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CASE STUDIES: ASSESSING THE ECONOMIC VALUE OF NATURAL INFRASTRUCTURE IN COASTAL ECOSYSTEMS IN THE APEC REGION

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CASE STUDIES: ASSESSING THE ECONOMIC VALUE OF NATURAL INFRASTRUCTURE IN COASTAL ECOSYSTEMS IN THE APEC REGION

US-APEC Technical Assistance to Advance Regional Integration (US-ATAARI)

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The APEC project, “Assessing the Value of Green Infrastructure in Coastal Ecosystems to promote Disaster Risk Reduction, Response and Coastal Resilience in the APEC Region” aims to promote an understanding of assessing the economic value of services provided by Natural Coastal Infrastructure (NCI) in coastal areas in the APEC region. Phase 1 consisted of a Literature Review and Gap Analysis. The second phase involves developing an approach for assessing the value of NCI in the Asia Pacific region. The locations of Metro Manila and Guangzhou are the areas of focus for the economic valuations. The methodology for the valuation was guided by tools developed by NOAA and by the World Bank.

The Two Case Studies

Manila, Philippines

Metro Manila is densely populated, with multiple types of natural coastal infrastructure within and adjacent to the city. However, the natural coastal infrastructure has been reduced due to increased economic development and is high risk for flooding and coastal storm inundation. Between 2005 and 2015, the Philippines was impacted by more than 2,300 hazardous coastal storms and flooding events.[1] Analysis from major catastrophic risk insurers estimates that Metro Manila faces an average of US$6 billion in risks each year from windstorms (typhoons) alone, over the next 10 years.[2] Using GDP growth estimates,[3] this would result in economic risks from severe storms of US$20 billion annually by 2050. Climate change is expected to exacerbate this risk.

NCI is a critical tool in mitigating risk from natural disasters. The Manila case study uses four scenarios based on different levels of annual mangrove restoration, 10 km^2 mangroves restored per year, 20 km^2 mangroves restored per year, 30 km^2 mangroves restored per year, and 40 km^2 restored per year. It is estimated that existing mangroves can potentially avert US$1.7 billion in damages for a 50-year storm over the entire Philippines, and also provide significant benefits for more frequent, lower intensity events.[4] The potential value of protection services from the restoration of mangroves in Metro Manila ranges from approximately US$171,000 to over US$1.1 million, over the same time period, for the scenarios developed for this report.

Guangzhou, China

The Pearl River Delta (PRD) is located in the central coastline of Guangdong Province in southern China. Formed as a vast flood plain (42. 657 km^2) of the Pearl River, it hosts eleven major cities, including the mega-city formed by Hong Kong, China; Shenzhen; and Guangzhou. Estimates in 2015 put the population at over 108 million, with projections estimating over 120 million residents by 2050.[5]

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[1] Losada, I.J., M. Beck, P. Menéndez, A. Espejo, S. Torres, P. Díaz-Simal, F. Fernández, S. Abad, N. Ripoll, J. García, S. Narayan, D. Trespalacios. 2017. Valuation of the Coastal Protection Services of Mangroves in the Philippines. World Bank, Washington, DC.

2 https://www.lloyds.com/cityriskindex/locations/fact_sheet/manila

3 Lloyd’s City Risk Index estimates average GDP growth for Manila to be 3.46%

4 Losada, I. J., et al. 2017.

5 Flood risk appraisal and management in mega-cities: a case study of practice in the Pearl River Delta, China, F. K. S. Chan, G. Mitchell, A. T. McDonald, Published December 2012, 7 (4) wpt2012060; DOI: 10.2166/wpt.2012.060, Water Practice and Technology

Guangzhou is a suitable candidate for the evaluation exercise due to the existence of urban land cover overlapping with the flood zone, potential risks recognized by policy makers, and the presence of extensive NCI (salt marshes) adjacent to the city. Storm surge and tidal flooding impacts are the primary cause of natural disasters in the Guangdong coastal regions. The Swiss RE report "Mind the Risk"[6] estimates over 12 million people in the delta are exposed to windstorms (typhoons) and flood risk, ranking it as the most highly exposed for both categories. Global analysis from major catastrophic risk insurers estimates that Guangzhou faces an average of around US$16 billion in risks annually from windstorms alone, over the next 10 years.[7] Projecting that figure out, using GDP growth estimates[8] would result in economic risks from severe storms of over US$118 billion annually by 2050. As the key port in the Pearl River Delta (PDR), natural disasters have the potential to damage critical port infrastructure which could have wide-ranging impacts beyond the economy.

NCI is a critical tool in mitigating risk from severe storms, flooding, and climate change in Guangzhou. Salt marshes could avert up to US$80 million in damages annually, and also provide significant benefits for more frequent, lower intensity events over the entire PRD. The case study uses four scenarios based on different levels of annual salt marsh restoration as a percentage of existing salt marshes, additional 25% salt marshes restored per year, additional 50% salt marshes restored per year, additional 75% salt marshes restored per year, and additional 100% salt marshes restored per year.

Conclusions and Recommendations

This report details comparisons that can be made between the two case studies. For example, Manila historically was protected from coastal storms by extensive mangrove forests but retains very few mangroves. Manila also has a sizable amount of seagrasses in Manila Bay, and corals at the mouth of the bay that can provide protective capacity. Guangzhou has sizable salt marshes along the banks of the Pearl River and throughout the delta. However, it lacks other types of NCI for protection from storm surge, flooding and to attenuate waves. Therefore, Guangzhou could seek to maintain and restore its existing salt marshes, while Manila could seek to undertake restoration activities.

However, it is not always feasible to undertake massive restoration projects. Opportunities to integrate natural coastal infrastructure with ongoing and new recovery efforts from severe storms should be examined. NCI should be considered part of existing Disaster Risk and Resilience Frameworks, such as the APEC Disaster Risk Reduction Framework (DRRF). Decision makers should look for key decision points, or "on ramps" for integrating NCI into this existing framework. The successful integration of NCI approaches within the APEC DRRF will require effective collaborative efforts between the public sector, private enterprises and civil society, and change policy and practice to better align private short-term goals with societal long-term goals.

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[6] Sundermann, Lukas, Schelske, Oliver and Hausmann, Peter. 2013. "Mind the risk – A global ranking of cities under threat from natural disasters" 2013. Swiss Re.

