus*) is the most abundant species and the sperm whale (*Physeter macrocephalus*) is the most abundant species among those of large size (more than 12 m) (Gerrodete & Palacios 1996, Gerrodette & Forcada 2002). For a few species there are total population estimates in the EEZ of countries with ETP shorelines and, at the same time, total population estimates for the ETP. For example, for the short-finned pilot whale, the population in the EEZ of the ETP is estimated at 26,345 individuals (Gerrodette & Palacios 1996), the highest individual population of the EEZ of Costa Rica (8,493 individuals). But total estimates in the entire ETP for the species are very variable, since there are estimates ranging from 60,000 individuals (Sylvestre 1995) to a little more than 300,000 individuals (Gerrodette & Forcada 2002). Although methodologies and years do not necessarily coincide, they give a better idea of the representation of the more local or regional populations in the total for the ETP.

However, there is one case (Table 1) where there are estimates using the same method, the same area and the same species for two different time periods that allows evaluation of trends in species with stable populations (e.g. *Stenella coeruleoalba*), species in decline (e.g. *Stenella attenuata*) or species that are increasing (*Globicephala macrorhynchus*). The two species with known low populations are the blue whale with 655 individuals for all the EEZ of the countries of the region (Gerrodette & Palacios 1996) and the harbor porpoise or vaquita (*Phocoena sinus*), endemic to the middle of the Gulf of California (Barlow *et al.* 1996 en Gerrodette & Palacios 1996), whose population is estimated at 224 individuals. In total, there is some kind of population estimate for 55.8% of the species in the ETP. Table 1 indicates the species for which population estimates have been made within the ETP.

Undoubtedly, there are species with very low populations that are threatened or endangered. Some of these, despite having a wide range of distribution extending beyond the ETP, are also showing this condition in other parts of the planet. The case of the spotted and spinner dolphins (principally) is widely known, as these species have suffered high rates of mortality in tuna nets in the ETP; despite significant reductions of these captures in the last 18 years, recent studies indicate that the dolphin populations are not recovering (Gerrodette & Forcada 2005). In the case of the endemic species, the mere fact of having a very restricted natural geographic distribution means their population sizes are very limited. It should also be noted that all of the planet's Cetacean species are on Appendix I or Appendix II of the CITES convention.

The effects of Global Climate Change (GCC) on cetaceans are not yet clearly explained or understood, although there is key baseline information available. However, it is important to bear in mind that drastic and sustained changes in the environment tend to more critically affect species 1) of large size, 2) that have specific environmental, food or reproductive requirements, 3) that have very restricted natural distribution ranges (endemics) and 4) that have populations more reduced by human activities. Therefore, it is also necessary to consider continuing efforts for reducing aspects of human origin that directly affect cetaceans, which indirectly would keep the impact of GCC from eventually becoming catastrophic for some of these species. Therefore, these are the species on which greater efforts should be concentrated against the effects of Global Climate Change (CCG) that are already present and, in the case of cetaceans, many of the species in the ETP unfortunately display one or several of the traits mentioned above.

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Table 1. Species for which censuses exist in the Eastern Tropical Pacific (ETP) [3]

Taxon/Site	Common name	Entire ETP 1986-1990* (total individuals)	Entire ETP 1998-2000* (total individuals)	ΣEEZs of ETP countries (total individuals) 1996	California EEZ (total individuals) 1995
Delphinidae					
Stenella attenuata	Spotted dolphin	11084,000	836,017	219,366	–
Stenella longirostris	Spinner dolphin	710,203	608,407	240,054	–
Stenella coeruleoalba	Striped dolphin	11203,655	11036,644	245,520	19,008
Delphinus capensis	Long-beaked common dolphin	–	–	100,892	9,472
Delphinus delphis	Common dolphin	11998,762	21856,829	471,641	225,821
Lagenorhynchus obliquidens [1]	Pacific white-sided dolphin	–	–	–	12,310
Steno bredanensis	Rough-toothed dolphin	–	–	55,380	–
Tursiops truncatus	Bottlenose dolphin	–	–	156,914	1,503
Lissodelphis borealis [1]	Right whale dolphin	–	–	–	9,342
Grampus griseus	Risso's dolphin	–	–	61,400	8,496
Globicephala macrorhynchus	Short-finned pilot whale	235,418	429,896	26,345	–
Orcinus orca	Orca or killer whale	–	–	–	307
Phocoenidae					
Phocoena phocoena [1]	Harbour porpoise	–	–	–	52,743
Phocoena sinus [+]	CA harbor porpoise or vaquita	–	–	–	240 [2]
Phocoenoides dalli [1]	Dall's porpoise	–	–	–	78,422
Physeteridae					
Physeter macrocephalus	Sperm whale	26,082	16,838	8,043	756
Kogia breviceps	Pygmy sperm whale	–	–	–	870
Ziphiidae					
Berardius bairdii [1]	Baird's beaked whale	–	–	–	38
Ziphius cavirostris	Cuvier's beaked whale	–	–	–	1,621
Balaenopteridae					
Balaenoptera edeni	Bryde's whale	6,683	11,882	1,331	61
Balaenoptera physalus [1]	Fin whale	–	–	925	935
Balaenoptera musculus	Blue whale	–	–	655	2,250
Balaenoptera acutorostrata [1]	Minke whale	–	–	–	526
Megaptera novaeangliae	Humpback whale	–	–	~175	626

*The value given corresponds to the average of the annual estimates in each period.
+ Endemic to the ETP.
[1] Species with marginal distributions in the northern ETP.
[2] Estimated population of the EEZ of the Gulf of California (part of the total EEZ of Mexico).
[3] Columns 3 and 4 (Gerrodette & Forcada 2002), Column 5 (Gerrodette & Palacios 1996), Column 6 (Barlow 1995).

Oceanography and Cetaceans in the Eastern Pacific

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Research at NOAA's Southwest Fisheries Science Center on oceanography and cetaceans in the eastern tropical Pacific and California Current is reviewed and possible implications of climate change for cetaceans are explored. Oceanographic conditions are the basis of the habitat or environment that determines the spatial distribution and population success of cetaceans. Although there are also top-down effects of fisheries, these are not of concern today; oceanographic variables are bottom-up cetacean habitat variables.

Prey availability is the key. Cetaceans are large-bodied, warm-blooded, and highly-evolved. They are not directly influenced by temperature or salinity changes. What is important is to find dense patches of prey (fish, squid or krill) when food is needed. Oceanographic variables have indirect effects through prey abundance and distribution. Some cetaceans migrate long distances to breeding grounds where they don't feed, but their success on the feeding grounds during the previous season is critical.

These habitat variables vary spatially over a range of spatial and temporal scales. Global patterns of the mean and standard deviation of monthly SST (1982-2008) and monthly satellite chlorophyll (1998-2008) are reviewed. Variability increases toward the poles, primarily due to increasing seasonality. In the equatorial Pacific, inter-annual variability is relatively high. There are two modes of inter-annual variability in the Pacific: the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The ENSO has its greatest amplitude in the central and eastern tropical Pacific and varies on scales of 3-7 years. The PDO has its greatest amplitude in the North Pacific and tends to vary most strongly on scales of 30-40 years.

