Mangroves for climate: Public, private and community partnerships for mitigation and adaptation in Ecuador

Annex 25: Adaptation beneficiary estimates

Contents

Introduction

This document summarizes key information already provided in the Feasibility Study that is used to estimate the expected adaptation benefits of the project.

The project's adaptation benefits come from the reduction of coastal flood risk for people and assets that will be achieved by strengthening the protection of current mangrove and by expanding mangrove cover. Important co-benefits will also be achieved by increasing the economic resilience of coastal fishing communities living in the four estuary areas targeted by the project.

Ecuador's coastal communities are highly vulnerable to climate change due to their high population, exposed infrastructure and high poverty rates that make people less resilient in the face of natural hazards. Large numbers of people in the rural areas of coastal zones are highly dependent on natural resources, especially fisheries resources. The hazard level of coastal flooding in all areas of the project is classified as high, the highest hazard level, according to the Global Facility for Disaster Reduction and Recovery (GFDRR), meaning that potentially damaging waves are expected to flood the coast at least once in the next ten years[1]. The southern coastal region of Ecuador (the region of the two southern estuaries included in the project) has been identified as the location with the highest coastal risk in the Latin America and Caribbean region due to a combination of coastal hazards, geographic exposure, and socio-economic vulnerability.

In coastal mangrove areas, official national statistics estimate that 198,000 people are currently exposed annually to high flood risks from either coastal or riparian flooding according to the National Disaster Response Plan[2]. These official data do not separate out the impacts of coastal flooding, which is the focus of the project since it's impacts can be mitigated by the presence of mangroves. To understand the impacts of coastal flooding and its interactions with mangroves, the project has followed the modelling approach of Menendez et al. (2020). This approach has been used to estimate the number of project beneficiaries (see below and Appendix 1 for details of modelling of flooding due to coastal surge).

Climate change is projected to create unprecedented changes in conditions along Ecuador´s coast, including increases in sea level, extreme El Niño-Southern Oscillation events, higher intensity and variability of precipitation, and increased atmospheric temperatures. The combination of these changes is expected to cause significant and more frequent coastal flooding, which will damage local communities and economic activity.

Fishing communities, including those dependent on mangrove resources are at risk of climate change impacts through loss of income and food insecurity due to changes in fish populations and distribution, property and/or asset loss due to flood damage, displacement and disruptions to transport routes and increased risk of infectious diseases following flooding events.

The importance of mangroves for coastal flood protection

[1] https://thinkhazard.org/en/report/73-ecuador/CF , accessed February 2022.

[2] https://www.gestionderiesgos.gob.ec/wp-content/uploads/downloads/2018/08/Plan-Nacional-de-Respuesta-SGR-RespondeEC.pdf

See section 2.4 of the Feasibility Study for further details and citations.

While mangroves provide a diversity of ecosystem services, their value for coastal protection and the reduction of flood risks is particularly well documented and relevant for Ecuador's coast. The use of "green infrastructure" in the form of natural ecosystems to reduce the effects of climate change hazards, for example to dissipate wave energy and reduce the intensity of storm surges, has been well documented. Mangrove species have dense roots that reduce wave energy and height, such as depicted in Figure 1. and Figure 2.. The ability of mangroves to reduce wave energy is related to the size of mangrove stands. Wider areas of mangrove reduce the wave height during storms the most.

Storm surges can raise water levels on the coast for periods of hours or days. By comparison, waves that come from normal winds or tides last for shorter times (seconds or minutes). So, greater widths of mangrove are required to reduce storm surges. Figure 1**Error! Reference source not found.** illustrates how the width of mangrove stands decrease wave height and therefore the impacts of storm surges.

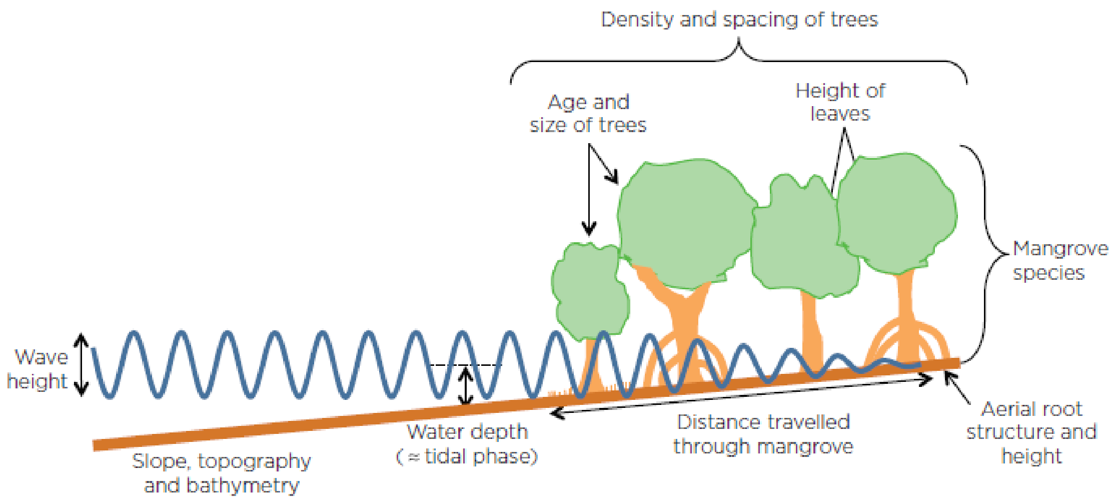


Figure 1. Key factors contributing to wave attenuation.

