Rising Sea Level Due to Climate Change at Playa Grande

Las Baulas National Park, Costa Rica

Carlos Drews & Ana Fonseca

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Summary

Flooding models under different sea-level rise scenarios are needed to better plan for coastal development and protected areas, in a way such that both marine turtles and local communities benefit. Playa Grande, the most important nesting site of the Eastern Pacific for the critically endangered leatherback turtle, is located in Las Baulas National Park, Costa Rica. It is realistic to expect a 1 m sea-level rise by the end of the century due to climate change. This would imply a 50 m retreat of the beach landwards. Additionally, the high-resolution, digital elevation model reveals that for the most part the inundation of the Playa Grande area will occur from behind. As sea level rises, the water will advance through the mouth of the Tamarindo estuary, and into the surrounding wetlands, inundating part of the land bordering the current mangroves. The future of Playa Grande depends on its ability to retreat as sea level rises and at the same time maintain adequate ecological conditions for the nesting of leatherbacks. This implies that existing and future infrastructure does not hinder the retreat of the beach and that the buffer zone of the national park warrants effective environmental mitigation measures in the light of the future locations of the beach and of the retreat of the mangroves. The law proposal to rectify the boundaries of the park that would reduce its width to a fringe of 50 m would imply that the park would be underwater by the end of the century. The beach would be located inside the proposed wildlife refuge and turtles and their nests would compete for space with houses and other infrastructure. Once the beach retreats against the infrastructure, the wave action against roads and buildings will cause erosion and, consequently, loss of nesting area. In relation to rising sea levels, the proposal to rectify the boundaries of the national park is shortsighted and not precautionary. It would compromise in the mid- and long-term its ecological role as leatherback nesting area, and as such, the very reason for the creation of this particular park. Implementation of adaptation measures to counter the impacts of climate change in turtle nesting beaches is an international commitment under the Inter-American Convention for Marine Turtle Protection and Conservation, to which Costa Rica is a signatory party. With the implementation of such measures, Costa Rica has the opportunity to maintain its regional leadership in the conservation of marine turtles and its status as a world-class reference in biodiversity conservation.

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Inundation simulation based on a high resolution, digital elevation model and implications for park management

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Introduction and justification

Climate change is an important force that is causing changes in coastal ecosystems and will continue to do so in the future. Costa Rica and the nations of the Wider Caribbean will be affected by rising sea levels, increased ambient and sea temperatures, reduced rainfall (northwestern Costa Rica) and more intense hurricanes and tropical storms. Consequences include the loss of beach area and islands, coral bleaching, impoverishment of fisheries, saltwater intrusion into aquifers, flooding of urban areas, increased disease, and other effects. The implications of these processes are profound for community livelihoods and national economies that depend on coastal areas and their natural resources for consumption or as a tourism attraction.

There is an urgent need to make progress on the design and implementation of adaptation measures to mitigate the inevitable local impacts of climate change, both ecological and social. Enormous knowledge gaps still exist and few concrete measures have been widely tested or applied. Rigorous and successful local precedents must be set that will stimulate communities, local governments and national institutions to understand and anticipate the impacts of climate change, and to design and test adaptation measures that will increase the resistance and resilience of ecosystems and their societies. This report is about a pioneer pilot experience in Latin America regarding coastal adaptation to climate change in a protected area of importance to sea turtles.

The July 4, 2009 issue of New Scientist published a review of forecasts for sea level rise due to global warming: in contrast with the projections of 19-59 cm published in 2007 by the Intergovernmental Panel on Climate Change, scientists now estimate that sea level will rise 1-2 meters globally by the end of the century due to accelerated thawing in Greenland and Antarctica, as well as thermal expansion of sea water, among other reasons. A sea level rise of at least 100 cm expected by the end of the century has been accepted as realistic by scientific leaders in the field (e.g. Grinsted, A. and Rahmstorf, S.[1]), and even for future scenarios of the IPCC that are low in greenhouse gas emissions, such as the B1 scenario. There is a registered, general tendency of rising sea levels, the rate of which increases towards equatorial regions [2].

The Costa Rican Pacific littoral zone is not immune to sea level rise. The ***La Nación*** newspaper of August 13, 2007 published projections of the devastating impact of a one-meter sea level rise on Puntarenas, according to data from Costa Rica's National Meteorological Institute and the International Ocean Institute [3]. Rising sea level due to climate change is one of the major threats to coastal communities and the sea turtles that nest on the beaches, because it will cause flooding, saltwater intrusion into aquifers, and it can damage infrastructure, erode key nesting sites and reduce the attractiveness of the beach to tourists.

The inundation regime occurring on coasts through the interaction of marine, coastal and meteorological dynamics is an especially complex phenomenon due to the large number of factors that contribute to the process. Determining these regimes and the erosion and sedimentation processes particular to an area is very important for defining and managing the maritime/terrestrial zone, in particular for the design of coastal adaptation measures for adaptation to climate change and, in general, for integrated coastal zone management plans. One of the essential steps for creating a rigorous model of littoral inundation is the generation of detailed beach topography and bathymetry. However, high-resolution elevation data (below 50 cm) for the Costa Rican littoral zone is currently not available.