We have developed cetacean habitat models of the eastern tropical Pacific (ETP) and California Current regions to predict local cetacean densities as a function of oceanographic habitat variables. Results for a few selected species in each region are presented. In the eastern tropical Pacific, eastern spinner dolphins tend to be more abundant in warmer Tropical Surface Water where the thermocline is fairly shallow. Common dolphins are more abundant in cooler waters affected by coastal and oceanic upwelling. The model results are less satisfactory for the Bryde's whale, which has a widespread distribution in tropical and warm temperate waters, because our surveys cover only a small part of its range and cannot define habitat limits. For common dolphins in the California Current, the model results were different than in the ETP; surface salinity and surface chlorophyll were relatively important predictor variables, as well as depth. For Dall's porpoise, a cold-water North Pacific species, the model explained a high proportion of deviance; SST and mixed layer depth were important predictor variables, as well as depth and surface chlorophyll. Blue whales feed along the California coast during the summer; yearly observations and predictions show inter-annual variability of habitat conditions and habitat use.

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The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) states that there are three basic responses to climate change: 1) move to track environmental changes, 2) adapt to changes, or 3) go extinct. Cetaceans are mobile, social and behaviorally adaptive; and long-lived or k-selected; and have been dealing with habitat variability for millions of years. IPCC global climate projections are briefly reviewed: the ocean is warming, although not uniformly; net freshwater flux into the ocean is increasing at higher latitudes and decreasing at lower latitudes, with concomitant changes in salinity of surface waters; vertical structure of the water column is changing, affecting stratification and nutrient input to surface waters. The dramatic retreat of sea ice in the Arctic Ocean, and around Antarctica, will have major consequences for ice-associated marine mammals.

For the eastern tropical Pacific, a weak shift towards 'El Niño-like' conditions is predicted. Weakening trade winds could result in reduced equatorial upwelling and primary production. There is evidence that productivity in the ETP has already declined, based on an analysis of satellite chlorophyll data (Gregg at al. 2003). We are working on modeling the effects of such a change on top predators in the ETP. An Ecopath with Ecosim model of the pelagic ecosystem was forced with a global warming projection of SST, with bottom-up effects on phytoplankton biomass and top-down effects on predator recruitment (Watters *et al.* 2003). Although phytoplankton decline by 50%, animals at higher trophic levels, such as spotted dolphins, decline by only 10-20%, or even increase (yellowfin tuna).

Direct effects of ocean warming are unlikely for most marine mammals, because of their mobility and thermoregulatory ability. Indirect effects on marine mammal populations might include changes in distribution, timing and range of migration, abundance of competitors and/or predators, prey availability, timing of breeding, and reproductive success (Learmonth *et al.*, 2006). Cetacean populations in the eastern Pacific Ocean have experienced and survived climate change in the past, along with severe fishery and whaling mortality. Ecosystem models will be useful to project effects of future climate change.

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Impact of climate change on krill and other food resources of whales in the southern ocean

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In the Antarctic, whales depend on plankton resources. Of these, krill has been recognized as the stapple food of whales since the early XIX century. The analysis of the possible effects of climate change requires an understanding of the mechanisms regulating abundance and distribution of plankton species. Plankton populations depend on the existence of circulation mechanisms that, coupled with the specific features of their life cycles, allow populations to remain within their geographic boundaries.

The main characteristic of euphausiid distribution is their strong association with specific water masses, not based on the physicochemical properties of the water but on the circulation processes generating the different waters showing latitudinal zonation (Tattersall, 1924, Ponomareva y Drobyisheva, 1978, John 1936)

Fecundation is external at a specialized organ in females (the thelycum). Fertilized eggs are liberated in the surface and, generally, they sink to different depths accordingly to the species and hatch. The emerging nauplii ascend while they develop into metanauplii and calyptopes stages and reach the surface. From this stage onwards krill larvae inhabit surface waters (0 to 150 meters), as well as the adult stages whose daily vertical migrations might be as deep as 200 meters (Marschoff, Calcagno and Amieiro, 1998). Sexual maturity is attained at 2-3 years of age (Siegel 2000).

While the eggs of *Euphausia superba,* the species generally known as krill, sink to great depths (between 800 and 1500 meters); those of *Thysanoessa macrura* reach less than 800 meters and those of *Euphausia frigida* and *Euphausia triacantha* are even shallower. *Euphausia crystallorophias* eggs do not sink at all and remain in surface waters for the whole of their life cycles (Makarov, 1979).

These features, coupled with the circulation of surface and subsurface waters, might be used to explain their distribution.

Water circulation is dominated by two main circumpolar currents, known as the West Wind and East Wind drifts. The West wind drift, also known as the Circumpolar Current covers a large latitudinal expanse, its presence is detected in the continental shelves to the north and to the south approaches the Antarctic continent, including most of the subantarctic islands. The prevailing strong easterly winds, with an annual mean of 25 (= 47km/h) knots, are the driving force of this current. The Coriolis force generates a northerly component in surface waters. Thus, within the Circumpolar Current, surface waters move to the north until reaching the Polar Front (formerly the Antarctic Convergence) where they sink below the lighter subantarctic waters. In addition the Circumpolar Current is divided into two main bodies of water, moving at some 35 km/day, The nucleus of the current might move in latitude up to 10 km/day; thus local ephemerous gyres are created, some of them becoming near permanent (Nowlin *et al.* 1977)

To the south, close to the Antarctic continent the winds blow to the west. The resulting surface current flows counterclockwise and is affected by the bottom topography, which creates a series of closed clockwise gyres. In the contact region of these currents develops the Antarctic Divergence, creating an upwards movement of deep water.

In addition to the Convergence and Divergence already mentioned, circumpolar frontal zones are, to the north, the sub-Antarctic front and subtropical convergence. Other fronts develop in the margins of the gyres of the East Wind Drift (an example of these is the Confluence Weddell Scotia) and on the boundaries of the continental shelves.

A number of circulation systems with high residence times allow the stability of plankton populations;

- The gyres found along the Polar Front finally form lenses of water moving to the north and south. Eggs and larvae included in the gyres invade waters of the Circumpolar Current.
- The gyres of the East Wind Drift that retain water for long periods (nine years in the inner Weddell Gyre).

- The East Wind Drift, limited to the north by the Antarctic divergence and to the south by the continental shelf front
- The shelves of the continent and islands.

One of the distinctive characteristics of krill distribution is the invasion of the circumpolar current through the Drake Passage and the Weddell Scotia Confluence by krill larvae from the system of gyres associated with the East Wind Drift.

The dependence of krill in the Scotia Sea on the influx of larvae across the Weddell Scotia confluence is demonstrated by plotting mean stage of krill larvae from a number of cruises and the plot of sizes of larvae across the confluence. In turn, the confluence position is associated with bottom topography becoming relatively stable. On the other hand, the volume of water invading the Scotia Sea is highly variable and determines, both, the presence of sea ice in the Scotia Sea and the size of krill population, a fact already known by whalers. The presence of ice improves development of larvae through offering food and refuge.

Other mechanisms involved are more of an ecological nature. It has not been fully demonstrated yet, but it seems that in the Scotia Sea system in years when the influx of water from the south is dominated by the Bellingshausen gyre the plankton community is dominated by salps.

Climate change will then have a double effect: less ice formation in the Weddell Sea and a change in the water flux across the Weddell Scotia Confluence. The overall effect on krill population and on the krill-salps balance will be significant but its magnitude and long term trends cannot be predicted at this stage of our knowledge. In addition, whales feed on highly aggregated krill. Small changes in the overall density of krill might result in large changes in its aggregation behaviour with the consequence that some of its predators will be benefited.