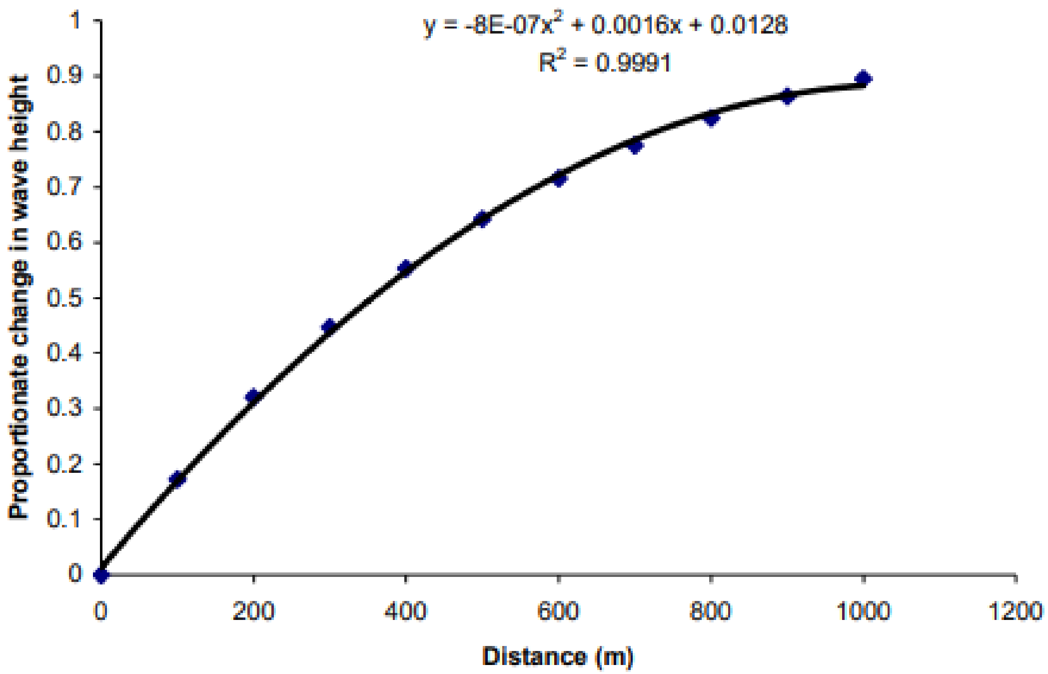


Figure 2. Reduction of wave height by mangroves (Kandelia spp.) at mid-tide where distance is measured from open water towards shore.

Mangroves serve as natural structural barriers reducing coastal erosion. They also provide important flood-control functions, by dissipating wave energy and storm surges through bottom friction and structural barriers formed by roots, trunks and canopy). The destruction of mangroves and replacement by other land uses that have a lower capacity for infiltration and storage of storm waters increases coastal flooding risks.

Estimating project beneficiaries from models of the flood protection benefits of Mangroves in Ecuador

An extensively validated model developed by the Coastal Resilience Lab (CRL) at the University of California, Santa Cruz (Menéndez, 2020[3][4]; see Appendix 1) was used to estimate the flood protection benefits of Mangroves by providing high resolution estimates of economic value using 20km long coastal segments, and predicting land area flooded, people affected, and property loss with and without mangroves. This CRL global model was adapted to use locally specific data for Ecuador as described in Appendix 1. See also the Feasibility Study, section 2.4 for further details of the model. The coastal flooding that occurs based on the model is for both typhoon and "regular" weather generated based on a historical data set from 1979-2010. The model outputs

[3] https://www.nature.com/articles/s41598-020-61136-6

[4] Additional detail on the methodology can be found here: https://static-content.springer.com/esm/art%3A10.1038%2Fs41598-020-61136-6/MediaObjects/41598_2020_61136_MOESM1_ESM.pdf

provide estimates of the height of floodwater following storm surges and provide estimates of the annual number of people that would be affected by flooding in scenarios 'with' and 'without' mangroves. Based on these estimates, an average value for the flood protection benefits of a hectare of mangrove can be calculated (expressed as the number of people at annual flooding risk and value of property at annual flooding risk).

Based on the model, on Ecuador's coast, mangroves reduce floodwater levels of areas within 5 km of their edges by over 1.10m on average, thereby reducing flooding risk for people and property during storm surge events. The analysis concludes that mangroves provide annual flood protection benefits to 86,200 people. The analysis also shows that the mangroves prevent approximately US$ 250 million of property loss from flooding annually. Based upon mangrove coverage in Ecuador from 2018 (156,633 ha), every hectare of mangrove prevents approximately US$ 1,600 of property loss from coastal flooding every year in Ecuador. Property loss in this case includes both industrial and residential stock where damage and property loss values increase with increasing flood depth. Similarly, based on these figures, approximately 1 person has reduced annual expected flood risk for each two hectares of mangrove in Ecuador[5].

The per hectare values of mangrove flood protection benefits are used to estimate the additional project benefits that will result from the additional hectares of mangrove that are expected by the end of the project (i.e. from a comparison of the project scenario with the baseline "without project" scenario). The method for estimating the 'additional' hectares of mangrove forest that will result from the project is the same as for the GHG calculations and is presented in detail in Annexes 22a and 22b. An additional 5,975 hectares of mangrove are expected due to the project during the implementation period. This equates to providing flood protection benefits to an additional 3,400 people[6] on top of strengthening flood protection (because mangroves are better managed) for people who currently benefit from mangrove cover. Therefore, a total of 89,600 people will benefit from the flood protection benefits provided by the project.