Playa Grande is the most important nesting beach in the entire tropical Eastern Pacific for the leatherback turtle (*Dermochelys coriacea*). It is situated in Las Baulas National Park and is one of five very important beaches for leatherbacks in Costa Rica, including Junquillal Beach, which is not a protected area. Besides the leatherback, black turtles (*Chelonia mydas agassizii)* and olive ridleys (*Lepidochelys olivacea*) also nest in Las Baulas National Park. In 1980, there were more than 91,000 adult female leatherbacks in the Eastern Pacific, whereas today the population barely passes 2,000 individuals[4]. At Playa Grande there has been a decline of more than 90% in nestings since the early 1990s.

The leatherback is critically endangered. The main causes of the global decline of its populations have been egg pillaging, nesting habitat deterioration due to accelerated urban development on some beaches and incidental capture in loglines and gillnet fisheries. Climate change is now added to these pressures, and could affect nesting beaches and the proper development of turtle eggs in the sand due to rising sea level and incubation temperature, respectively. Specifically, rising sea level threatens to erode key nesting sites for sea turtles, where infrastructure or natural obstacles impede the landward retreat of the beaches.

The specific decline in nesting at Playa Grande is probably firstly a response to historic egg pillaging, mortality of leatherbacks in longlines and gillnets in their feeding zones, and perhaps light pollution from Tamarindo to some extent. One of the main challenges to the integrity of Las Baulas National Park is its capacity to mitigate the impacts of sea level rise and to consolidate a development scheme in the buffer zone that is compatible with its ecological function as the main leatherback-nesting beach in the Eastern Pacific.

Long-term protection of the natural resources of Las Baulas National Park and a reduction of its vulnerability to climate change will maintain its function as a tourism attraction that generates local and national economic benefits. Las Baulas National Park, for example, generated 1.3 million dollars in 1994, equivalent to one-third of all tourism revenues for the area[5]. Moreover, good coastal planing that addresses vulnerability to inundation due to sea-level rise, could generate economic benefits by minimizing damage to coastal infrastructure and lost investment on vulnerable lands.

Since 2005, WWF has promoted Pacific leatherback conservation in Costa Rica through a model project at Junquillal Beach, Guanacaste. In its four years of existence, this initiative has made profound changes to the relationship between the coastal community and the turtles that come to nest: nest plundering has been reduced from 100% prior to the project to less than 5% today. This effort on the beach is complemented by a regional program from Mexico to Peru, including Costa Rica, which is reducing incidental mortality of sea turtles in the longline fleet of artisanal fishermen.

One of WWF's priorities in the Wider Caribbean and Eastern Pacific region is to design adaptation measures that will reduce the vulnerability of sea turtles and coastal communities to imminent sea level rise. Efforts at Junquillal Beach have become a case study that generates and exports methodologies and lessons learned in the field of community-based sea turtle conservation and adaptation to climate change, among others. Given the global importance of Playa Grande to sea turtles, WWF began collaboration with Las Baulas National Park in 2009 to help estimate the impacts of sea level rise due to climate change and to design adaptation mea-

1 http://www.glaciology.net/Home/Miscellaneous-Debris/rahmstorf2007lackofrealism

2 Miller K.M. 2006. *Land under siege. Recent variations in sea level through the Americas.* Report to the World Bank by the University of the West Indies, Trinidad and Tobago, pp. 41

3 IMN 2000. *Estudios de vulnerabilidad al cambio climático. Informe final.* MINAE, Institute for Environmental Studies, Costal Zone Management Center, San José, 238 pp

4 Spotila, J. R., Reina, R. D., Steyermark, A. C., Plotkin, P., and Paladino, F. V. (2000) Pacific leatherback turtles face extinction. *Nature* **405**, 529-530

5 Troëng S. & C. Drews 2004. *Money talks: Economic aspects of marine turtle use and conservation.* WWF International Species Program, www.panda.org (in Spanish and English)

sures. This report graphically presents the results of simple models to simulate inundation due to sea level rise at Playa Grande and it mentions the implications of the expected landward retreat of the beach for the management of the national park.

Purpose and scope of this study

Massive hotel development and the parceling of real estate for condominiums are exerting major ecosystem pressures in Guanacaste province that are most intensive on the coastal-marine environments, where aquifers, wetlands and mangroves are being affected. The main challenge at Playa Grande is to achieve environmental compatibility of present and future coastal development with the ecological function of the national park. Some properties are still held within the park boundaries and the government as per the corresponding legal ruling should expropriate these. A draft law has been submitted by the Presidency of the Republic for the consideration of the Legislative Assembly that proposes a reduction in the width of the park in order to exclude these properties from the area of maximum protection and avoid the extensive costs of the expropriation. WWF has expressed its opposition to this draft law based on considerations of the implications of sea level rise, arguments that up until now did not figure in the debate. Furthermore, a technical document from SETENA is in preparation about the park buffer zone (500 m wide, see Fig. 9) that will recommend mitigation measures for the environmental impact on the park of development. Construction permits have been paralyzed in this zone until the Constitutional Court makes a ruling on SETENA's recommendations. Consideration of sea level rise is pertinent in these processes because this will determine the location and condition of the beach in the medium and long term.

The purpose of this study is to generate inundation simulations for some scenarios of sea level rise due to climate change, which can be used to raise awareness in coastal communities about this problem and aid the management authorities of protected wildlands in designing infrastructure-free setbacks that will allow Las Baulas National Park to fulfill its ecological function in the long term. We made a tridimensional, high-resolution digital land model of Playa Grande using LIDAR technology[6]. At this stage the study has been limited to generating a simple "bath tub" flooding simulation for the sea level rise projected for the end of the century, based on detailed topography of the littoral zone. However, we also discuss the management implications of projections for beach retreat based on published accounts by other authors. A subsequent stage is expected to generate a dynamic model of the inundation that also considers bathymetry, wave action and the littoral zone's response in shape and size. The latter will allow calculation of eventual reorientations of the beach in the future and the range of extreme storm surges.