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Possible physiological and pathological consequences of climate change for cetaceans

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It is now widely recognised that climate change is taking place on a global scale, and that one of its main causes is the high level of anthropogenic greenhouse gas emissions (IPCC, 2001; Learmonth *et al.*, 2006). The Arctic seems to be the most severely threatened ecosystem in this regard (Bradley *et al.*, 2005), but changes are being documented throughout the world (Simmonds & Isaac, 2007; Robinson *et al.*, 2008). Climate change can have several effects on cetaceans, including a shift in distribution, abundance, migration range, community structure, competiton, prey availability/distribution, timing of breeding, reproductive success, and survival (Learmonth *et al.*, 2006). Effects of climate change can be organised in direct and indirect effects. Direct effects are related to changes in the physical environment, whereas indirect effects are due to changes in food availability (Boyd & Hanson, 2006; Laidre *et al.*, 2008). Most of these effects cause different types of stress which may in turn cause immunodepression and open the door for pathological disorders (Burek *et al.*, 2008).

Cetaceans have certain plasticity in their adaptation to changes in their environment and can tolerate quite an array of conditions (Boyd & Hanson, 2006). Nevertheless, this capacity for adaptation requires time. If climate change consequences fall within the margins of their physiological adaptive plasticity, cetaceans may adapt; if the changes go beyond those margins, the result will be pathological disorders and/or possibly death.

Relatively few specific studies have been carried out on the exact effects of climate change on cetaceans. There is not enough baseline data to carry out such studies, and many other factors complicate the attempt at identifying climate-related impacts. No clear causative relationship has been established between climate change and cetacean pathology (Burek *et al.*, 2008).

Some physiological effects related to climate change have been observed but no absolute causality with climate change could be established. For example, sperm whales (*Physeter macrocephalus*) produced less calves in years following an ENSO (El Niño Southern Oscillation) effect (Whitehead, 1997). In fin whales (*Balaenoptera physalus*), ovulation has been found to be suppressed if body condition falls below a certain threshold. Growth rate and age of sex maturity in harbour porpoise (*Phocoena phocoena*) change and appear to be linked to changes in prey availability (Learmonth *et al.*, 2006).

Higher temperatures may physiologically stress organisms, like the bowhead whale (*Balaena mysticetus*) which lives in arctic waters throughout the year (Moore & Laidre, 2006). This stress may increase serological concentrations in cortisol and thus increase the susceptibility to some diseases (Lafferty *et al.*, 2004).

Indirect effects are due to changes in prey abundance and/or distribution. The decline of North Atlantic right whales (*Eubalaena glacialis*) in recent years has been attributed to high calf mortality in relation to increasing sea surface temperature and to a decrease of copepod availability (Learmonth *et al.*, 2006). Climate change has been proved to have negative effects on sandeel availability for harbour porpoises during the coldest months of spring in the Scottish North Sea. This has been identified as the cause of the increase in harbour porpoise strandings due to starvation-induced hypothermia (McLeod *et al.*, 2006). An increase in ice melting may decrease the salinity of sea water, potentially causing higher skin lesion prevalence and severity, leading to physiological stress, which makes cetaceans more vulnerable to natural infections (Wilson *et al.*, 1999).

Burek *et al.* (2008) note that some of the indirect effects of climate change on animal health in the Arctic will likely include changes in pathogen transmission and effects on body condition due to changes in prey and toxicant exposures and other factors associated with changes in human use. Some recent epidemics have highlighted the risk associated with species moving into areas where they had not previously been, like in the case of the striped dolphin (*Stenella coeruleoalba*) epidemic of morbillivirus in the Mediterranean in the early 90's. This epidemic is thought to be due to the transmission of the virus from endemic long-finned pilot whales (*Globicephala melas*) to the immunely naïve striped dolphins (Simmonds & Mayer, 1997; Duignan, 1999). Because they are long-lived and at the top of the food pyramid, pollutant concentrations are of particular importance to cetaceans, and can lead to reproductive failure, endocrine disruption and immunodepression. In case of nutritional stress, lipophilic contaminants are circulated and may lead to increased disease susceptibility (Burek *et al.*, 2008).

Warmer temperatures may allow pathogens to survive longer in the water, and thus increase the range of certain diseases, or the duration of infectivity. Changes in pollutant pathways may lead to higher exposure of cetaceans to these compounds, as well as to events of harmful algal blooms. These algal proliferations have increased in frequency during the last years (Burek *et al.*, 2008). In addition, the decrease in sea-ice will have a series of accompanying anthropogenic consequences due to more intense and long human presence in the Arctic during summer months: there will be an increase of shipping and its accompanying collision risk, entanglement risk will increase as well as chemical and acoustic pollution (Burek *et al.*, 2008).

Most of the effects mentionned earlier have also synergistic effects, and their consequences will not be linear. With so many threats and effects occuring simultaneously, it is very difficult to isolate the effects due solely to climate change, and assess their clear impact.

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Cetaceans, Climate and Sensitivity

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There is now unequivocal evidence that climate change is happening (IPCC, 2008). Species loss is one irreversible change resulting from this and the IPCC estimate that 20-30% of the plant and animal species assessed so far are at an increased risk of extinction if global temperatures rise by only 1.5-2.5ºC.

The International Union for the Conservation of Nature (IUCN) has recently started a process to consider species vulnerabilities and its preliminary analyses suggest that up to 35% of birds, 52% of amphibians and 71% of reef-building corals have traits that are likely to make them particularly susceptible to climate change (IUCN, 2007).

Similar work has yet to be undertaken for cetaceans although several authors have produced reviews considering the susceptibility of cetaceans to climate change, including MacGarvin and Simmonds (1996), Learmonth *et al.* (2006), Simmonds and Isaac (2007), Moore and Huntington (2008), Kovacs and Lydersen (2008), Laidre *et al.* (2008), and Simmonds and Elliot (2009). Impacts on cetaceans will be both direct and indirect, particularly via changes to their prey in terms of its abundance and distribution, and are outlined in figure 1. Climate-mediated changes in human behavior may also have an impact on cetaceans. For example the retreat in sea-ice may allow industrial and fishing activities into sea areas that they have not been able to exploit previously with implications for the marine mammals living there. Similarly, dwindling fish stocks may lead fishers to turn to cetaceans for bait or even as primary targets. Overall, cetacean species with restricted geographical distributions have been identified as especially vulnerable along with those for which polar regions are key habitats.

Laidre *et al.* (2008) developed a climate change sensitivity index specifically for Arctic cetaceans and this suggested that the narwhal is the most vulnerable. Laidre *et al.* looked at nine variables: population size; breadth/extent of geographic range; habitat specificity; diet diversity; migrations; individual site fidelity; sea ice changes; influences of changes in trophic web; and maximum rate of population increase.

Other sensitivity criteria might include:

- the potential for climate change to bring increased inter-specific competition or increased negative interactions with humans, as for example highlighted by Kovacs and Lydersen (2008);
- ‘environmental tolerances’, relating to whether the species’ physiological tolerances – for example to temperature - might be exceeded due to climate change;
- the presence of barriers to dispersal to a new range;
- the genetic diversity of a species (usually assessed for ‘neutral’ genetic markers such as control region sequences or microsatellite profiles);
- susceptibility to capture (i.e. how valued or desired is the species, or its close relatives?); and
- to what extent the species is affected by the seasons, for example environmental triggers that might be disrupted by climate change. (These last five suggestions are based on IUCN 2007, 2008).

In addition, the species red list designation provided by the IUCN might itself be used as a sensitivity indicator.

Simmonds and Smith (2009) reported on an exercise which attempted to apply all the above indicators to a range of cetacean species with widely differing biology, including the narwhal. The initial ranking derived from most to least sensitive was narwhal>gray whale (western population)> southern right whale>gray whale (eastern)>humpback whale>blue whale>boto>common dolphin.