Adaptation beneficiaries

The project will contribute to the following GCF Adaptation Areas: ARA1 Most vulnerable people and communities and ARA4 Ecosystems and ecosystem services. – Hectares of natural resources brought under improved low-emission and/or climate resilient management practice. The project lifetime is assumed to be 20 years, which is the approximate time it will take for restored mangroves to reach maturity.

For sex disaggregation estimates, it has been assumed that males and females each make up 50% of the beneficiary population.

GCF Adaptation Results Areas	Adaptation Benefit

[5] Or, more precisely 1 hectare of mangrove provides protection for 0.58 people on average.

[6] The exact calculation is 5,975 x 0.58 = 3,465 people, which has been rounded down for the presentation of figures in the Funding Proposal.

ARA1 Most vulnerable people and communities	Increased mangrove cover (by comparison to the baseline scenario with no project) will provide additional flood protection benefits for coastal people. Based on the modelling approach explained above, a total of 89,600 people will benefit from the flood protection benefits of mangroves. The project will strengthen the protection of existing mangrove and make it less likely that current flood protection benefits will be lost in the future.
IRMF Supplementary indicator 2.1 Beneficiaries (male/female) adopting improved and/or new climate-resilient livelihood options	The project will support the expansion and increase in capacity for community mangrove management using AUSCEM agreements. Participating communities will have security overfishing rights and be supported through improved livelihood activities and more economically productive community businesses. A total of 41,500 people from vulnerable fishing communities are expected to benefit over the course of the project. We conservatively assumed that these people are included within the 89,600 people who will benefit from flood protection provided by mangroves.
IRMF Supplementary indicator 3.1 Change in expected losses of economic assets due to the impact of extreme climate-related disasters in the geographic area of the GCF intervention	Increased mangrove cover (by comparison to the baseline scenario with no project) will provide additional flood protection benefits for coastal communities because economic damage will be reduced. Based on the modelling approach explained above, each additional hectare of mangrove is expected to reduce losses by $1,600 per year. Over the course of the project an additional 5975 hectare are expected (by comparison to the baseline), which is equivalent to avoided economic loss of assets of US$ 30.4M over the course of the project implementation period. This benefit is in addition to the US$ 250M of annual benefits provided by current mangrove cover (as explained in the preceding section).
ARA4 Ecosystems and ecosystem services	
IRMF core indicator 4: Hectares of natural resources brought under improved low-emission and/or climate resilient management practice.	A total area of 156,633 hectares of mangroves will have strengthened climate resilient management as a result of project interventions. This is total area of mangroves in Ecuador. This area encompasses areas of AUSCEM and protected areas targeted for management improvements and areas

	without formal protection that will benefit from the national level strengthening of measures to protect mangroves in Component 3.

Project interventions are expected to directly benefit 89,600 people, including 44,800 males and 44,800 females. The project is expected to indirectly benefit 3.4 million people living in coastal municipalities, including 1.7 million males and 1.7 million females.

The table below provides a breakdown of the beneficiaries for the relevant project outputs.

Output	**Definition of beneficiaries**	**Beneficiaries (sex-disaggregated)**
Output 1.1 Reduced exposure to flood risk for vulnerable people and reduced GHG emissions from mangrove restoration are achieved by strengthening community-based management through AUSCEMs and protected areas.	Direct beneficiaries: Number of people benefiting from the flood protection service provided by mangroves	89,600 people, including 44,800 males and 44,800 females The baseline is 86,200 people who will continue to benefit and by strengthening mangrove protection the future flood protection benefits for these people are more likely due to the project.
Output 1.2 Improved livelihood activities and more economically productive community businesses enable local people to become more resilient to climate change and incentivized to participate in, and maintain, mangrove conservation and restoration.	Direct beneficiaries: Number of people benefiting from increased economic resilience due to more secure fishing rights and/or improved livelihood activities due to project activities	41,500 (20,750 male and 20,750 female)
Output 3.2 Legal and regulatory frameworks at local and sectoral level are harmonized and include climate resilience and mitigation strategies and enforcement.	Indirect beneficiaries: Number of people benefiting from improved coastal development and zoning plans and other participatory instruments that incorporate climate change adaptation and mangrove management.	3.4 million (1.7 million male and 1.7 million female), which is the total population of the eight municipalities[7] prioritized by the project because they contain most of Ecuador's mangroves.

[7] Based on 2022 Census data

Appendix 1. The Value of Mangroves in Ecuador for Flood Risk Reduction

The Value of Mangroves in Ecuador for Flood Risk Reduction

An analysis for Conservation International in support of a Green Climate Fund proposal with the government of Ecuador

Professor Michael W. Beck & Dr. Pelayo Menéndez
University of California Santa Cruz

Overview

Mangroves provide coastal protection by reducing the flooding that would occur from storms and the resulting damages to people and property if these mangroves were absent. The 'avoided damage' valuation approach uses the cost of damages prevented by mangroves to estimate the value of mangroves (see Figure 1). This value is estimated using a combined set of process-based storm and hydrodynamic models. The models (i) identify the area and depth of flooding; (ii) run model scenarios with and without mangroves; (iii) for five storm frequency events, 1 in 5, 10, 25, 50, 100-yr driven by the frequency of local storm data. Flood extent and depth data are overlaid on produced capital stock and population, downscaled to 90 x 90 meters to identify a probabilistic distribution of flood damages (risk) and avoided damages (habitat benefits). Based on work recently developed for the World Bank Changing Wealth of Nations project (Lange et al. 2021) we estimated flood risk and mangrove benefits for three time periods 1996, 2010 and 2015, with global data on the historical distribution of mangroves.