[7] https://www.lloyds.com/cityriskindex/locations/fact_sheet/guangzhou

[8] Lloyd's City Risk Index estimates average GDP growth for Guangzhou to be 8.4%

INTRODUCTION

This report provides an assessment of the economic value of the benefits and services provided by natural coastal infrastructure (NCI) in coastal ecosystems, for the purposes of disaster risk reduction and response and coastal resilience in the APEC region.

This assessment is part of the second phase of the APEC project, "Assessing the Value of Green Infrastructure in Coastal Ecosystems to Promote Disaster Risk Reduction, Response and Coastal Resilience in the APEC Region," which seeks to promote a better appreciation of the economic value of services provided by NCI in coastal areas in the APEC region. A sound understanding of the protective services and the economic value of NCI allows policy makers to allocate resources effectively for the management of coastal resources and guide disaster risk reduction and mitigation strategies.

The first phase of the APEC project focused on identifying knowledge and policy gaps through conducting a comprehensive Literature Review and Gap Analysis. Data was gathered through a review of existing studies on the economic values of NCI and surveys of APEC economies to determine critical knowledge gaps and regulatory barriers within economies, which limit policy makers' ability to value NCI in the region.

In the APEC context, assessing the economic value of NCI is critical. The region is prone to natural disasters. The Asia-Pacific region has witnessed disruptions caused by natural disasters firsthand, which have resulted in the loss of life, widespread damage, and significant economic costs. A UNESCAP study[9] indicates that between 1970 and 2014, Asia and the Pacific accounted for approximately 56.6% of global fatalities due to natural disasters. It is estimated that more than one-third of the world's population live in coastal areas and small islands which makes up around 4% of the earth's total land area.[10] Several economies in the region, in particular Australia; Indonesia; Japan; Malaysia; New Zealand; Papua New Guinea; the Philippines; Thailand; the United States; and Viet Nam, have long coastlines that are home to coastal populations that are vulnerable to natural disasters, such as storms; hurricanes; and tsunamis. NCI offers protection to coastal settlements by reducing the intensity of storms and hurricanes and providing shelter. Therefore, APEC economies have recognized the critical importance of NCI in mitigating the impacts of natural disasters and reducing the vulnerability of coastal populations.

Building on the findings of the Literature Review and Gap Analysis completed in Phase 1 of this project, the second phase of the project focuses on the development of a suitable approach and methodology for assessing the value of NCI in the Asia-Pacific region. To this end, the study team drew on peer reviewed methodologies identified in the previous phase of the project to undertake the economic valuation. More details on the range of methodologies available is contained in Annex II of this report.

The report focuses on case studies of two cities in the APEC region – Manila and Pearl River Delta/Guangzhou. These two cities were selected on the basis of specific criteria that the team developed based on existing analytical studies and information. Details involving the selection criteria are contained in the sections below and the selection process is detailed in a diagram contained in Annex III of this report.

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[9] Overview of Natural Hazards and their impacts in Asia Pacific 1970-2014 UN-ESCAP. (2015). http://www.unescap.org/sites/default/files/Technical%20paper-Overview%20of%20natural%20hazards%20and%20their%20impacts_final.pdf

[10] Barbier, Edward, B. "Progress and Challenges in Valuing Coastal and Marine Ecosystem Services. Review of Environmental Economics and Policy, Volume 6, Issue 1,Winter 2012.

Both these cities reflect a substantial presence of NCI and, as a result, were identified by the study team as ideal candidates to conduct the economic valuation. Prior to the selection of the representative location, a geographic visualization of NCI in the APEC Region was conducted. This provided information on the populated coastal areas in the region that are most vulnerable to natural disasters and therefore dependent on the ecosystem services provided by NCI. Additionally, this exercise yielded key information and data that formed the basis upon which the candidate locations for this study were identified. The process for selecting the locations is described in greater detail below.

The first step involved identifying approximately 10-15 locations for analysis across the APEC region. This was based on risk level (vulnerability) and population density. The next stage involved defining the selection criteria for narrowing down the locations identified for the economic valuation analysis. Once the study areas were identified, the type of valuation methodology that is most suited for these locations (based on type of NCI and the availability of data) was selected by the team. The methodologies that were used in the analysis are described in the Methodology section below.

METHODOLOGY AND SELECTION PROCESS

To begin, the geographic visualization of NCI and Coastal Vulnerability mapping serve to illustrate the existence of NCI in densely populated areas that are most at risk from natural disasters. The key outputs from this exercise include a series of maps (Figures 1 to 4 below) which display the extent of NCI in the region, as well as of populated areas and locations with a high degree of exposure to natural disasters. The maps contain spatial analysis of multiple layers of data with geographic properties that have been sourced through the use of satellite imagery, elevation/terrain data, data on densely populated areas, areas covered by NCI, among others. The visualization of NCI and populated areas was undertaken through the use of various GIS tools using the software ArcGIS and QGIS. These include land cover estimates (in km2) of NCI located in densely populated areas in the APEC region.

VISUALIZATION RESULTS

As noted above, four maps that display the results from this visualization activity are provided below. This includes a map of relevant features in all APEC economies (Figure 1) and additional maps demonstrating specific regions within APEC that have particularly large concentrations of NCI (Figures 2-4). Five maps displaying specific types of NCI and four maps that group entire APEC region into four geographic regions are included.