The development of climate change sensitivity indicators was further explored at the Costa Rican workshop where, firstly, delegates were surveyed on their opinions on these indicators and, secondly, via an exercise where cetacean experts considered the sensitivity of cetaceans in the Eastern Tropical Pacific using this approach. More details are available in Simmonds and Smith (2009) and this matter will also be explored in further publications.

It is worthy of note here that delegates at the Costa Rican workshop strongly recommended the development of other indicators that would allow other factors impacting on the taxa in question to be taken into account, including fisheries pressure and chemical pollution. They also urged that weighting should be developed for the indicators, noting that more would be known about some indicators for some species and less for others.

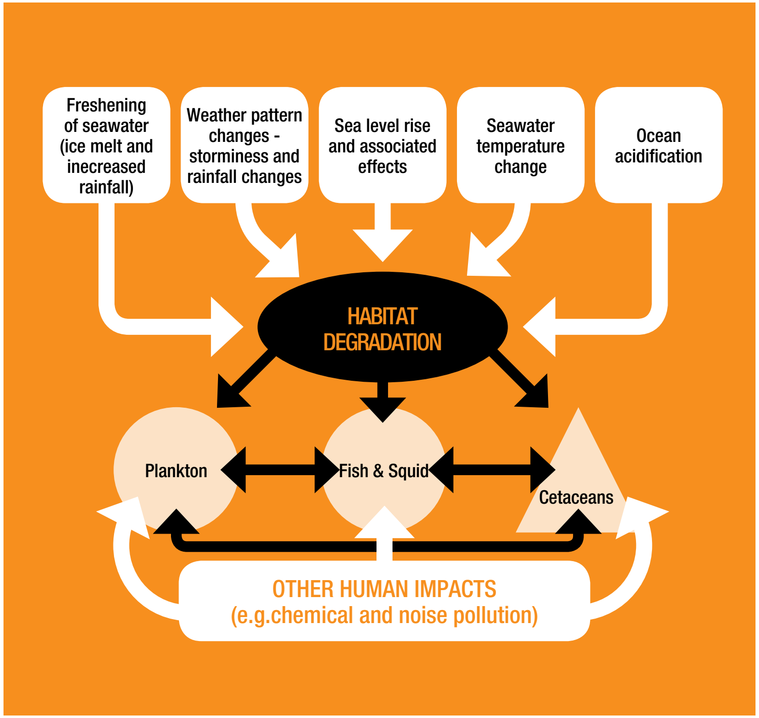

Figure 1. Some of the interacting variables which will be affected by climate change and their links to cetaceans (after Simmonds and Elliot, 2009).

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Vulnerability of top predators to climate change and adaptation options for their coastal and pelagic ecosystems: sharks case study

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The Eastern Tropical Pacific (ETP) covers a vast area of highly productive ocean, bordered on its eastern boundary by the west coasts of southern California south to Ecuador and northern Peru. Its coastal fringe includes all types of coastal habitat – mangroves, rocky shores, sandy beaches, deltas and estuaries. Its open water habitats include the continental shelf, seamounts, oceanic islands, deep sea ridges and the abyssal plain. It supports large fleets of commercial long liners and seiners, but also boasts several marine protected areas (MPA), notably the oceanic reserves of Galapagos (Ecuador), Cocos (Costa Rica) and Malpelo (Colombia) and several coastal areas which include some nearshore islands such as Coiba (Panama) and Gorgona (Colombia).

The ETP lies under the descending limb of the atmospheric Walker cell (Bjerkness 1969), an area where south easterly trade winds push warm surface water to the west, allowing colder subsurface currents to rise. During El Niño events, SST rises as trade winds slacken, upwelling weakens and a deeper mixed layer replaces the shallow thermocline (Conroy *et al.* 2009). It is the upwelling that accounts for the high productivity of the region – the Humboldt Current to the south, the California Current to the north and the Cromwell Current, which rises to the surface along the equator at the Galapagos islands, all drive primary production, the base of the marine food web. Recent analyses show that the Walker Circulation is weakening as a result of human-induced global warming (Vecchi *et al.* 2006). The results of this over the next century may be further warming of the ocean, sea level rise and increasing frequency and intensity of El Niño events.

There are at least 88 species of sharks in the region (Zarate & Hearn 2008), and they inhabit every marine habitat present, from the brackish estuarine bull shark (*Carcharhinus leucas*), to the open water oceanic white tip (*C. longimanus*), and the recently discovered deep water Galapagos catshark, (*Bythaelurus sp. B*). Some species are highly migratory and have a global distribution, such as the blue shark (*Prionace glauca*), whereas others are more sedentary and may be endemic to very small areas, such as the Galapagos bullhead shark (*Heterodontus quoyi*). Several species are heavily fished (sometimes as by-catch, sometimes as target species for their fins) – the scalloped hammerhead (*Sphyrna lewini*), threshers (*Alopias sp.*) and makos (*Isurus sp.*). Little is known about the reproductive behavior and population status of many of the shark species present, so it is difficult to predict how each species will adapt to changing climatic conditions. However, a look into the past might give some insights.

The first chondrychthyans evolved over 450 million years ago. As a group, they are ancient, and highly successful. They have survived through several major extinction events. At the end of the Devonian period, 377 million years ago, 51 of the 70 families of fishes present at the time were wiped out – an extinction rate of 73%, one of the highest ever recorded. This may have been a direct result of the loss of many primary producers, or due to a rapid cooling of the oceans, which would have wiped out many tropical species. The greatest extinction occurred at the end of the Permian, 251 million years ago, when 80-96% of all marine species were lost over a period of 500,000 years. The majority of the extinctions occurred at low latitudes near the equator. Other mass extinctions occurred in the Triassic (212 million years ago) and the Cretaceous (65 million years ago). Each extinction event is thought to have brought about harsh and long-term changes in environmental conditions – biodiversity took over a million years to recover in each case (Klimley in prep.).

One particular species, the giant-tooth shark, *Carcharadon megalodon*, a larger relative of the great white, may have become extinct due to climate change – although in this case global cooling rather than warming may have been the trigger. It first appeared around 65 million years ago, when all the oceans were warm, and it fed on toothed cetaceans, unlike the great white, which feeds on pinnipeds. As the waters cooled during the Pliocene, great whites were able to develop an endothermic physiology, whereas it seems that *C. megalodon* was unable to do this, and was thus cut off from its main prey, who had adapted to living at the cooling high latitudes (Klimley in prep.).

However, current climate change points in the opposite direction – towards warming of the waters. It has been suggested that this may actually be good news for the Australian grey nurse shark, *Carcharias tauras*. This species is split into two isolated populations, one on the east coast of Australia, and one on the west, both of which are endangered. It is thought that the warming of the waters south of Australia may permit mixing of individuals between the populations and thus reduce the risk of extinction (http://www.abc.net.au/news/stories/2008/09/23/2371480.htm).

Until recently, it was also thought that marine extinctions were virtually impossible, and that fertile seas were the source of inexhaustible supplies of fish. This view has changed abruptly over the last few years. According to Myers & Ottensmeyer (2005), many marine species may be vulnerable to extinction because of a variety of factors:

I. Long age at sexual maturity

II. Low reproductive rate

III. Adaptation to an environment with little disturbance

IV. Targeting by industries encouraged to overexploitation through subsidies

Unlike most bony fish, sharks tend to be long lived, attain sexual maturity late in life, and produce few offspring. They generally display low levels of natural mortality, but this makes them especially susceptible to un-natural mortality (such as fishing). Many shark stocks have been driven to dangerously low population levels by unsustainable fishing practices - in a study of 17 shark fisheries carried out worldwide, only one was considered sustainable at the time of study (Stevens *et al.* 2000).