Methodology

Playa Grande beach is approximately 4.3 km long with white sand, located in Guanacaste province. Its geographic coordinates are: northern end 10º 20' 44" N, 85º 51' 37" W and southern end 10º 18' 30" N, 85º 50' 11" W. The beach is protected within Las Baulas Marine Park that also includes Ventanas, Langosta and Carbón beaches, the San Francisco and Tamarindo estuaries, and 125 m landward from the regular high tide line. Leatherbacks nest mainly in the center of the beach where there is very little infrastructure at present.

On June 6, 2009, a fly-over of Playa Grande and Junquillal Beach was done in a Piper Azteca PA-23-250 aircraft, equipped for flights with simultaneous LIDAR and digital photography technology. Flight hours for Playa Grande were 08:04 to 08:16 am and for Junquillal from 08:21 to 08:28 am, which determines the tide level shown in the photographs. At the time of the overflight on that day, low tide was at 7.35 h (46 cm) and high tide was at 13.52 h (265 cm) in Puntarenas as a point of reference. Thus, the photographs portray low tide conditions. During the flight laser data were captured with a LIDAR Leica ALS 50 II sensor for generating the Digital Terrain Models (DTM, see Fig. 4) and Digital Surface Models (DSM) from the lowest low tide point to 500 m landward, with a resolution of 4 to 5 points/meter2 and an altitudinal precision of 15 cm. Additionally, aerial photos were taken on a 1:30,000 scale with a medium format RCD 105 digital camera that were then ortho-rectified (Figs. 3, 5-10). The images were integrated into a tridimensional vision system called Stereocaptor to produce animations[7] of the possible inundation of Playa Grande under different sea level rise scenarios (from 0 to 150 cm, every 10 cm).

The anticipated 50-m retreat of the beach landward has not been reflected in the simulations of simple inundations. In order to illustrate this retreat, the orthophotograph of the future scenario in Figure 8 was edited using Adobe Photoshop, moving the beach landward and maintaining current building locations as points of reference. In Figures 9 and 10, lines are used to indicate the modified boundaries of the beach as a consequence of their eventual future displacement.

Results and discussion

Simulation of the inundation of Playa Grande

One important preliminary step toward the definition of adaptation measures for sea level rise and global warming due to climate change are accurate local inundation models that take the greatest number of atmospheric, terrestrial and oceanographic variables into account. Inundation modeling is a complex process that involves several analytical stages of the marine-coastal and atmospheric dynamic. As a first stage, a digital land model was generated using LIDAR technology, an aerial sensor that scanned the beach with laser beams, yielding high-resolution data on topographical elevation. A possible inundation was simulated statically based on this topography, orthophotography and different sea level rise scenarios (0 to 150 cm)[8]. These simulations, images and maps are useful tools for raising awareness and helping governmental and civil society decision makers plan the incorporation of sea level rise into protected area and coastal development management. The next stage of this project will gather and add data on wave action, tides, bathymetry, currents, tectonics, precipitation, temperature, and more to the topographic data, to analyze a wide range of vulnerabilities and generate a more accurate, dynamic model of beach movement and inundation due to the impact of climate change on these beaches.

According to the most recent estimates of a one-meter sea-level rise anticipated for the end of the century, the beach at Playa Grande will retreat some 50 meters during this period [9], as the beach is pushed landwards by wave action as the sea level rises. Under this assumption, Figure 9 represents the landward displacement of the beach, relative to the current tide line. The public zone of 50 meters and the maritime-terrestrial zone will gradually shift landwards too. If there were buildings in this zone, in the future nesting turtles would compete directly for space with houses and other infrastructure as the beach shifted to surround those buildings. In theory, this could turn out to be the case with regards to some of the buildings now in existence (Fig. 10), although it is unknown whether the nesting zone preferred by the leatherbacks will include these specific stretches of

6 LIDAR (*Light Intensity Detection and Ranging*): This is an active laser system that works in the visible, ultraviolet and near infrared spectrum. It has applications in studies of the atmosphere and as an altimeter in overflights that generate very accurate digital elevation models.

7 These animations are not included in this report and are distributed by WWF upon request.

8 Modifications to the littoral zone during the period contemplated in the simulation are not illustrated. This simulation is also known as a *bathtub model of sea level rise*. It does not take the retreat of the beach as sea level rises into account.

9 Source: Díaz-Andrade, J.M. 1996, *Análisis de la vulnerabilidad de la zona costera ante el ascenso del nivel del mar por un cambio climático global – Costa del Pacífico de Costa Rica, Informe final del Proyecto Centroamericano sobre Cambio Climático, Comité Regional de Recursos Hidráulicos*. San José, Costa Rica.

the beach in the future. However, once the beach reaches the infrastructure, wave action on roads and/or buildings will cause erosion and loss of beach area. In Bonaire, for example, it is estimated that 32% of the beach area will be lost with a sea level rise of 50 cm, due to the infrastructure and natural obstacles that would impede the gradual retreat of the beach[10]. It is essential that the current size of Las Baulas National Park is maintained and buffer zone measures are defined to compensate for beach displacement so that the park best fulfills its ecological function in the short as well as the long term.