Methods

Below we summarize the core methods and models. These methods have been applied in previous projects to assess the value of mangroves for coastal protection in the Philippines, Jamaica and globally (Menéndez et al. 2018, Beck et al. 2019a,b, Menéndez et al. 2020, Lange et al. 2021). These models have been extensively validated (Menéndez et al. 2018, 2019, 2020)[8]. We use this approach in coastal profiles (from land to sea) spaced 1 km apart for all mangrove coastlines. We group profiles to create core 20-km study units.

[8] Additional detail on the methodology can be found here: https://static-content.springer.com/esm/art%3A10.1038%2Fs41598-020-61136-6/MediaObjects/41598_2020_61136_MOESM1_ESM.pdf

(i) **Estimate offshore dynamics from storms.** We first define the atmospheric events (e.g., cyclones and extratropical storms) that could affect the profiles in each study unit. These storms could be hundreds of miles away from the coast. We identify the maximum waves and sea levels (i.e., surge) driven by these storms. The data sets on tropical cyclones and waves are global and provide locally specific information from more than 7,000 historical cyclones (Knapp et al., 2010) and 32 years of data on waves and sea level, respectively.

(ii)**Estimate nearshore dynamics.** Once we resolve offshore dynamics, we obtain maximum waves and storm surge on the seaward side of each profile. These waves and storm surge interact with the sea floor and other nearshore features (e.g., islands), which affects water height and direction through shoaling, refraction, diffraction, and breaking processes.

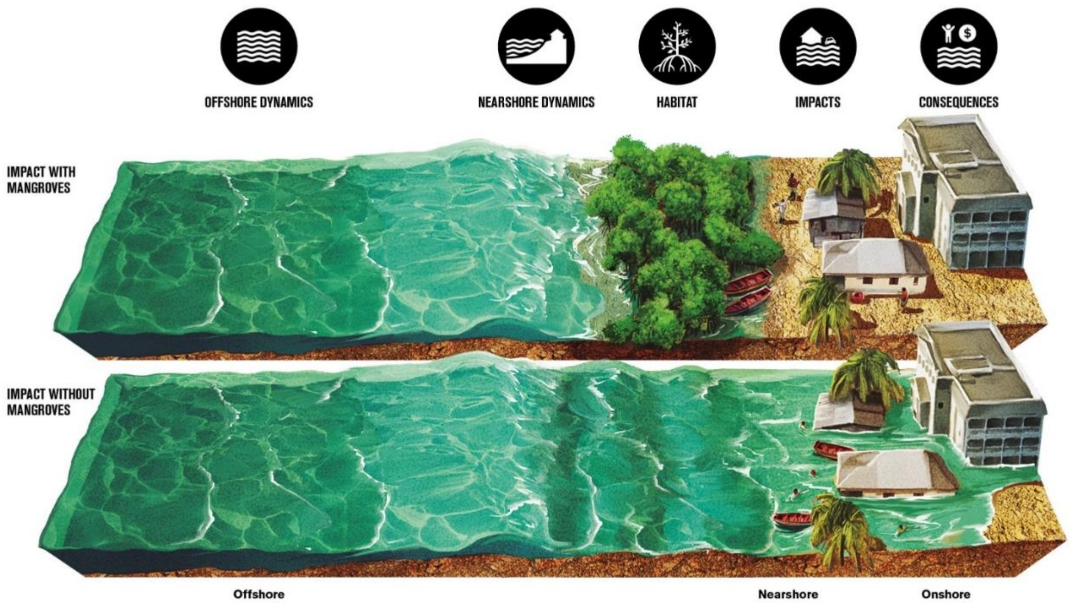
(iii) **Estimate the effects of mangrove habitat on flood reduction.** Waves and storm surge are dissipated as they propagate through the mangrove forest towards the shore. We developed and validated a model in the Philippines that assesses the effects of mangroves on waves and storm surge and calculates the resulting flood height at the coast. We use the maximum flood height of each storm to reconstruct long term time series. Then, we apply an extreme value analysis to obtain 1-in 5, 10-, 25-, 50- and 100-year extreme sea levels at the coast.

(iv) **Calculating impacts by developing flood maps.** To estimate the extent and depth of flooding onshore due to extreme sea levels at the coast (1-in 5, 10, 25, 50 and 100 year). We use a GIS model that intersects flood height with topography and accounts for hydraulic connectivity (i.e., ensuring that flooding in a 90m x 90m cell is physically connected to nearest neighboring cell). The outcome of this stage are flood maps for different return periods (1-in- 5, 10, 25, 50- and 100-years) with and without mangroves for each of the 3 years assessed, 1996, 2010, and 2015 (see Figure 2 for an example flood map).

(v) **Assessing Consequences by valuing flood risk and mangrove benefits.** The expected flood risk and benefits provided by mangroves are assessed socially and economically. We intersect the flood maps with population data from GHS-POP (https://ghsl.jrc.ec.europa.eu/ghs_pop2019.php) and built stock data from the Penn World Table version 9.1 (https://www.rug.nl/ggdc/productivity/pwt/). This intersection gives the number of people and the value of assets to coastal flooding. We determine flood damage using depth-damage curves, which identify the flood damage that would occur at specific water depths. Two sources of information have been used to obtain these damage curves: the EU Joint Research Centre (JRC) (Huizinga et al., 2017) and US Hazus (Scawthorn et al., 2006).