The direct effects of global warming include a rise in sea temperature and therefore a lower level of oxygen in the water, and possible salinity changes in coastal areas due to runoff. While temperature may influence behavior – many sharks will feed in warmer waters and rest in cooler waters (Matern & Cech 2000), their mobile nature may lead to a change in their distribution as they seek optimal conditions elsewhere.

Indirect effects may be more damaging – loss of key nursery habitat such as coastal mangrove areas, and degradation of the food web, starting with loss of primary production resulting from decreased upwelling. Whale sharks may feel the effects directly – their movements have been correlated with the availability of plankton, and Stewart & Wilson (2005) suggested that coral bleaching events, which are related to increasing water temperature, and rapid climate change are amongst the greatest threats to whale sharks.

Chin & Kyne (2007) undertook a vulnerability assessment of sharks to climate change at the Great Barrier Reef, dividing the sharks (and rays) into six functional groups and looking at the climate change drivers which affected each group (Figure 1). They developed a vulnerability index composed of exposure, sensibility (habitat specificity, rarity) and inadaptability (chemical intolerance, trophic specificity), for specific climate change drivers.

There is little that regional managers can do to limit climate change – that is a matter for world governments to address issues such as energy use. However, some of the other pressures on sharks can be relieved to a certain extent, such as overfishing and habitat loss. In the ETP, headway has already been made with the creation of a network of marine protected areas and new legislation regarding by-catch and shark finning. We recommend the following actions be taken:

I. Focus on species which are already of concern due to anthropogenic activities, and on endemic species.

II. Provide protection and/or restoration of key nursery habitats such as mangroves,

III. Reduce fishing mortality. Are shark populations sustainable? If not, their fishing mortality must be reduced regardless of what is done with the meat once the shark is dead.

IV. Research to understand movement patterns, connectivity and population status throughout the area.

V. Protect cold-water refugees (e.g. the endemic Galapagos bullhead shark is found mainly in the cold upwelling western bioregion of the Galapagos islands).

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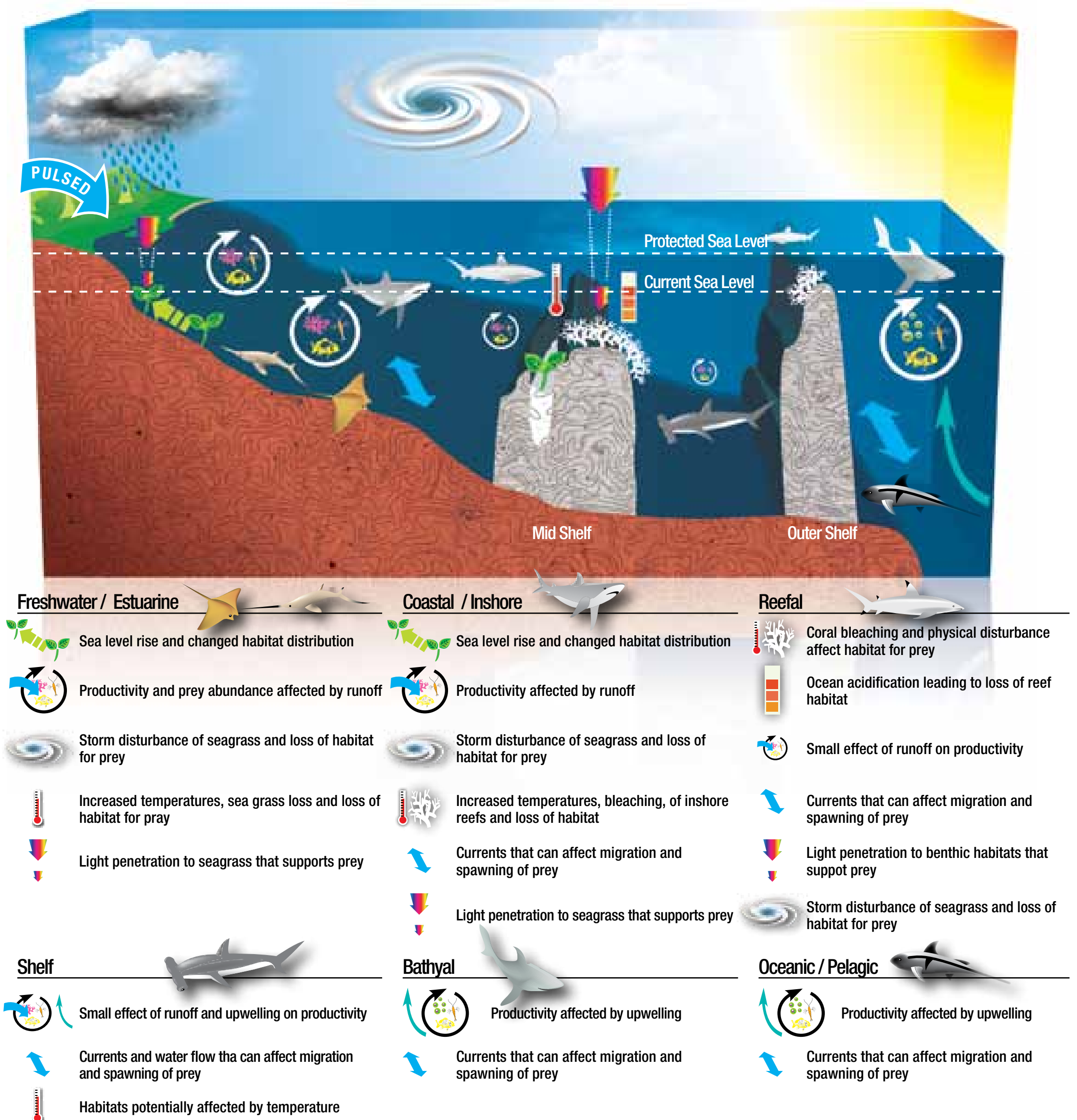

Figure 1. Six functional groups of sharks and rays and the main climate change drivers that may affect the habitats and biological processes upon which they depend (from Chin & Kyne 2007).

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The littoral zone and climate change dynamics: lessons for the Eastern Pacific

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Issues related to coastal zone management are highly relevant to many of the world's coasts because of their many uses, such as coastal defense, tourism, natural ecosystem protection and/or port uses, among others. Given the development of Latin America's coasts (Caribbean and Pacific), it is clear that these activities can generate environmental impacts such as ecosystem degradation, coastline alteration from erosion and sedimentation; diminished water quality, species disappearance, and more as an outcome of inadequate planning and ignorance of the natural processes that occur on the coasts. Moreover, the climate system, such as we understand it today, consists of a series of components (atmosphere, ocean, geosphere, cryosphere and biosphere) that are interacting on different time scales. The effects of climate change have been evident on the elements of the coastal zone and are being studied in earnest by many research groups around the world. In the case of the Caribbean and the Eastern Pacific we are generally learning about some of these interactions but there are many open questions about particular components, spatio-temporal variability, connection with the global climate and effects on the coastal and continental zone.