According to the preliminary simulation for a 1-meter sea level rise, it is very probable that a large part of the inundation of the Playa Grande zone would occur from behind, as sea level rises and water advances via the mouth of the Tamarindo estuary and the surrounding wetlands, flooding some lands adjacent to the current mangrove area (Figs. 1, 2, 5 and 6). The small estuary zone of Ventanas Beach will be significantly inundated, making the road parallel to the beach and the buildings in this sector highly vulnerable (Figs. 7 and 10).

A quantitative assessment of the current tectonic tendency in the area is still pending, in order to estimate the component of sea-level rise due to the subsidence of the continental platform. The west coast of the Nicoya peninsula, on which Playa Grande is located, is subsiding. Observations in Junquillal beach suggest, that in fact, the mean sea level is rising along this stretch of the coast. It is evident that the official landmarks of the public zone need to be relocated inland, since their distance to the ordinary high tide line is noticeably less than 50 meters. The tendency of the relative sea level in Puntarenas for the period 1941-1978 is a net rise, with a total increment of 51 mm over that period. The current high tide level (usually drawn and defined as the boundary between the maritime and terrestrial domains for cartographic and legal purposes) is inundated approximately 8% of the time. However, if average sea level rises by 1 m, this value increases to 51%, which is the percentage of inundated time currently corresponding to the mean tide level (mean between the average low and the average high tide). Unfortunately, there is lack of data series for changes in sea level along the Pacific littoral of Costa Rica, which have the continuity and duration needed to estimate with more precision these tendencies for several locations along the coast (A. Gutiérrez, personal communication).

Sea level rise is a gradual process. Extreme tidal action will increasingly reach those areas that today seem safe from inundation. Along the northern Pacific coast of Costa Rica, spring tides can reach up to 1 m above the level of ordinary high tides[12]. This preliminary flooding simulation does not reflect that a 1-meter sea level rise by the end of the century, considered realistic by the scientific community, would probably also completely inundate the 50-meter strip of the current public zone. Figure 8 reconstructs the eventual location of the beach by the end of the century, displaced some 50 m landward, and it illustrates how some buildings would be immersed on the beach (also see Figs. 9 and 10). The estimated 50-meter retreat of the beach by the end of the century due to sea level rise means that the current public zone will be totally submerged by that time (Fig. 9). The draft law for rectifying the boundaries of Las Baulas National Park[11] (in review by the Permanent Special Commission for the Environment of the Legislative Assembly) would reduce the park to this 50-meter strip, condemning it to be under water in the future and, thus, to disappear by the end of the century. In addition will be completely within the proposed wildlife refuge, in immediate conflict for space with buildings and other infrastructure. Under these conditions, the ecological function of the beach as a leatherback-nesting site would be seriously compromised.

Figures 8, 9 and 10 are approximations of the possible impact of the retreat of the beach due to sea level rise but this estimate could be made more accurate in a one-to-two year investigation of Las Baulas National Park[10] that would consider the evolution of wave action, winds, tides and the topography under climate change scenarios in a way that would also reflect the intrusion of peak high tides, to generate a dynamic inundation model with probability levels for normal and extreme events. Infrastructure-free setbacks must be designed to reduce the vulnerability of the investments in coastal development to the flooding due to rising sea level and so as not to block the formation of new beach inland, thus maintaining conditions suitable for nesting sea turtles. Such setbacks are a fundamental tool in sea turtle conservation, particularly in the context of adaptation to climate change[12].

Infrastructure-free setbacks to compensate for sea level rise

The *Manual sobre técnicas de manejo y conservación de las tortugas marinas en playas de anidación de Centroamérica*, published in 2008 by the Inter-American Convention for the Protection and Conservation of Sea Turtles, of which Costa Rica is a member, indicates that " … a periodic record should be made of the distance from several points on the beach to fixed points on the coast, such as buildings and boundary markers … These records are necessary for designing the inclusion of setbacks (zones behind the beach with no infrastructure) in land-use regulatory plans as an adaptation measure to sea level rise." Las Baulas National Park has still not designed the setbacks that are technically necessary to compensate for sea level rise, such that the beach can retreat landward and continue exercising its function as the most important nesting site of the Eastern Pacific for leatherbacks, a critically endangered species.

The setback zone is essential to maintain the integrity of the coastal vegetation strip, which will also shift farther inland; the vegetation functions as a natural barrier for mitigating the effects of artificial lighting from buildings that disorients the turtles, and also provides shade that can reduce the probability of nest overheating[13]. Furthermore, prudent setbacks must also be established to allow the gradual retreat of this park's mangroves without harming their ecological function. National parks should be designed to fulfil their protective function long-term. WWF is preparing to work in coordination with SINAC and the authorities of Las Baulas precisely to address this challenge.

International commitment to adaptation to climate change

In April 2009, during the 4th Conference of the Parties to the Inter-American Convention for the Protection and Conservation of Sea Turtles held in San José, the government of Costa Rica (a signatory nation) proposed resolution CIT-COP4-2009-R5 *Adaptation of sea turtle habitats to climate change*, which was approved by consensus. This trailblazing resolution urges signatory nations to design, identify and implement stronger corrective measures and adaptations to climate change in management plans, regulatory plans, and programs for the protection and conservation of sea turtles and their habitats, among others. The implementation of corrective and adaptation measures is an international commitment, in which Costa Rica is already showing clear leadership with regard to sea turtles, as demonstrated by the conservation project at Junquillal Beach where adjustments in management are now being implemented on the beach to mitigate the impacts of climate change. This kind of initiative is pending for Las Baulas National Park and the other Costa Rican nesting beaches of regional and global importance.