Additionally, we use data from the Ecuadorian census identifying the distribution of the overall population and those living in poverty. The latter is defined in the census as “Poverty due to Unsatisfied Basic Needs (UBN)” using a multidimensional poverty measure developed in the 1980s by the Economic Commission for Latin America and the Caribbean (ECLAC). The method covers five dimensions (economic capacity, access to basic education, access to housing, access to basic services and overcrowding) and within each dimension there are indicators that measure deprivation.

Figure 1: Key Steps and Data for Estimating the Flood Protection Benefits Provided by Mangroves. Step 1. Offshore dynamics: Oceanographic data are combined to assess offshore sea states. Step 2. Nearshore dynamics: Waves are modified by nearshore hydrodynamics. Step 3. Habitat: Effects of mangroves on wave runup are estimated. Step 4. Impacts: Flood heights are extended inland along profiles (every 1 km) for 1 in 10, 25, 50, 100-yr events with and without mangroves to estimate impacts. Step 5. Consequences: The consequences to land, people and built capital damaged under the flooded areas are estimated (adapted from Beck et al., 2019a). ©PuntoAparte.



Results

The maps below summarize a few of the key results provided in the attached spatial databases.

Figure 2: Flooding in Ecuador with and without mangroves for the 1 in 25-year storm event.

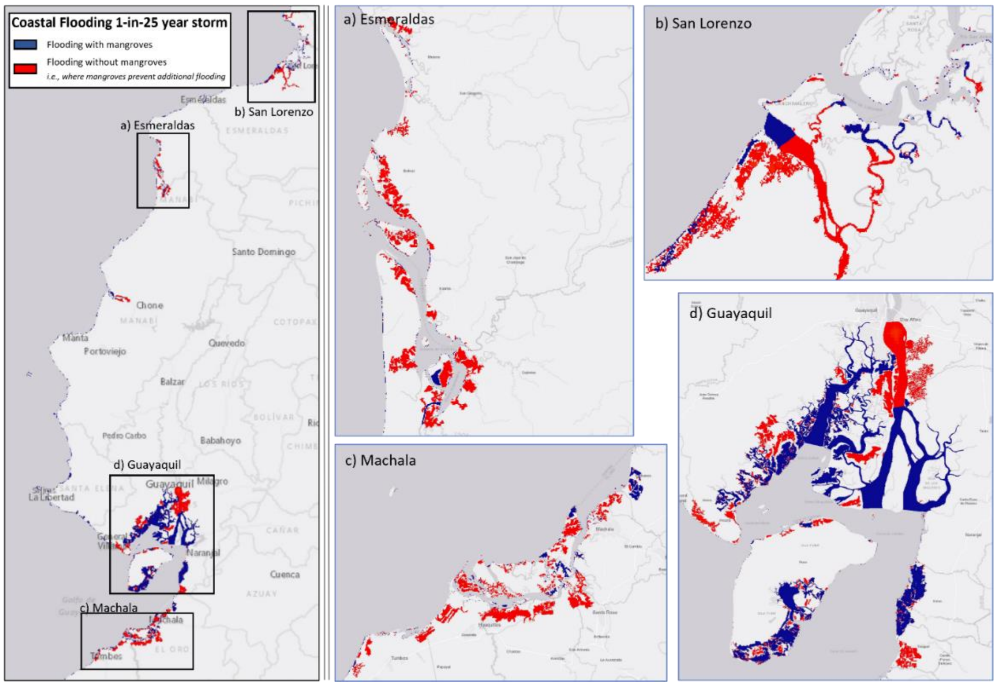


Figure 3: Mangroves Distribution and their Annual Expected Benefit for flood risk reduction by parish across Ecuador (2010).

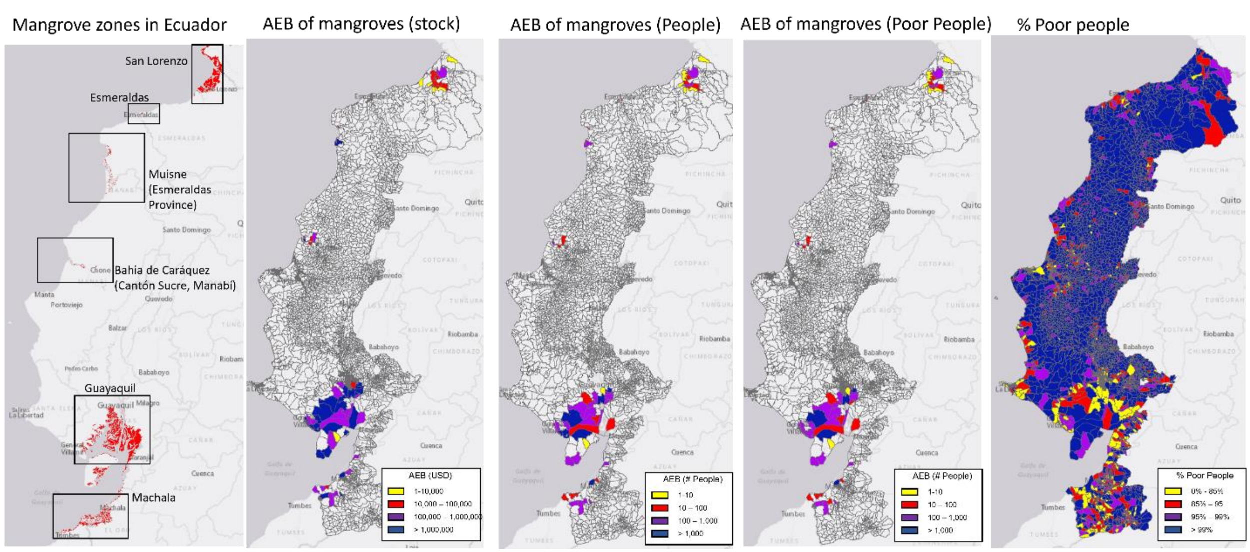


Figure 4: Mangrove Distribution and their Annual Expected Benefit for flood risk reduction by parish across Guayaquil.