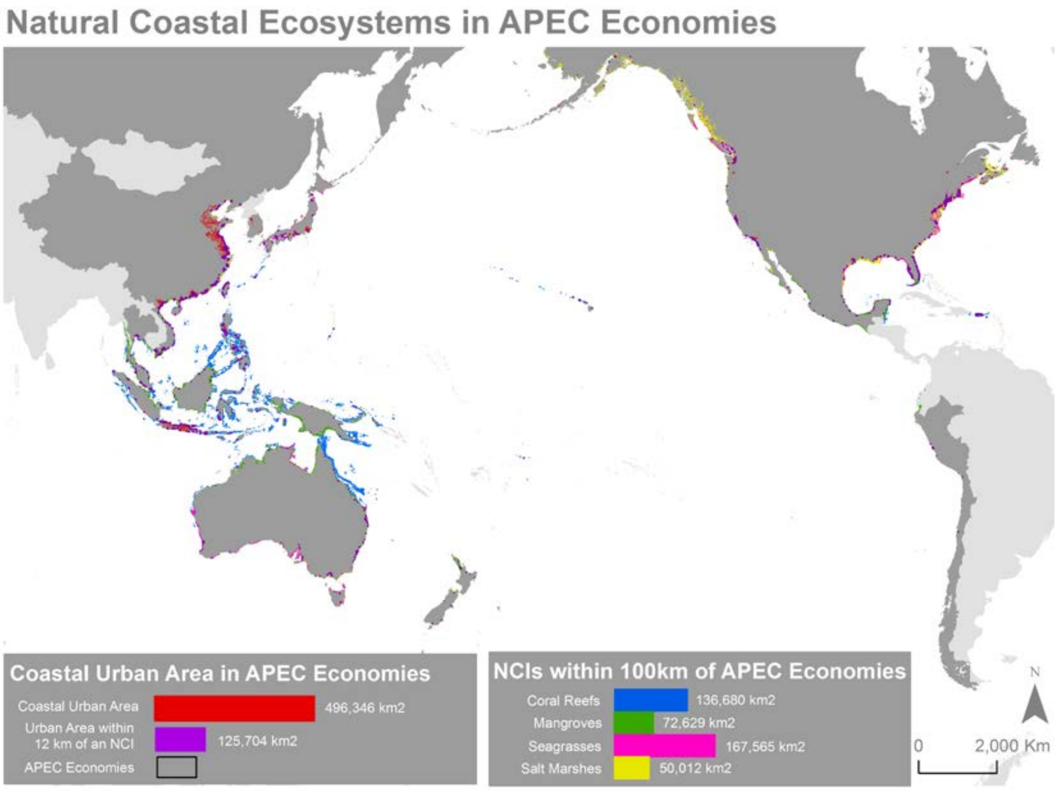
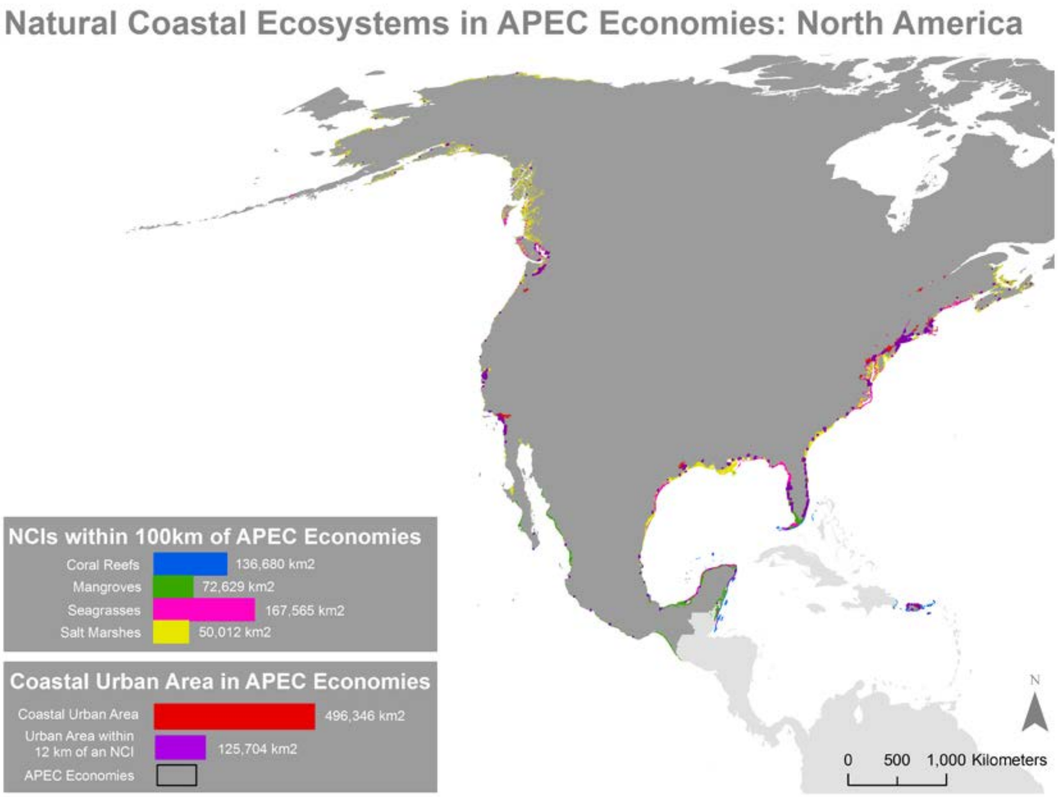


Figure 1: Visualization of all NCI in the APEC region

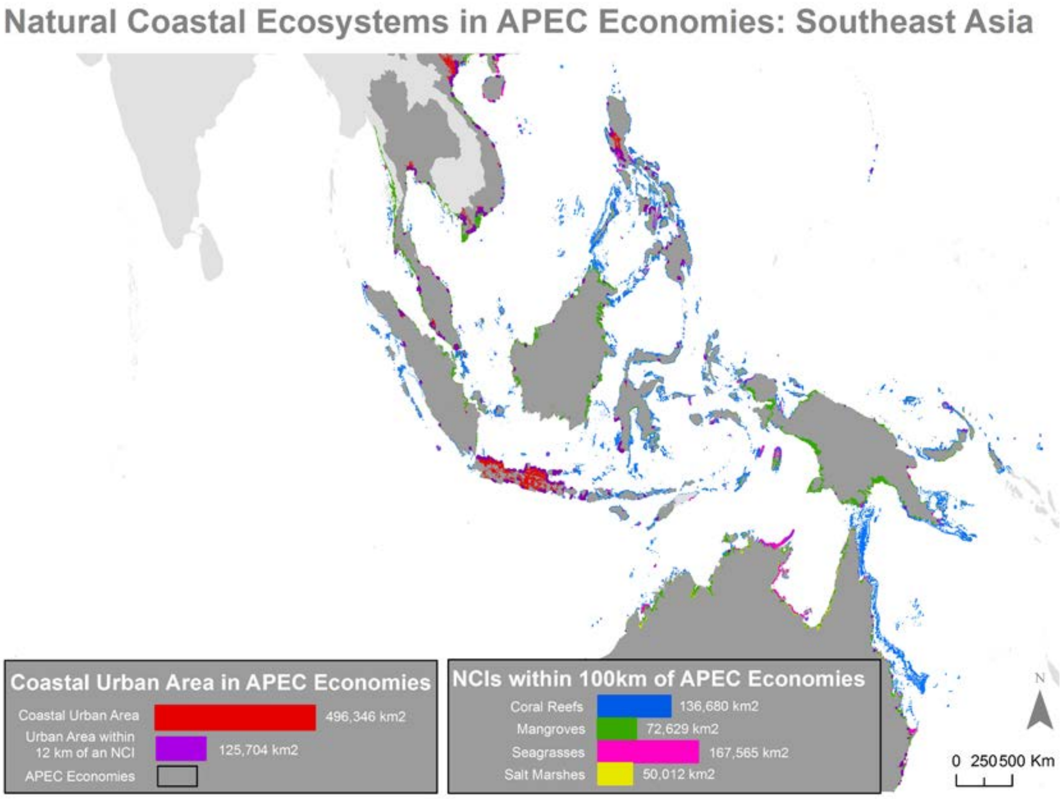
Source: Nathan Associates Inc., with data referenced in Table 1