10 Fish, M.R., I.M. Cote, J.A. Gill, A.P. Jones, S. Renshoff and A.R. Watkinson. 2005. *Predicting the impact of sea-level rise on Caribbean sea turtle nesting habitat.* Conservation Biology 19:482-91.

11 Expediente No. 17.383, "Rectificación de Límites del Parque Nacional Marino Las Baulas y Creación del Refugio de Vida Silvestre Las Baulas de Propiedad Mixta"

12 Fish M.R., I.M. Côté, J.A. Horrocks, B. Mulligan, A.R. Watkinson and A.P. Jones. 2008. *Construction setback regulations and sea-level rise: mitigating sea turtle nesting beach loss.* Ocean and Coastal Management 51:330-341.

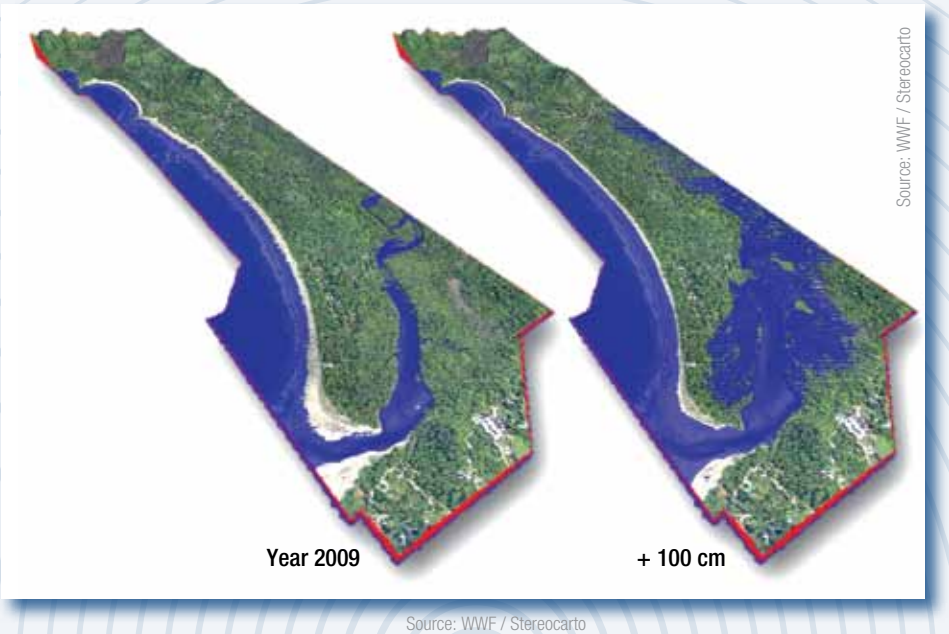
13 Measurements made by WWF at Junquillal Beach indicate that the coastal vegetation strip can reduce incubation temperature by 2-3 degrees Centigrade along the higher elevation stretch of the beach.

Conclusion

Flooding models are needed for different sea level rise scenarios in order to better plan for coastal development, in a way that would benefit both sea turtles and local residents. This project aims to contribute case studies to enhance knowledge of the coastal processes associated with climate change on beaches of the tropical Eastern Pacific that will allow better management of the challenges of erosion, territorial management, conservation of marine-coastal biodiversity and responsible development. The future of Playa Grande beach depends on its capacity to retreat from rising sea levels while maintaining ideal ecological conditions for leatherback nesting. This implies that existing and future infrastructure must not block this retreat and that the buffer zone of the national park ensures effective environmental mitigation measures for the future landward location of the beach. Due to the forecast retreat of the beach, a rectification of the park boundaries that would reduce its current width and allow continued development of infrastructure within the 125-meter strip above the current regular high tide level is neither a precautionary nor a preventative measure and it would compromise in the medium and long term its ecological function as a leatherback nesting site, the very reason for which this protected area was declared. The implementation of adaptation measures for climate change on nesting beaches is an international commitment under the Inter-American Convention for the Protection and Conservation of Sea Turtles, to which Costa Rica is a signatory party. In implementing such measures, Costa Rica has the opportunity to maintain its regional leadership in sea turtle conservation and as a global reference in biodiversity conservation.

Figures

Figure 1. Inclined orthophotograph of Playa Grande illustrating the inundation area corresponding to a 1-meter sea level rise, probable by the end of the century.



Source: WWF / Stereocarto

Figure 2. DTM image of Playa Grande topography illustrating differences in elevation details in relief with 15-cm vertical resolution and the inundation area corresponding to 50-cm and 100-cm sea level rises.