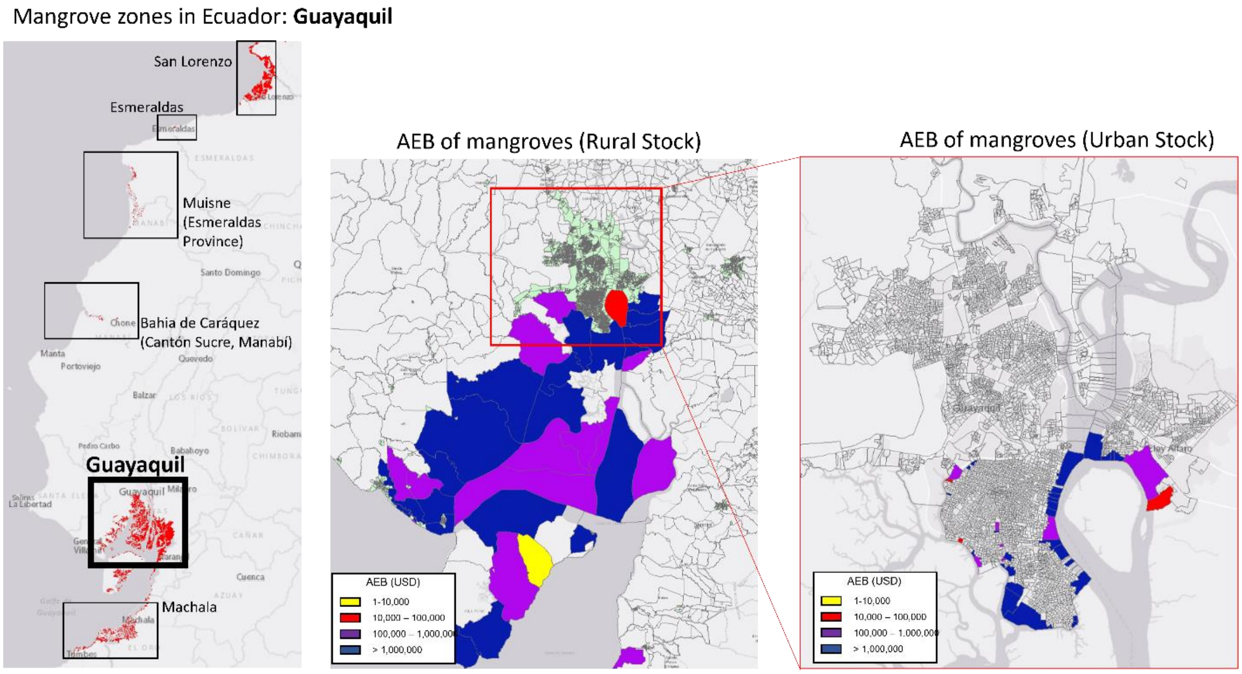


Figure 5: Annual Expected Benefit for flood risk reduction to people by parish across Guayaquil.