Therefore we need: 1) to develop new systems for data acquisition and measurement networks that will allow coastal and marine monitoring, with the timely and systematic collection of marine parameters at high spatial and temporal resolution (wave action, currents, water levels, winds, physical-chemical parameters, morphology from video images, etc.); 2) to develop new techniques for the systematic processing of data collected at different spatial and temporal scales, allowing coastal technicians and scientists to use the information and understand the functioning of the systems; 3) to develop new methodologies and numerical tools that help predict coastal behavior; and 4) to create new research groups and testing laboratories in universities and research centers to prepare new generations of investigators and technicians.

Toward this end, the research group on oceanography and coastal engineering (OCEANICOS - http://oceanicos.unalmed.edu.co) of the National University of Colombia, in a consortium with research groups of other countries (Spain, Mexico, Brazil, Italy, England, and others) is currently advancing several projects that aim to explain some climatic interactions on a seasonal and inter-annual scale. The Atmosphere-Ocean-Land Interaction Process project is studying the spatio-temporal variability of winds, sea surface temperature, salinity and sea level in the Colombia Basin through a time series to explain the role of winds in the distribution of water masses, warm and cold coastal pools, the spatial field of sea level and the connection of these processes with the ENSO (Bernal *et al.*, 2009; Ruiz and Bernal, 2008). Wave action, a clear example of an atmosphere-ocean-land interaction, is also being studied to define the maritime climate of the Caribbean and the Pacific and better explain average conditions and extreme events, spatially as well as temporally. At present, the Central and South American countries do not have programs for the ongoing systematic measurement of wave action data in the Caribbean or the Pacific. The deficiency is felt increasingly due to the presence of coastal problems that are often created by the need for new infrastructure, and an understanding of marine dynamics is vitally important for ecosystem protection purposes. In particular, the Eastern Pacific is especially important in terms of marine diversity. Efforts have been made in this realm by many research projects that have allowed the determination of average and extreme wave action regimes in deep waters with various databases, visuals from boats en route, simulated data using numerical modeling (e.g. WaveWatch III, WAM) (Montoya and Osorio, 2007) and satellite images (Agudelo *et al.*, 2006; Osorio *et al.*, 2009). To estimate average and extreme wave action regimes, a methodology is needed that can make use of the scant information in hand and generated by the existing models (parametric and numerical) for the study areas, in order to determine correction equations for the raw data and increase its precision (Agudelo *et al.*, 2006; Banton, 2002; Osorio *et al.*, 2009), so that a sufficiently appropriate model can be proposed for Central and South American conditions.

Finally, the impact of these processes on sea level (flood levels) in the continental coastal zone is being studied. Flood level is the maximum elevation the sea attains due to the joint effect of the variables used for its calculation; it is an unpredictable phenomenon resulting from the combination of different processes occurring in marine dynamics. Methodologies have been used for several decades in different parts of the world to determine flood levels in coastal zones (Cannon, 2007). One of the few studies conducted on flood levels in the Pacific is the one proposed by Agudelo *et al.* (2004) for Colombia. The calculation procedure was proposed in Spain by Medina *et al.* (1997). The determination of the flood level is, therefore, a problem that involves deterministic variables (MA, astronomical tide) and stochastic variables (MM or meteorological tide, Ts or Tsunamis, Qf or Fluvial discharge, and Ru or Run-up), as well as others that cannot be predicted with certainty (Global Climate Change, among others); or, flood levels should be determined via coupled ocean-atmosphere models on a larger scale (ENSO) (see Figure 1). The information available in the existing global and national databases (tides, wind, wave action, hurricanes, etc.) should be processed in accord with the methodology to determine flood levels. The methodology used and applied in some regions of the world, with approximations in the Colombian Pacific (Agudelo *et al.*, 2004) and Caribbean (Martinez *et al.*, 2008) to study the influence of climatic variables on the coastal zone, is considered to be very valuable and fully replicable throughout the Eastern Pacific, and should be added to other global initiatives.

Finally, this document presents the experience acquired by the author in numerous investigations and international consultancies in the following areas: numerical modeling of hydrodynamic processes and the development of image processing techniques in coastal monitoring systems. Regarding numerical modeling of the physical coastal processes, a joint project of the General Directorate of Coasts and the University of Cantabria stands out, having developed a group of pioneering methodologies and tools that allow better understanding of coastal systems and a more reliable model of behavior on the coast (González *et al.*, 2007). The CMS (Coastal Modeling System) is software that integrates a series of specific numerical models prepared in the project to systematize the methodologies proposed. The general structure consists of three major modules: data pre-processing, models and data post-processing. The preprocessing module covers everything related to the analysis of data on wave action as well as bathymetric treatments. The module on models includes different tools for the calculation of wave propagation, study of currents, transport of sediments, evolution of the coastline, etc. Finally, the last module prepares the results for their graphic representation.

Some experiences developed in European, Ibero-American and Colombian projects related to coastal management and the use of innovative video system techniques have been rescued. As some authors have shown, the use of video and image processing allows the study of concrete coastal problems (see Figure 2). The reliability, precision and versatility of coastal video systems have been rigorously demonstrated and reviewed in the scientific literature (Holland *et al.*, 1997; Osorio *et al.*, 2007; 2008). In the European Coastview project (www.thecoastviewproject.org) it was investigated and demonstrated that video systems could support Integrated Coastal Zone Management (ICZM). The European project links some of the most relevant universities and research centers for coastal studies with institutions responsible for management. It had two specific objectives: showing the usefulness of the coastal management system and understanding the morpho-dynamic processes on the coast. Mention should be made of applications related to coastal protection (Kroon *et al.*, 2007; Osorio, 2005).

The experience acquired with the numerical models developed to study coastal dynamics and coastal monitoring techniques have been applied successfully in several parts of the world and recently in Latin America. They are also considered to be very valuable and fully replicable throughout the Eastern Pacific.

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Figure 1. Schematic of factors that have an effect on flood levels.

Figure 2. Panoramic view using three cameras angles at Bocagrande beach (Cartagena,Colombia).

Climate change scenarios in the eastern tropical Pacific - the Galápagos vulnerability assessment

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The Galapagos Islands are recognized worldwide for the high level of endemism (Bustamante *et al.*, 2000) and their pristine marine and terrestrial ecosystems. This is due to the geographical isolation of the islands and late colonization by humans. All species present have adapted to the unique conditions of the archipelago and developed a mechanism to cope with the natural cycles of change. The Galapagos Marine Reserve (GMR) in particular, located in the Eastern Tropical Pacific, 600 miles off the coast of Ecuador, presents a diverse marine biogeography. This diversity is generated by a unique confluence of oceanic currents (Chavez and Brusca, 1991) and a dramatic marine landscape that encompasses coastal platforms, submarine mountains and plunges on all sides to the deep abyssal plain. As climate changes, marine communities shift across fragmented coral reef, rolling *Sargassum* beds, mangrove fringed lagoons, exposed cliffs, hydrothermal vents and vertical drop offs. Endemic species such as the Galapagos penguin and flightless cormorant "stranded" outside the extremes of their normal range have evolved into endemics within upwelled cold water "oases". Meanwhile periodic sustained El Niño Southern Oscillation (ENSO) warming episodes have allowed tropical and Indo-Pacific species to establish and coexist.

Due to strong ENSO events Galapagos is no stranger to regional climate variations. Global climate change over different scales presents a backdrop of increased sea level, sea temperature rise, air temperature rise, rainfall increase and pronounced ocean acidification. These effects could potentially exacerbate the witnessed regional climate impacts of warm ENSO episodes. Compounding human activity over the last 25 years adds a new suite of stressors which alters normal ecosystem function and natural recovery of marine habitats (Glynn and Ault, 2000).