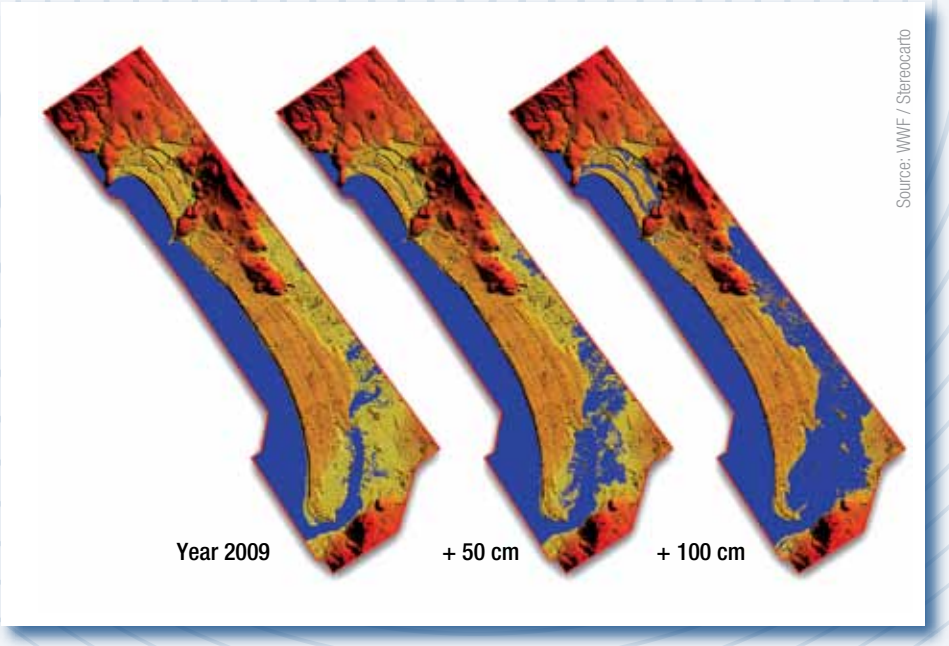


Figure 3. Inclined orthophotograph of Playa Grande, taken on June 6, 2009.

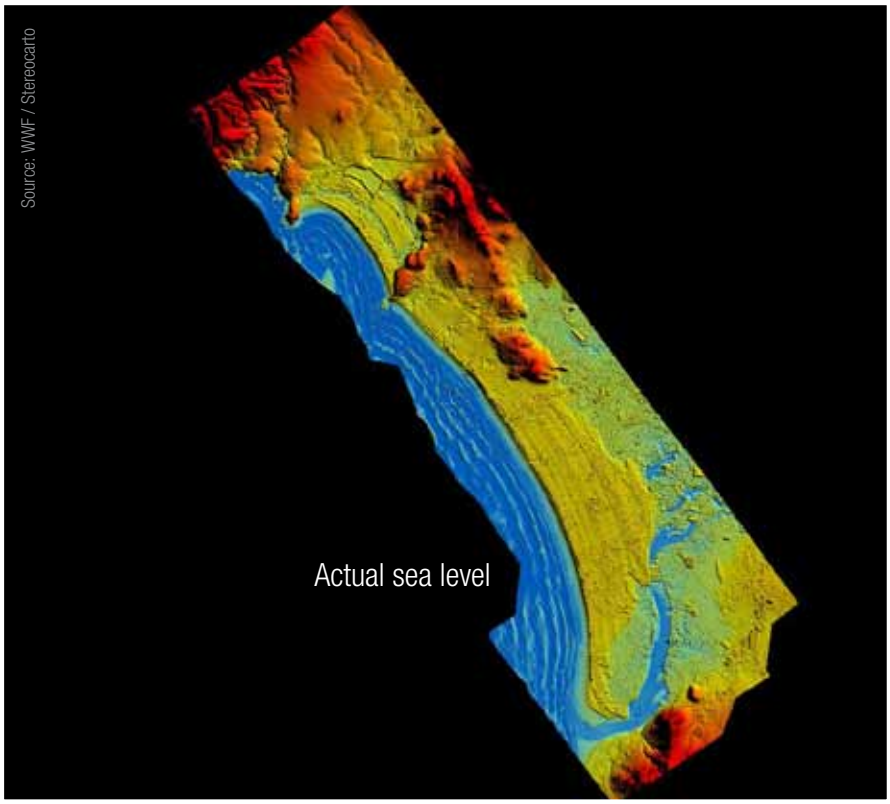


Figure 4. DTM image of Playa Grande topography illustrating details of differences in elevation in relief with 15-cm vertical resolution. Note the low elevation of the mangrove zone around the Tamarindo estuary and the estuary behind Ventanas Beach. The beach dune stands out with an elevation a little higher than the landward terrain behind it.

Figure 5. Comparison of vertical image orthophotographs of the eastern sector of Playa Grande illustrating current sea level (above) and the inundation area with a 100-cm sea level rise, estimated for the end of the century. This image does not include the expected 50-m displacement of the beach landward (see Fig. 9).