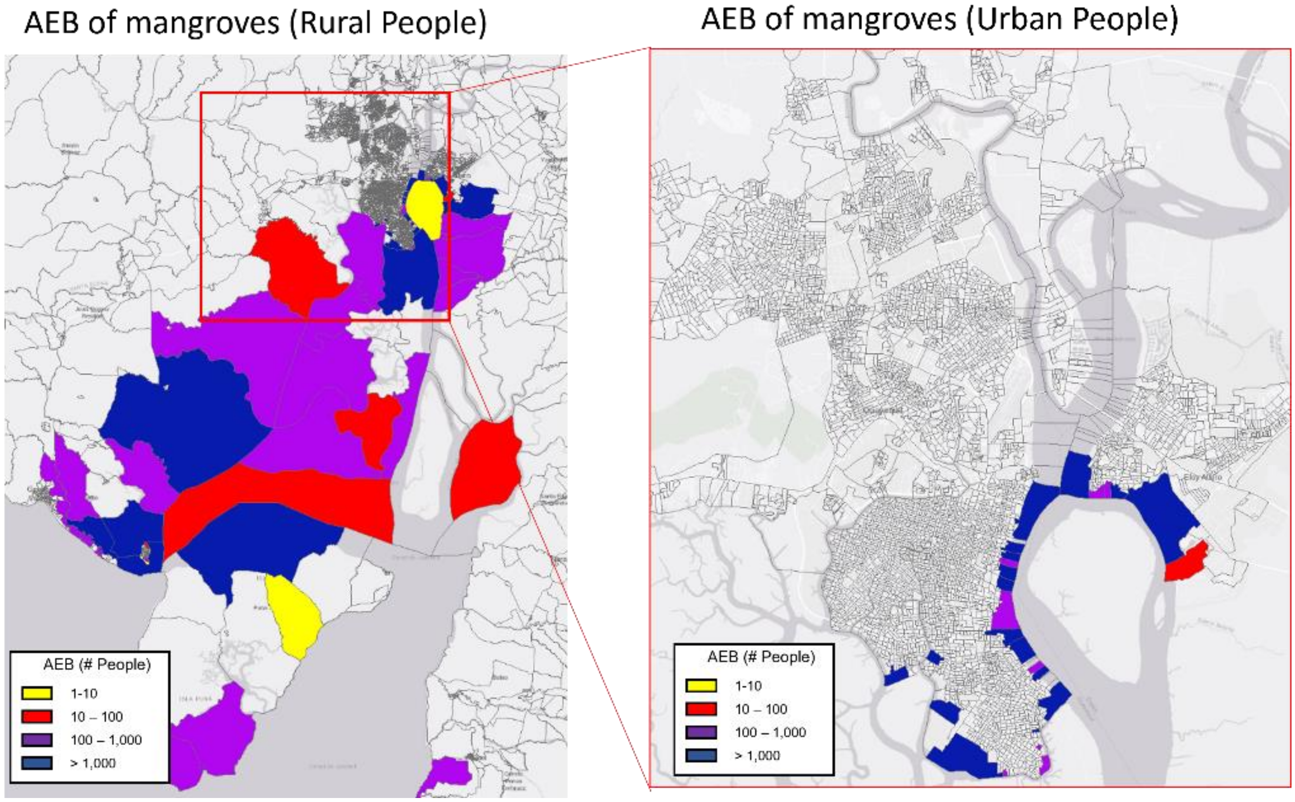


Figure 6: Annual Expected Benefit for flood risk reduction to people living in poverty by parish across Guayaquil.

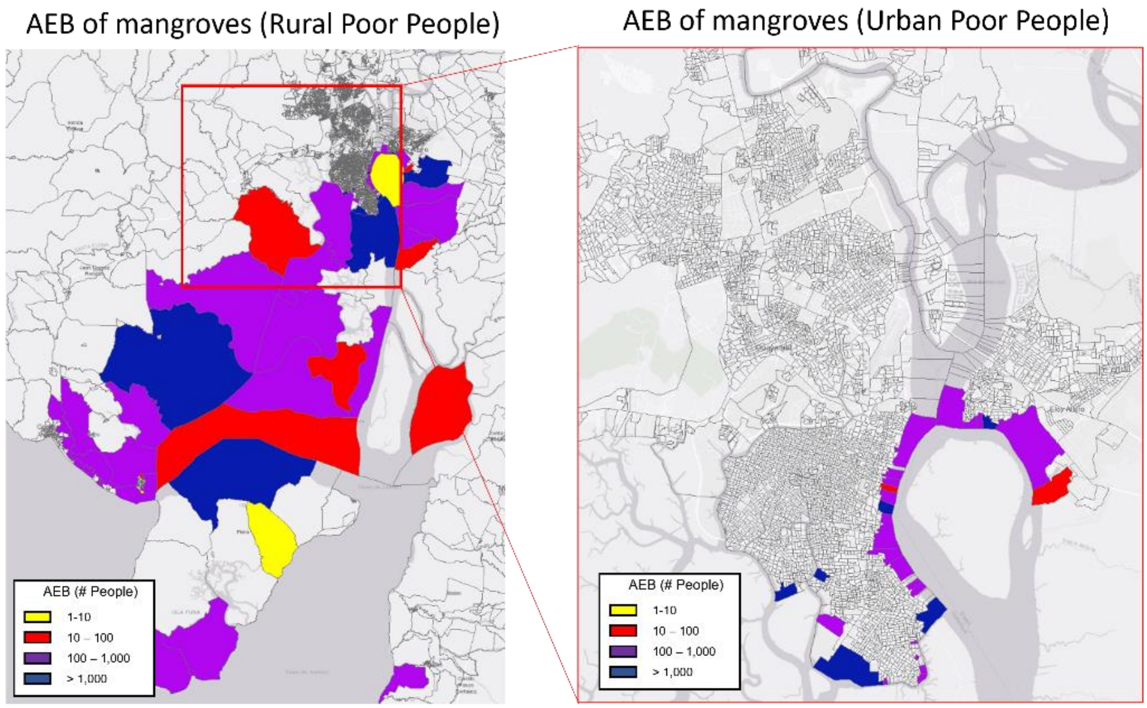


Figure 7. Change in Mangrove Distribution in Ecuador 1996, 2010, 2015.

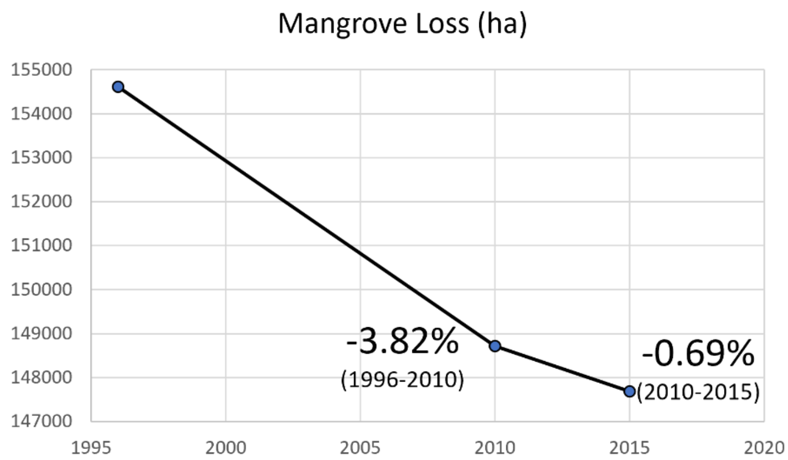


Figure 8. Change in Flood Risk on Mangrove Coastlines 1996, 2010, 2015.