Figure 2: North America Region



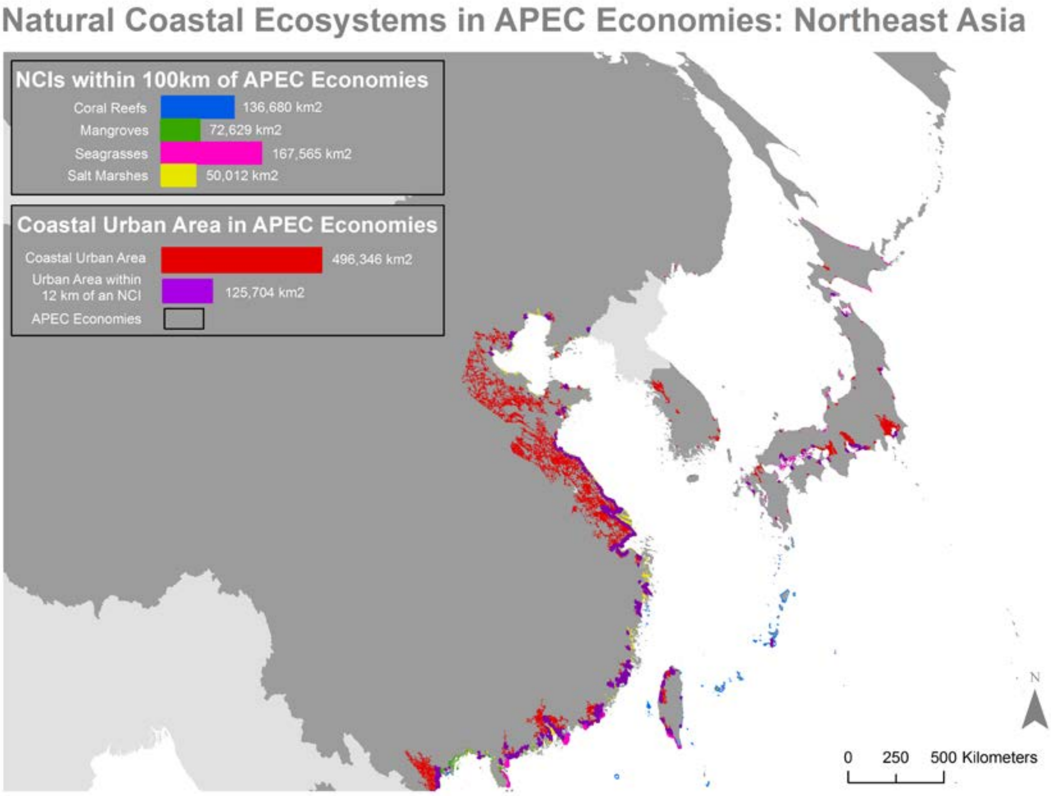
Source: Nathan Associates Inc.

Figure 3: Southeast Asia Region



Source: Nathan Associates Inc.

Figure 4: Northeast Asia Region



Sources: Nathan Associates Inc.

CITY SELECTION FOR VALUATION STUDY LOCATIONS

This section details the methodology and approach employed by the study team to select the candidate cities of Metro Manila and Pearl River Delta/Guangzhou. The selection process is illustrated in a diagram included in Annex III of this report.

The process of city selection consisted of three main steps:

1. A scoping exercise to arrive at a long-list of cities to be considered for analysis;
2. Screening the long list of cities in the region using a visualization exercise to narrow the initial selection; and
3. A second level of screening employing multi-criteria analysis to identify the two cities.

The first step essentially explored the question: Which cities in the APEC region are most vulnerable to natural disasters?

This involved wide-ranging desk research, including a review of key APEC resources, technical studies prepared by research institutions with expertise in the topic and documents prepared by the private sector (e.g. insurance companies). Two sources of information emerged as key to identify the cities that are most at risk of being impacted by natural disasters. These are: Swiss Re's "Mind the Risk[11]" report, and the "100

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[11] Sundermann, Lukas, Schelske, Oliver and Hausmann, Peter. 2013. "Mind the risk – A global ranking of cities under threat from natural disasters" 2013. Swiss Re

Resilient Cities"[12] initiative. As a result of the findings, the study team produced a list of 10 at-risk cities in the APEC region, listed in order of vulnerability, which include Yokohama, Japan; Pearl River Delta, China; Osaka-Kobe, Japan; Jakarta, Indonesia; Nagoya, Japan; Shanghai, China; Manila, Philippines; Taipei, Chinese Taipei; Bangkok, Thailand; Phuket, Thailand.

The second step involved a screening process to obtain a short-list of cities for further analysis. The screening was conducted via a visualization exercise of NCI for the long-list of at-risk cities, using GIS tools. The team assessed the existence of NCI and their extent and magnitude within or adjacent to the city in question. If the team found the presence of a considerable amount of NCI near the city, that city was included in the short-list for further screening. In addition, the screening considered the extent of urban land cover overlapping with 50-year flood zone.[13] It is important to note here that Osaka-Kobe and Nagoya in Japan are the two cities that did not pass this screening test, due to the fact that there are limited levels of NCI adjacent to these two locations. Since the objective of this study is to assess the value of NCI to protect against natural disasters, the fact that these two cities did not have NCI resulted in the elimination of these cities from the valuation exercise.