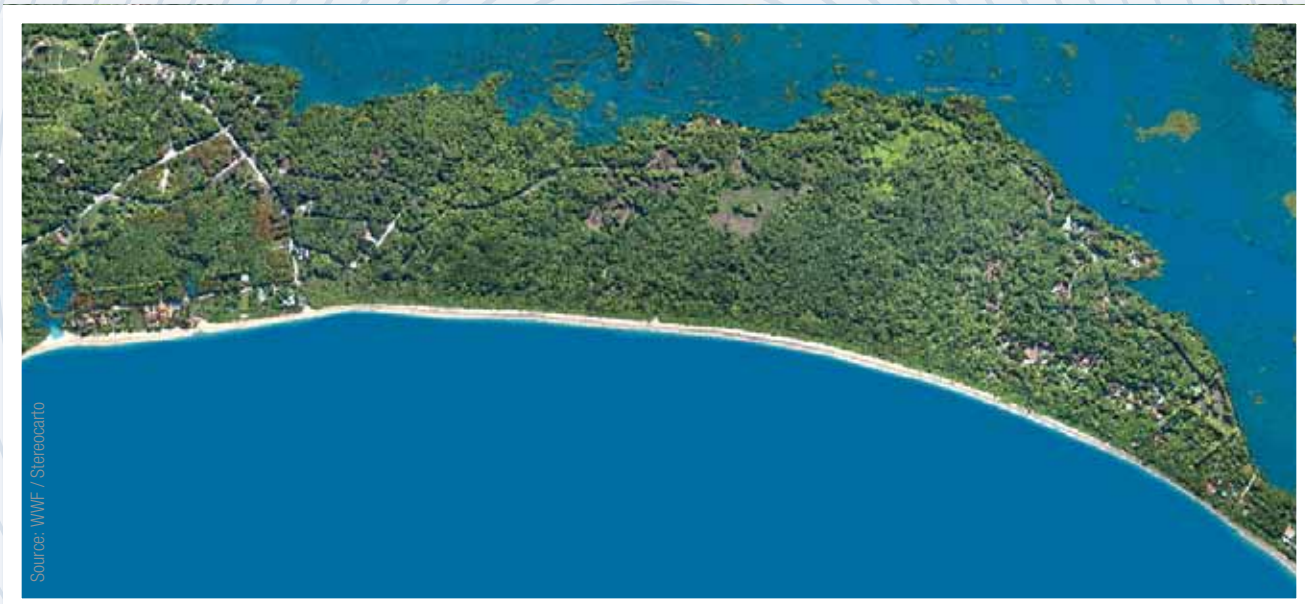


Figure 6. Comparison of vertical image orthophotographs in the central sector central de Playa Grande illustrating current sea level (above) and the inundation area with a 100-cm sea level rise, estimated for the end of the century. This image does not include the expected 50-m displacement of the beach landward (see Fig. 9).

Figure 7. Comparison of vertical image orthophotographs of Ventanas Beach, western sector of Playa Grande, illustrating current sea level (above) and the inundation area with a 100-cm sea level rise, estimated for the end of the century (below). This image does not include the expected 50-m displacement of the beach landward (see Fig. 10).

Source: WWF / Stereocarto

Source: WWF / Stereocarto

Figure 8. Comparison of vertical orthophotographs of Playa Grande illustrating current sea level (above) and a 100-cm sea level rise, estimated for the end of the century (below). This image recreates the expected 50-m displacement of the beach landward in response to sea level rise. Some buildings would end up on the beach, subject to the impact of storm surges. Note that the road parallel to Ventanas Beach is highly vulnerable to eventual erosion, as it is situated on a narrow sand bank, flanked by water on both sides and exposed to the beating of the waves and storm surges (left side of the image).