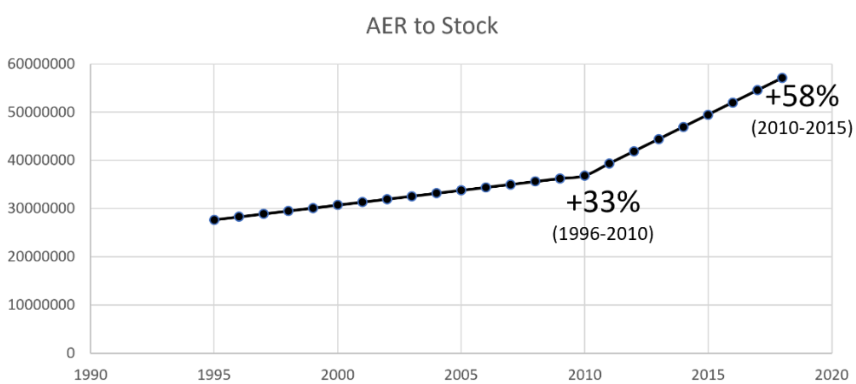
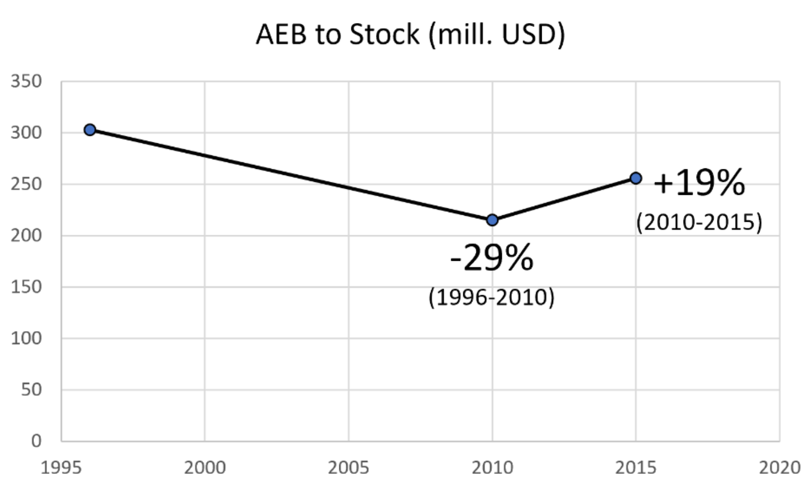


Figure 9. Change in Mangrove Benefits in Ecuador for Flood Risk Reduction 1996, 2010, 2015.



Literature Cited

Beck, M. W., I. Losada, P. Menendez, Reguero, B.G., P. Diaz Simal, F. Fernandez. 2018. The global flood protection savings provided by coral reefs. *Nature Communications* 9:2186.

Beck, M. W., N. Heck, S. Narayan, P. Menéndez, S. Torres-Ortega, I. J. Losada, M. Way, M. Rogers, L. McFarlane-Connelly. 2020. Reducing Caribbean Risk: Opportunities for Cost-Effective Mangrove Restoration and Insurance. The Nature Conservancy, Arlington, VA.

Beck, M. W., Torres, S., I. J. Losada, A. Espejo, S. Abad, S. Narayan. 2019. The Flood Protection Benefits and Restoration Costs for Mangroves in Jamaica: Technical Report. World Bank, Washington.

Huizinga, J., De Moel, H. & Szewczyk, W. 2017. *Global flood depth-damage functions - Methodology and the database with guidelines*.

Knapp, K. R., Kruk, M. C., Levinson, D. H., Diamond, H. J. & Neumann, C. J. 2010. The international best track archive for climate stewardship (IBTrACS) unifying tropical cyclone data. *Bull. Am. Meteorol. Soc.* 91, 363–376.

Lange, G-M, M. W. Beck, V. Lam, P. Menéndez, R. Sumaila. 2021. Lange, G-M, M. W. Beck, V. Lam, P. Menéndez, R. Sumaila. 2021. Blue natural capital: mangroves and fisheries in G. M. Lange et al. (eds). Changing Wealth of Nations 2021: Managing Assets for the Future. World Bank, Washington.

Menéndez, P., Losada, I. J., S. Torres-Ortega, S. Narayan, M. W. Beck. 2020. Global flood protection benefits of mangroves. ***Scientific Reports* 10:4404.**

Menéndez, P., Losada, I. J., M. W. Beck, S. Torres-Ortega, A. Toimil. 2019. Assessing the effects of using high-quality data and high-resolution models in valuing flood protection services of mangroves. PLoS ONE 14(8): e0220941.

Menéndez, P., Losada, I. J., M. W. Beck, S. Torres-Ortega, A. Espejo, S. Narayan, P. Díaz-Simal, GM Lange. 2018. Valuing the protection services of mangroves at national scale: The Philippines. *Ecosystem Services* 34:24-36.

Scawthorn C, Flores P, Blais N, Seligson H, Tate E, Chang S, et al. 2006. HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment. Nat Hazards Rev. 2006; 7: 72–81.