The third step consisted of a further screening process to arrive at the two APEC cities that would undergo the valuation exercise. Employing the Multi-Criteria Analysis Method, the team identified nine relevant criteria, including types and areas of NCI; population growth; population density; poverty; losses due to floods; availability of data/studies; and policymaker's perception of the extent of risk in these locations. Table 1 lists the identified criteria used for the screening process.

The team then conducted further research to gather relevant data and information pertaining to each of the criteria. Based on the outcome of the research, the team evaluated each city against each of the criteria. The total scores were ranked in order and the two cities with the highest scores were selected for the valuation exercise.

While most of the criteria is self-explanatory, it is important to note here that in addition to the objective evaluations that are based on data, two of the criteria used by the team require a more subjective evaluation: policymaker's perception of high-risk areas and sufficient available data in economy.

To evaluate policymaker's perception of high-risk areas, the team considered the types of disasters against which that the NCI in proximity to the long-listed cities can protect. From a list of natural disasters, which include storms/floods; earthquakes; volcanic eruptions; among others, storms/floods were selected for the assessment. Therefore, for this filter, the team assessed the level of (high) risks associated with storms and/or floods. The team then collected information/data on vulnerability of the long-listed cities to storm/flood risk. Based on the results of the research, the cities were scored on a scale of 1 to 5, with 5 being at most risk.

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[12] https://www.100resilientcities.org/ - is an initiative which help cities around the world become more resilient to the physical, social and economic challenges that are growing.

[13] The term "X"-year flood is a term used to indicate the probability that a flood of a certain severity will hit in any given year. For instance there is a 1% probability that a 100-year flood event will happen in any given year, and a 2% probability that a 50-year flood event will happen in any given year, etc. The 50-year flood zone is simply the geographic area where that probability is predicted to hold true.

For sufficient available data in economy, the team scoped out data at a broad range, including macro and micro economic; social and environmental indicators; relevant studies to inform the methodology and data collection; the validity of sources for the data, and relevant newspaper/magazine articles, among others. The scores were ranked from very low (score: 1) to very high (score: 5).

For the purpose of distinguishing between the criteria, sufficient available data in economy is not independent from the other criterion for which the team collected data. In particular, the criterion on one previous study specifically refers to existing valuation studies. The research for this criterion drew on the information contained in the Literature Review under Phase I of the NCI Valuation Study, where a number of peer reviewed NCI valuation studies were identified. The team also found additional studies, including Digital Coast; a National Oceanic and Atmospheric Administration-supported website[14] that provides coastal data and Wealth Accounting and the Valuation of Ecosystem Services (WAVES)[15], of particular relevance to this exercise.

The remaining criteria sought data from a range of sources. For example, the team utilized a number of online databases, worldwide and local, to obtain economic, social and environmental data, to the extent possible. The data was then assigned scores and ranked based on relevant coverage and availability.

Table 1 below details the city selection process undertaken by the team through the two levels of screening. The column on the extreme right shows the results of scoring and ranking. The results revealed that the Pearl River Delta (PRD) in China and Manila in the Philippines had the same total and highest scores in relation to other locations and were selected as the two representative APEC areas to be analyzed for NCI valuation analysis.

The PRD is defined as a metropolitan region, which is the reason it was considered as one of the candidate cities suitable as a case study. However, due to the size of the PRD region and, after examining the data and evaluating the alignment with the valuation model, the team determined that it would be more appropriate to pick one city in the PRD region to conduct the valuation analysis. The valuation of ecosystem services and the benefits they provide to communities is best conducted in a policy-relevant scale. The more closely the analysis relates to the communities that will implement the approaches, the better the assessment will inform the decision-making context. Guangzhou was selected, largely due to the presence of NCI (salt marshes) in the river delta and throughout the southern reaches of the city, but also due to its strategic location and economic importance, given that it is a major port and transportation hub in East Asia.

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[14] https://coast.noaa.gov/digitalcoast/

[15] https://www.wavespartnership.org/

Table 1: Representative City Selection Matrix

	Screening 1		Screening 2									Total / Rank
	1	2	1	2	3	4	5	6	7	8	9	
Metropolitan Areas	NCI within or adjacent to city	Urban land cover overlaps with 50 y.o. flood zone	Policymaker's perception of high risk area (Score of 1-5 scale, 5 being riskiest); >1	Sufficient Available Data in Economy	Type of NCI adjacent to city (Wetlands:3, Sea Grasses: 2, Coral Reefs 1, 2 or more NCI: 4)	Area (km2) of NCI adjacent to city (>2,000:4, >1,000: 3, >500: 2, >50: 1)	% of people in poverty (>15%: 3, >10%: 2, >5%: 1)	Pop growth > 5% (2pts),	1 prev. study (2pts,),	Pop density	Mean annual flood loss (% of city GDP)[16]	
Tokyo-Yokohama, Japan	Y	Y	5	Very High (5)	Sea Grasses (2)	2.16	15.7% (3)	0.60%	0	6,168.5/km² (3)	0%	18 / 3
Pearl River Delta, China	Y	Y	5	Medium (3)	Sea Grass, Salt marshes, Mangroves, Coral Reefs (4)	2,018 (4)	10.4% (2)	10%? (3)		7,864.75/ km² (3)	>.5%	23 / 1
Osaka-Kobe, Japan	N											

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[16] Assuming sea level rise of 20 cm and that the defenses will be improved to maintain coastal flooding by the same magnitude as relative sea level rise in each city. https://images.nature.com/full/nature-assets/nclimate/journal/v3/n9/extref/nclimate1979-s2.pdf

Jakarta, Indonesia	Y	Y	4	Low (2)	Coral Reefs (1)	60 (1)	20.8% (3)	3.30%	2 (Hong Level) (3)	15,292/km^2 (3)	0.22%	17 / 4
Nagoya, Japan	N											
Shanghai, China	Y	Y	4	Very Low (1)	Salt marshes (3)	1,860 (3)	Gini Coefficient: 0.5 (3)	6.2% (2)		3,895.2/km^2 (2)	0.01%	18 / 3
Manila, Philippines	Y	Y	4	High (4)	Sea Grasses, Mangroves, Coral Reefs (4)	2,194 (4)	6.5% (1)	2.90%	3 (Local and Central Government Levels) (3)	46,178/km^2 (3)	0.06%	23 / 1
Taipei, Chinese Taipei	Y	Y	1	Very Low (1)	Salt Marshes, Coral Reefs, Mangroves (4)	46					0.12%	6/7
Bangkok, Thailand	Y	Y	3	Low (2)	Mangroves (3)	50 (1)	2.70%	3.70%	1 Central Government (2)	5,578.2/km^2 (3)	0.09%	14 / 5
Phuket, Thailand	Y	Y	1	Low (2)	Sea Grasses, Mangroves, Coral Reefs (4)	893 (2)	~0%	0.30%		6,576.9/km^2 (3)	N/A	12/6

Sources: Nathan Associates Inc.