Galapagos provides a globally-unique 'field laboratory' for assessing impacts of climate change on marine biodiversity through well designed experiments and ecosystem monitoring. Global warming will presumably affect communities more through increasing magnitude and frequency of extreme events comparable to El Niño rather than through gradual changes in oceanographic conditions (Reaser *et al.*, 2000; Boer *et al.*, 2004).

How will ecosystems respond to these changes? Which endemic species are most vulnerable and require special protection, what are the consequences of unprecedented levels of fishing or tourism upon the capacity of a marine ecosystem to recover from strong climatic stress? How should the human component adapt, which management measures are most effective and what are the socio-economic and cultural implications? In the terrestrial biome, increased temperatures and rainfall encourages plant and insect growth, but also provides a window of opportunity for invasive species that can rapidly outcompete native and endemic specialists. It also creates a more favorable environment for mammals over reptiles. As climate boundaries shift the risk of exotic terrestrial species and pathogens will also change. The level of human interaction with the environment in Galapagos may also be indirectly affected – as global climate changes, global resources, migration patterns, markets and economies change affecting local regional development and in turn the biodiversity resource.

In light of these scenarios, Conservation International – in cooperation with the Ecuadorian Ministry of the Environment, World Wildlife Fund, Charles Darwin Foundation, and the Galapagos National Park - began a vulnerability assessment for the biodiversity and related human well-being in the Galapagos in September 2008. The goals of this initiative are to assess 1) the likely impacts of climate change on the marine and terrestrial ecosystems and the human communities dependant upon them, 2) the expected response of given species and ecosystems to those impacts, and 3) the actions needed to ensure the adaptability and the resilience of the biodiversity of the archipelago and the human society.

To achieve such goals, the vulnerability assessment involves a number of activities and actions designed to provide critical information for adaptive management and conservation of the Galapagos natural resources. These initiatives include planning, development actions, data collection and revision of available scientific literature as well as conservation initiatives. Moreover, a "science-2-action" process is developed to a) communicate the potential effects of climate change in the Galapagos to local communities, government agencies and other stakeholders and b) develop a mutual communication between all actors on the potential effects of climate change in Galapagos to elaborate recommendation for the adaptive management of the natural resources. All those activities lead to the final "experts" workshop, which brings together experts on the Galapagos marine and terrestrial environments, the local fauna and flora, ocean and atmospheric climate scientists, social scientists as well as the government officials and local stakeholders. This workshop is intended as a starting point rather than the conclusive event of the work done in Galapagos, where a summary is compiled on the expected impacts of climate change on the biodiversity of the Galapagos Islands and the related human communities, such as species population change, disappearance or shifts in emblematic species with impacts on the tourism industry. The workshop also intends to provide recommendations to all stakeholders for immediate adaptation actions needed to address these impacts in terms of urban policy and coastal management plans. Those recommendations will include priority research areas where funding and investigations should be focused.

Our presentation provided an overview of the concepts briefly described above, the vulnerability assessment approach of Conservation International and intends to raise interest in addressing the impacts of climate change in the ETP and particularly in the Galapagos Island to other species and coastal marine habitats other than those discussed at this venue.

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Adaptation to climate change in practice – lessons from marine turtles

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Lack of regional climatic projections is no longer an excuse for inaction in the field of adaptation. General climate trends are already well documented for Latin America in the IPCC reports. Additional, regional analyses indicate, for example, that precipitation will decrease along the Pacific coast in the Northern half of the Mesoamerican isthmus (-10% to -27% A2-high scenario, or -3% to -8% in a B2-low scenario by 2080) and increase in its Southern half in Costa Rica and Panama (3% to 9% under B2-low to A2-high scenarios by 2080) (Hulme & Sheard 1999 WWF and CRU, see also The World Bank 2007). The susceptibility of the coastline to flooding from sea level rise can be easily visualized using the on-line tool by Weiss & Overpeck of the University of Arizona.

The design of adaptation measures for marine ecosystems in the Eastern Pacific needs to take into account the livelihood implications of climate change to coastal communities. Impacts will not be distributed or felt uniformly, as those "with the least resources have the least capacity to adapt and are the most vulnerable" (IPCC 2001). Heavy dependence on ecosystem services places their welfare at the mercy of environmental conditions. As the availability and quality of natural resources decline, so does the security of their livelihoods. Adaptation needs to be conceived as an integral and participatory process that includes the ecological, social and economic dimensions.

Increasingly more coastal communities incorporate marine turtles and their habitats as income generating assets. Turtles as tourist attractions and subjects of research and conservation efforts can generate more than twice as much revenue as their consumptive uses (Troëng & Drews 2004). In the Western Hemisphere alone, there are at least 15 nations and 50 sites, with turtle tourism schemes, including Barbados, Brazil, Cayman Islands, Costa Rica, Ecuador, Grenada, Guyana, Mexico, Panama, Puerto Rico, St Lucia, St Vincent, Suriname, Trinidad & Tobago and USA. The leatherback turtles nesting in Las Baulas National Park, Costa Rican Pacific coast, generate over US$ 2 million yearly. In addition, marine turtle habitats such as beaches and coral reefs are by themselves tourism assets that will be impacted by climate change, affecting local economies.

WWF´s Marine Turtle and Climate Change Program in Latin America and the Caribbean seeks to mitigate the impacts of climate change to marine turtle habitats by designing, testing and rolling-out adaptation measures, in partnership with local and international organizations, as well as governments. Some of the main vulnerabilities of marine turtles to climate change result from (1) increasing incubation temperatures that strongly skew sex ratios to females or cause embryonic mortality, (2) nesting area may be lost to sea level rise, (3) extreme weather events cause beach erosion and rising water tables flood nests, and (4) coral reefs bleach and die. The program rests on two pillars: *ClimAware*: Understanding and visualizing the impacts of climate change, and *ClimAdapt*: Adapting to the impacts of climate change. The main action lines are to: 1. strengthen the knowledge base, 2. design and implement adaptation measures, 3. enable conditions by building and strengthening local capacity and policy instruments, and 4. monitor the impact of adaptation. A toolkit in development includes a review of climate change impacts on marine turtles, manuals for the monitoring of incubation temperature and for beach profiling, GIS on-line tool to assess vulnerability of nesting sites in the Wider Caribbean and Eastern Tropical Pacific, among others.

Adaptation is not rocket science. A blend of out-of-the-box thinking, common sense, and local knowledge often results in feasible and simple adaptation measures (Hansen *et al.* 2003). For example, in Junquillal beach, a leatherback nesting site in Costa Rica, rising temperatures are kept at bay by restoring coastal vegetation with native tree species that cast some shade on nesting areas, thereby reducing incubation temperature by 2-3 degrees centigrade. Planting trees, in addition to removing CO_2 from the atmosphere, is a participatory activity, which engages children and adults, residents and visitors. Nests at high risk of either overheating or erosion are moved to low risk areas of the beach or to the hatchery. The hatchery has thermometers to monitor risk of overheating. A removable shade cover 1.6 m above the ground and water sprinkling are means to avoid lethal incubation temperatures. A flooding model will paint local sea level rise scenarios for the community and decision makers, such that setbacks free of infrastructure may be included into development plans. In this way, the beach will be able to shift inland and the vulnerability of real estate investments reduced. Adaptation is a pillar to be included into community livelihood improvement plans. Marine turtles and adaptation to climate change are useful and pertinent vehicles to illustrate the positive synergies between adequate natural resource management, foresight and local livelihoods in coastal communities.