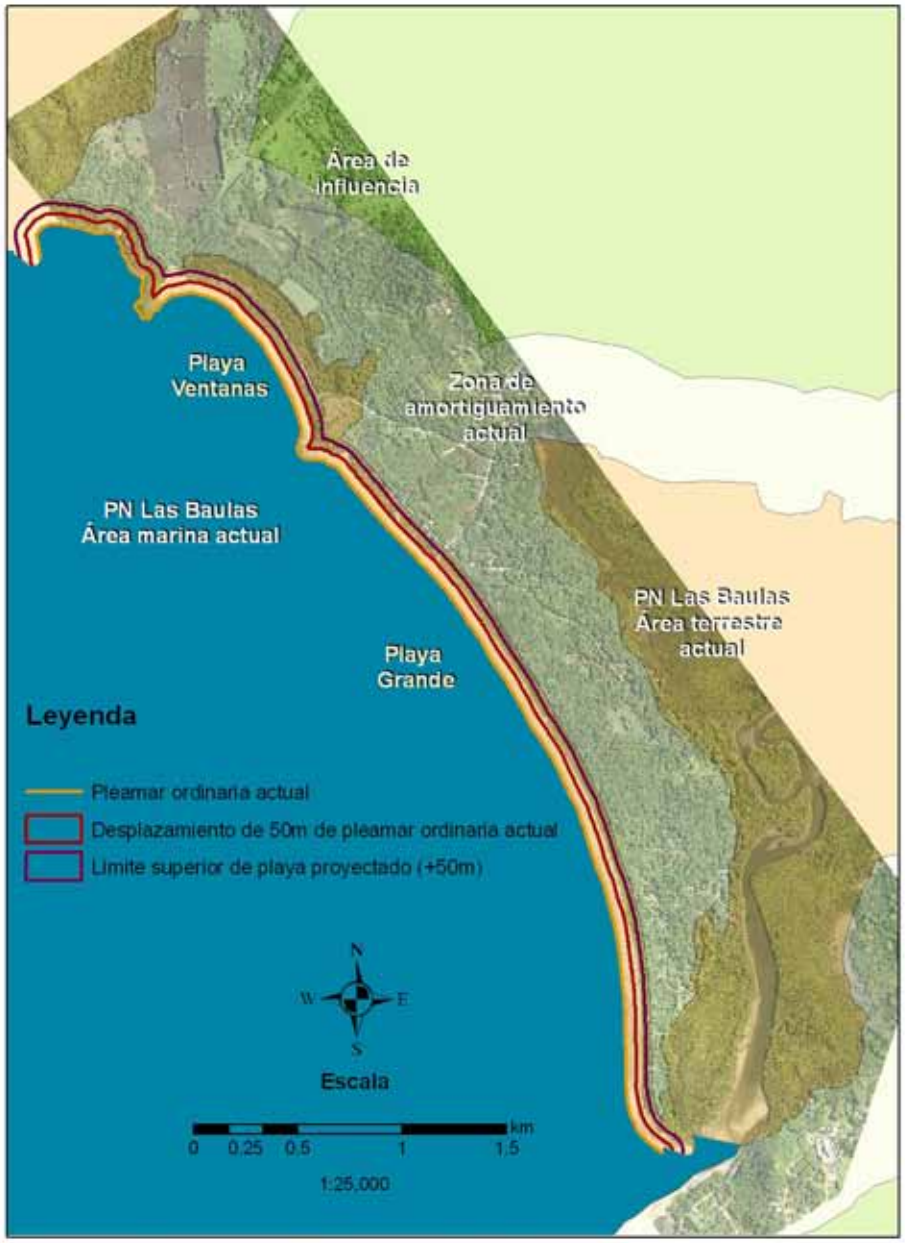


Figure 9. Vertical orthophotograph of Playa Grande, illustrating areas of Las Baulas National Park in this sector, as well as the expected landward displacement zone of the beach of 50 m in response to sea level rise, estimated using the Bruun rule (see the text).

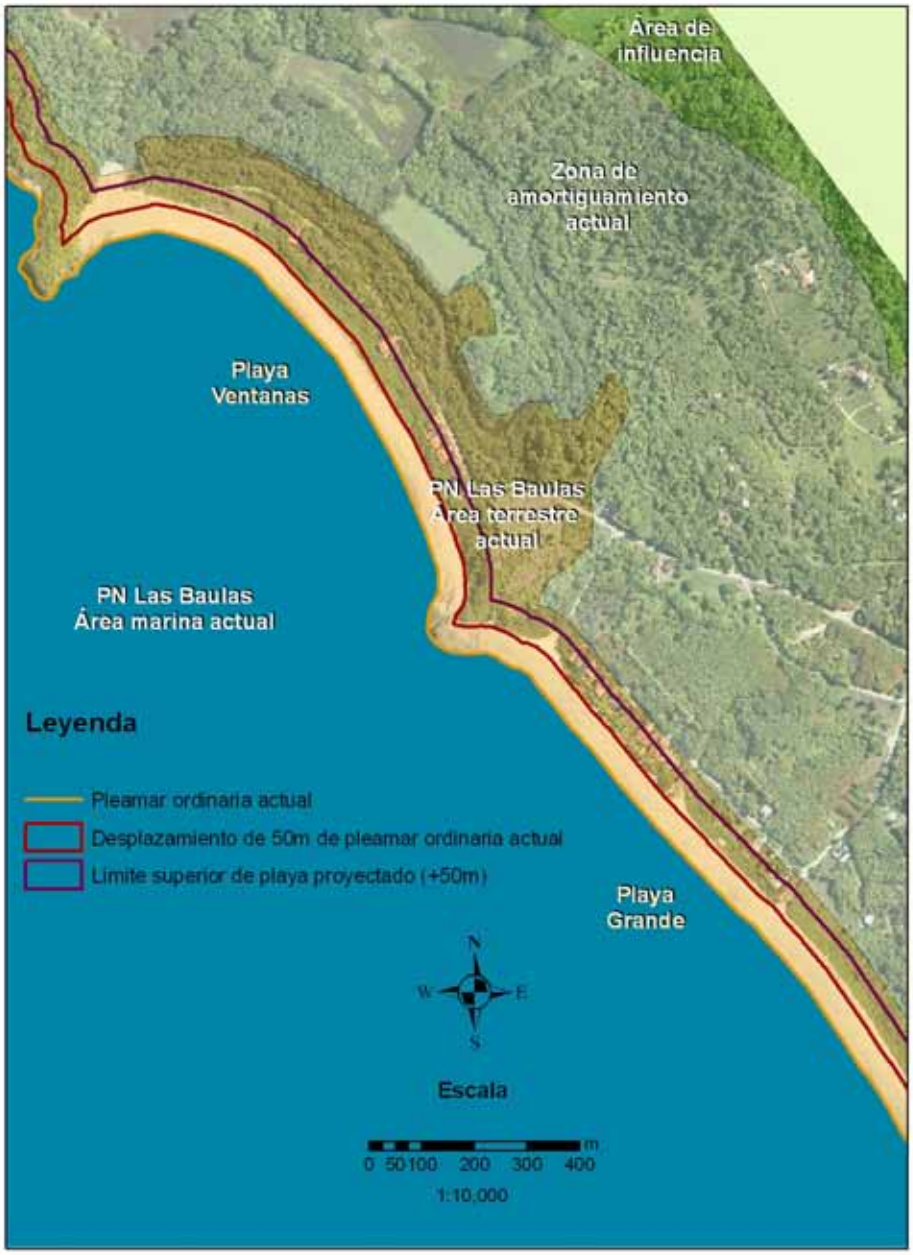


Figure 10. Vertical orthophotograph of Playa Grande and Ventanas Beach, illustrating areas of Las Baulas National Park in the northwestern sector, as well as the expected landward displacement zone of the beach of 50 m in response to sea level rise, estimated using the Bruun rule (see the text).

WWF is the largest and most experienced independent conservation organization in the world. WWF was funded in 1961 and is known by its panda logo. WWF is supported by more than 5 million people and its global network works in more than 100 countries.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature by:

- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption

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