ECONOMIC VALUATION METHODOLOGY

The valuation framework and methodology were identified based on the results of the scoping process described above, on the availability of relevant data, and resulted from a review of several existing frameworks developed to determine the feasibility; costs; and benefits of implementing NCI approaches. Once the locations of the study area were selected, assessment of the types of data that were needed and that could be accessed easily was undertaken. Methodologies that can be applied to estimate the economic value of the NCI's protective service are listed in Table 2.

It is important to note here that different types of evaluation methodologies that are applied toward NCI's ecosystem services in disaster risk reduction were explored in detail in the Phase 1, Gap Analysis Report. The table below provides a synopsis of the analysis.

Table 2. Economic Valuation Methods

Valuation Method	Implication	Data Needs
Cost Avoided/Expected Damage Valuation Method	Appropriate if the required economic damage data is available	• Baseline and projected ecological flood protection assessments before and after restoration (cost of preservation measures, or estimated costs from damages incurred); o Scenarios of Storm Impacts • Location and extent of NCI (before and after restoration efforts); • Infrastructure conditions including type of adjacent settlements and transport networks. • GDP and population grids • Employment data • Number of residents and businesses affected • Industry Sector Diversity
Benefit Transfer Method	Useful for gross estimates, as it applies values from secondary sources to areas with similar characteristics, however, implicit transfer errors impact accuracy, limiting its use in decision-making	• Location and extent of NCI; • Demographic and socioeconomic data; • Infrastructure conditions including type of adjacent settlements and transport networks; • Valuation formula from previous similar study (or studies)
Hedonic Pricing	May be an appropriate metric when assessing developed economies, as data often is	• Index of the environmental amenity of interest; • Price per square meter (or foot); • Cross-section and/or time-series data on property values and property and household characteristics for a well-defined market area that includes homes

Valuation Method	Implication	Data Needs
	more readily available for these economies	with different levels of environmental quality, or different distances to an environmental amenity, such as open space or the coastline; • Location and extent of NCI; • Infrastructure conditions including type of adjacent settlements and transport networks.

The list below provides an overview of the data analysis tools and sources that may be applied to conduct the valuation study.

- USGS high-resolution satellite imagery
- Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Partnership Tools and Valuation Approaches (https://www.wavespartnership.org/)
- GIS Analysis software, including ArcGIS and QGIS
- Federal Emergency Management Agency (FEMA) database footprint of flood zones
- NOAA's Coral Reef Information System (CORIS) https://www.coris.noaa.gov/
- NOAA Wind and Wave III Data
- NOAA – Digital Coast
- The Nature Conservancy (TNC) https://www.nature.org/
- InVEST mapping and valuing models
- UNEP Global Risk Data Platform Hazard and GDP Grid data
- UNISDR – Storm Surge Data
- United National Environment Project (UNEP) Ocean Data Viewer – NCI Footprints
- WWF Data Basin - NCI Footprints
- NASA SEDAC World Population Grid
- National Ocean Economics Program

NCI ECONOMIC VALUATION FRAMEWORK

The analysis in this report uses as a guiding framework "A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction,"[17] which was developed by NOAA. This presents a useful decision-making and analytical framework to assess the costs and benefits of natural coastal infrastructure. The Guide covers the full spectrum of the natural coastal infrastructure decision framework from identifying the area at risk and the problems it faces, to performing hydrological modeling, comparing costs and benefits of natural infrastructure solutions, and placing the results within the context of a comprehensive natural coastal infrastructure strategy — all while communicating and engaging with an appropriate group of stakeholders.

However, the assessment uses a modified version of the NOAA Guide because certain elements of the document, such as hydrological modeling; modeling the costs of implementing natural coastal infrastructure solutions; and stakeholder engagement are outside the scope of this activity. The analysis draws mainly on steps 1, 2, 5, and 6 (see Figure 5). Steps 1 and 2 (defining the flooding problem, and assess flooding scenarios

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[17] https://coast.noaa.gov/data/digitalcoast/pdf/gi-cost-benefit.pdf

without green infrastructure) are described in the previous sections, while the remaining steps are described below.

In addition, the study on "Managing Coasts with Natural Solutions",[18] developed by the World Bank, provides a detailed technical reference for assessing the modeling the hydrodynamics of coastal ecosystems and the valuation of natural infrastructure benefits. It recommends similar steps, including offshore and nearshore hydrodynamic modeling; understanding the interactions between different types of coastal structures; and estimating flooding scenarios. It also provides additional guidance on the most appropriate methods for valuing expected damages from coastal storms and averted damages, or benefits, from natural coastal infrastructure. By valuing the services provided by natural coastal infrastructure, we are assessing their value as a "productive input" to the economy. Barbier[19] notes that this is a "viable methodology" for policy analysis. This approach assumes that the NCI yields a benefit in terms of reducing the severity of economic damage from storms and values the protective services of mangroves by estimating their ability to mitigate damage costs.

The two frameworks referenced in this analysis, are very similar in intent and process, however, NOAA's "Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction," provides a path to developing an overarching strategy for assessing the benefits of NCI—which is a first critical step for projects of this type. It also focuses more on the critical process of community and stakeholder engagement, and is aimed at a more diverse audience, which includes local; domestic; and regional decision-makers and other critical stakeholders. Essentially providing an answers to the key question, "What do we do?"

The other, the World Bank's "Managing Coasts with Natural Solutions," provides a more technical overview of techniques for modeling hydrodynamics and valuing coastal protection benefits, and is aimed at scientists, economists, and hydrologic modelers. This guide helps to provide the answers to the question, "How do we do it?" It is important to note that both guides recommend using an Expected Damages approach to valuing the changes in ecosystem services as described in Table 2, the approach used in both case studies below. Once a strategy is developed using NOAA's "Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction", the World Bank's "Managing Coasts with Natural Solutions" can appropriately be used to provide additional scientific, economic and technical guidance in terms of how to undertake the hydrologic modeling, and coastal protection service valuation.