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Constructing marine conservation networks: Strategies for ecosystemic adaptation[1]

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Our knowledge of the resilience of ecosystems in response to climate change is developing. The fact is that we do not know all the answers about how to manage the impact of climate change on biodiversity. In conservation management of biodiversity, one answer confronting climate change is to distribute the risks of our decisions on biodiversity conservation (Lovejoy, 2006) and the ecosystemic services they provide. We do this when we protect samples of the major types of habitats and at least three replicas of these – and we must distribute them. In this way, we consolidate the redundancy within the system (Salm, 2008). Some elements to consider on resilience (Salm, 2008):

I. Distribute the risk through representativity and replicability

- Try to conserve representative samples of each type of habitat
- Try to include at least 3 dispersed samples and 20% of the area from each bioregion
- Include critical areas (special and unique)
- Include the most resistant areas, e.g. resilient to coral bleaching
- Include areas that host high biodiversity of species
- Include critical habitats for target species

II. Incorporate connectivity patterns

- Use a broad orientation system, which recognizes connectivity patterns between and within ecosystems
- Include whole biological units (e.g. reef systems)
- Prioritize large areas before the smaller ones

The Nature Conservancy (TNC) together with allies such as the World Wildlife Fund (WWF), governments involved and local allies have advanced the implementation of basic elements that search to increase the resilience in the Mesoamerican Reef. This is the second largest reef in the world. There are 326 evaluated sites in this reef , of which 62 show resilience conditions, 21 are included in the protected area system, and 46 are include in the portfolio for conservation of the ecoregion (see figure 1), (Windevoxhel, 2007).

At Kimbe Bay in Papua New Guinea, The Nature Conservancy together with other allies have supported the design and establishment of a network of protected marine areas that are resilient to climate change. Figure 2 shows the system that is based on what MARXAN identified as the ideal and most cost effective network design for protected marine areas that satisfies all defined criteria. The design captures reefs with high biodiversity, high coral coverage and areas known to be resilient to coral bleaching. The risk was distributed by including at least three samples of all distinct types of coastal and non coastal reefs that are located at the eastern and western sides of the bay, since they exhibit different levels of exposure to ocean waves and currents. Likewise, the design considers its connectivity through the size and spread (distance between) the protected marine areas (Salm, 2008).

To conclude, the example of Costa Rica stands as a case at a national level, where institutional and normative arrangements are undertaken. The National Program for Climate Change Adaptation of Biodiversity is developed within the National Strategy for Climate Change, in order to consolidate an institutional and coordinated response to climate change. This initiative seeks to consolidate marine conservation networks as a strategy of ecosystemic adaptation towards climate change, with the support of several projects (e.g. The Costa Rica Forever Project, BID-Golfos, GEF- surpassing protected area barriers). At the present time, the Costarican government intends to:

I. evaluate and map risks and consequences of climate change on biodiversity, ecosystemic service and human well-being

II. develop the Strategy for Resilience of Ecosystems/AP

III. develop the indicators of a Monitoring System for Potential Impacts of CC (PROMEC)

IV. strengthen strategies of ecosystemic adaptation by supporting a network of protected marine areas, the conservation of mangrove areas and the protection of coral reefs

V. keep these areas healthy through effective management

VI. design, advance and monitor projects with communities and other users

Likewise, the institutional capacity is strengthened (in SINAC), through the creation of a marine department and through effective management. An increase of $1M a year in the government budget for national marine conservation (Coast Guard, Incopesca and SINAC) has already been accomplished.

Figure 1. Location of potential sites for resilient reefs and protected areas in the Mesoamerican Reef.

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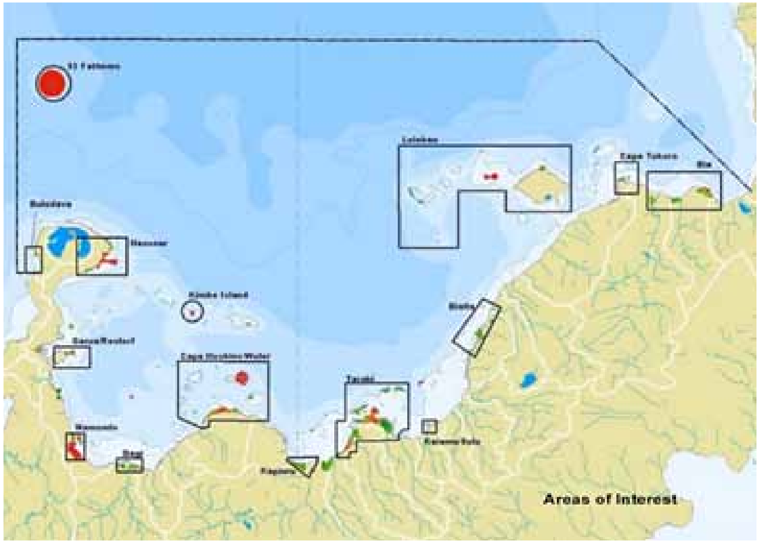

Figure 2. Location of protected marine areas at Kimbe Bay, Papua New Guinea

Appendix A
Additional Resources

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Appendix B
Definitions

Adaptation:

General definitions for adaptation:

- To change to much better match present or future circumstances (Websters dictionary)
- An adaptation is a trait that has been selected for by natural selection. (Wikipedia)

In the context of climate change:

(An) adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions or activities to climatic change and variability (IPCC 2001)

Adaptation is: (a) adjustments to the pace of use or access to the natural resource base in order to maintain a reliable services from the affected ecosystem; or (b) reorganization to reduce exposure to loss or to exploit new opportunities from the affected resource (Arnell *et al.* 2004 World Bank)

A complementary strategy to mitigation for effectively managing climate change risks and must be placed within the context of a country's sustainable development (UNDP & GEF http://www.undp.org/gef/adaptation/climate_change/02.htm)

Adjustment in practices, processes or structures in response to actual or expected climatic stimuli or their effects, with an effort to reduce a system's vulnerability and to ease its adverse impacts (CBD)

Vulnerability:

Patwardhan (2006) defines vulnerability in 5 key steps, the amount of data required to estimate, and understanding of vulnerability, increases through the list:

I. The degree of exposure – a measure of the potential hazards, e.g. a likely range

II. The degree of effects – a measure of the physical impacts caused by the hazards

III. The degree of loss – a measure of the change in benefits caused by the hazards when nothing is done to mitigate

IV. The degree of least loss - a measure of the change in benefits caused by the hazards when the optimal amount is done to mitigate

V. The opportunity cost of inaction – the difference in loss between (v) and (iv)

Resistance:

Resistance is the ability to withstand change

The concepts of resistance and resilience have a long tradition in ecological and applied math circles. Adaptation is more associated with geographers and natural hazards people.

Resilience:

Ability to recover from change

Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb change of state…. And still persist (Holling 1973 Resilience and stability of ecological systems. Annual review of ecological systems 4, pp 1-23)

Resilience for socio-economic systems if often referred to as related to three different characteristics:

I. The magnitude of shock that the system can absorb and still remain within a given state

II. The degree to which the system is capable of self organization

III. The degree to which the system can build capacity for learning and adaptation (Folke *et al.* 2002 Synthesis: building resilience and adaptive capacity in socio-ecological systems: building resilience of complexity and change. Cambridge university press)

The capacity of a system to absorb disturbance and re-organise while undergoing change so as to still retain essentially the same function, structure, identity and feedback (Walker *et al.* 2004 Regime shifts, resilience and biodiversity in ecosystem management. Annual review of ecology, evolution and systematics 3:557-582)


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Conservación Internacional

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