Because the extensive hydrologic and economic modeling approaches recommended by the World Bank's "Managing Coasts with Natural Solutions" are outside the scope of this study, the following case studies follow the modified version of the NOAA framework described above, and only use the World Bank Guide as a reference.

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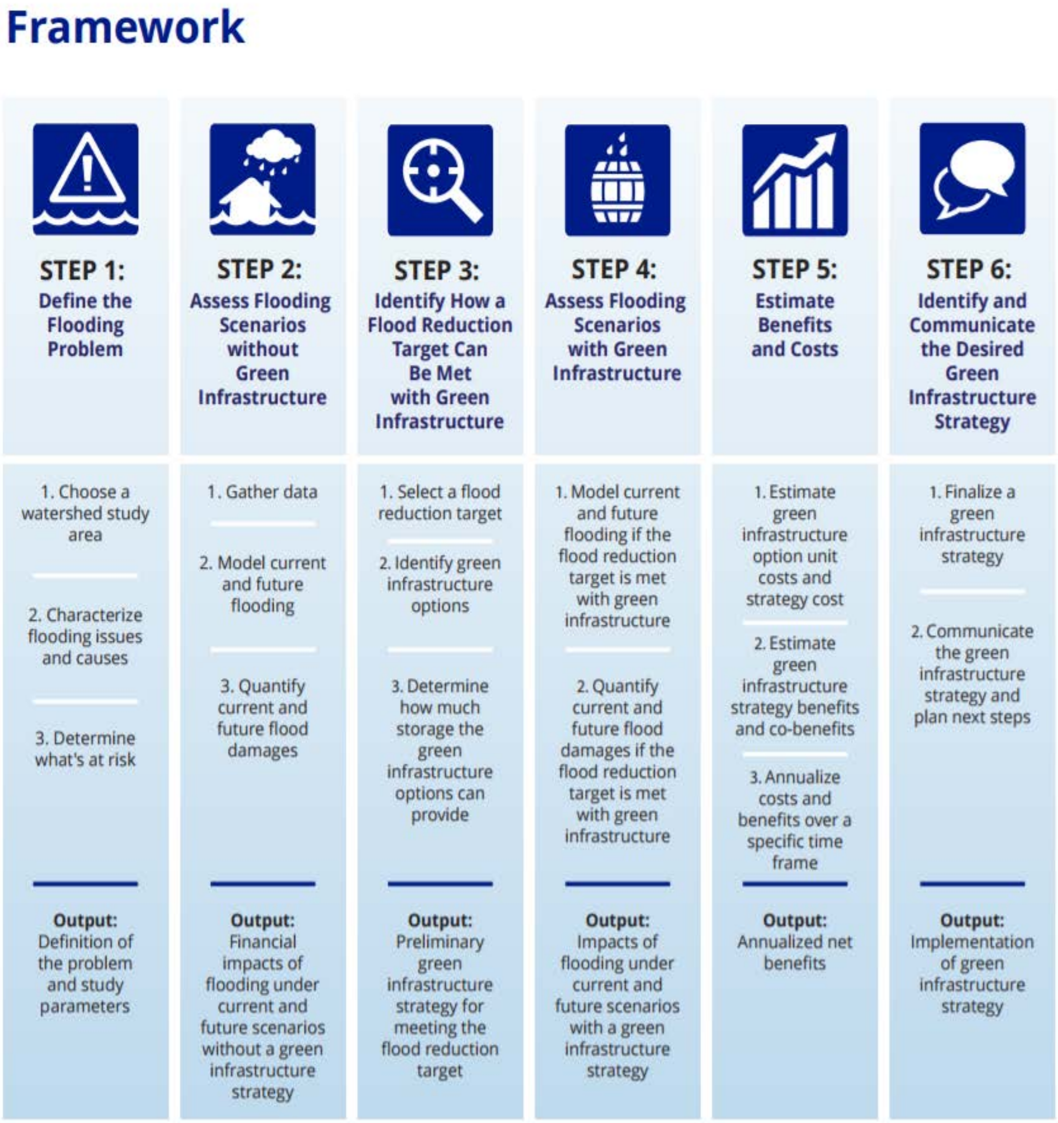
[18] World Bank. 2016. Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. M. W. Beck and G-M. Lange, editors. Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC.

[19] Barbier 2007. Valuing Ecosystems as productive inputs.

Figure 5. NOAA Framework for assessing costs and benefits of natural coastal infrastructure



Framework

STEP 1: Define the Flooding Problem	STEP 2: Assess Flooding Scenarios without Green Infrastructure	STEP 3: Identify How a Flood Reduction Target Can Be Met with Green Infrastructure	STEP 4: Assess Flooding Scenarios with Green Infrastructure	STEP 5: Estimate Benefits and Costs	STEP 6: Identify and Communicate the Desired Green Infrastructure Strategy
1. Choose a watershed study area 2. Characterize flooding issues and causes 3. Determine what's at risk	1. Gather data 2. Model current and future flooding 3. Quantify current and future flood damages	1. Select a flood reduction target 2. Identify green infrastructure options 3. Determine how much storage the green infrastructure options can provide	1. Model current and future flooding if the flood reduction target is met with green infrastructure 2. Quantify current and future flood damages if the flood reduction target is met with green infrastructure	1. Estimate green infrastructure option unit costs and strategy cost 2. Estimate green infrastructure strategy benefits and co-benefits 3. Annualize costs and benefits over a specific time frame	1. Finalize a green infrastructure strategy 2. Communicate the green infrastructure strategy and plan next steps
Output: Definition of the problem and study parameters	**Output:** Financial impacts of flooding under current and future scenarios without a green infrastructure strategy	**Output:** Preliminary green infrastructure strategy for meeting the flood reduction target	**Output:** Impacts of flooding under current and future scenarios with a green infrastructure strategy	**Output:** Annualized net benefits	**Output:** Implementation of green infrastructure strategy

CASE STUDY: METRO MANILA

[Step 1: Define the Flooding Problem
Task 1: Choose a Watershed Study Area [20]]

The City of Manila, Philippines originally named after its wealth of flowering mangrove forests, locally known as "nilad". Metro Manila is a densely populated urban area, with multiple types of natural coastal infrastructure within and adjacent to the city. Over the past century, as in many coastal cities, the natural coastal infrastructure has been reduced due to increased economic development. At the turn of the century, more than 500 square kilometers (km^2) of mangrove forest fringed the bay, providing a wealth of benefits in terms of coastal protection from storms, food and wood products. Currently, less than 20 km^2 of mangrove forests remain (Figure 6). Fortunately, for decades, the government of the Philippines, as well as community organizations have been experimenting with innovative coastal management techniques[21] aimed at reversing trends. These approaches targeted declining fisheries, mangrove and coral reef destruction, and poverty among coastal communities.

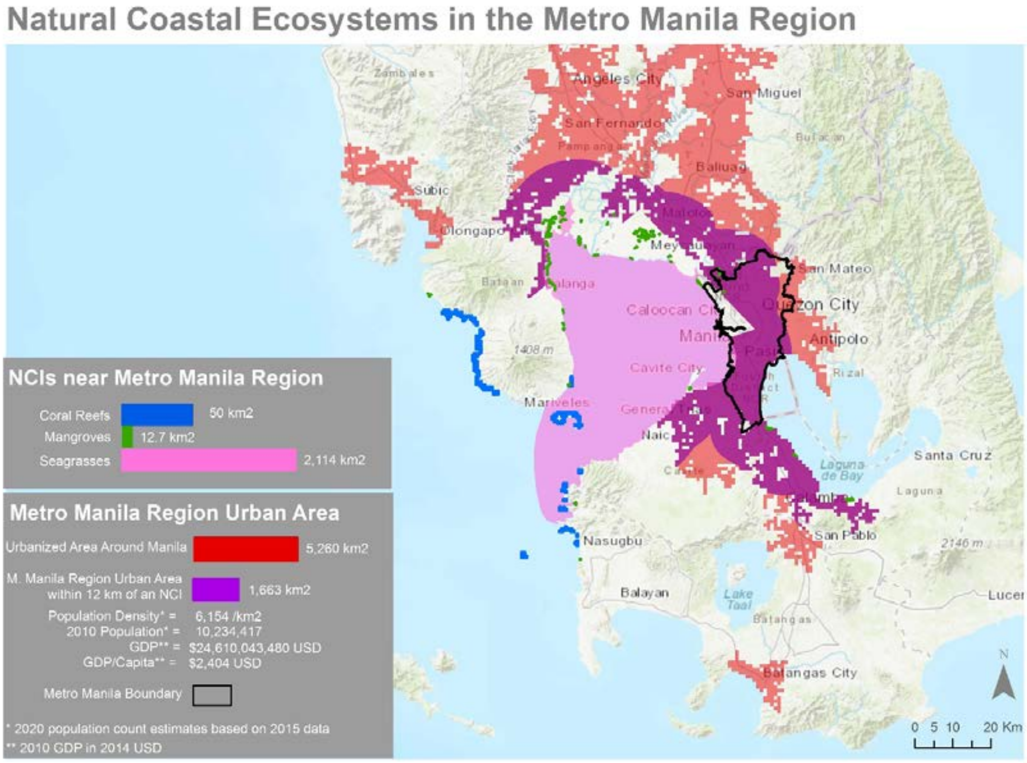


Figure 6. Metro Manila, including presence of Natural Coastal Infrastructure

Metro Manila consists of the City of Manila and sixteen municipalities covering over 600 km^2. It is a low-lying region (2-3 meters above sea level) encompassing the vast drainage basin of the Pasig River watershed, consisting of mostly reclaimed lagoons which support commercial districts, residential areas and fishponds.[22]

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[20] See page 19 for reference to steps and tasks in the NOAA Framework

[21] White, A. T. 2007. Fisheries and Coastal Management in the Philippines. In Fisheries Management Progress towards Sustainability. Eds McLanahan and Castilla

[22] The World Bank. 2010. Coastal Risks and Adaptation in Asian Coastal Megacities: A Synthesis Report. Washington, DC.

[Step 1: Define the Flooding Problem Task 2: Characterize Flooding Issues and Causes[23]]

The population and infrastructure in Metro Manila is at high risk for flooding and coastal storm inundation. In the ten years between 2005 and 2015, the Philippines was impacted by more than 2,300 hazardous coastal storms and flooding events.[24] The Philippines is also impacted by an average of 20 typhoons annually.[25] Metro Manila, in particular, experiences frequent severe flooding events due to its location relative to the paths of typhoons and propagation of monsoons. In 2009, tropical storm Ketsana, locally known as Typhoon Ondoy, caused the heaviest flooding seen in decades. More than 80% of the city was underwater, displacing almost 300,000 people in Metro Manila,[26] and causing approximately US$1.45B in direct damages, and almost US$3B in indirect[27] impacts to the economy.[28]

It is important to note that acknowledging these increasing risks and of the potential role of natural defenses to reduce these risks, the Government of the Philippines has committed to restoring mangroves as part of its risk reduction strategy, and the Philippines WAVES program on natural capital accounting is helping the Philippines incorporate the value of mangroves into their national accounts.[29]

Climate change is also expected exacerbate this risk. In flood-prone cities such as Manila, potential sea level rise and increased frequency and intensity of extreme weather events poses enormous challenges on urban local bodies' ability to adapt. The World Bank estimates under varying International Panel on Climate Change (IPCC) emissions scenarios that mean seasonal precipitation in Manila will increase by 4% and 2.6% for high and low emissions scenarios, respectively.[30] Even with the implementation of current flood infrastructure plans, by 2050 under the high emissions scenario, flooded areas will increase by 42% and 2.5 million people will be at risk in the event of a 100-year flood. A 30-year flood event is expected to lead to costs ranging from US$0.9B, given current infrastructure and climate conditions, to US$1.5B with current infrastructure and a high emissions climate scenario.[31]

WHAT IS AT RISK?

[Step 1: Define the Flooding Problem Task 3: Determine what is at Risk[32]]

Overall, the Philippines faces extreme risks in terms of exposure to hazardous coastal storms, and economic and social vulnerability. The World Risk Index, which evaluates the exposure and inherent vulnerability of nations to natural hazards ranked the Philippines

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[23] See page 19 for reference to steps and tasks in the NOAA Framework

[24] Losada, I.J., M. Beck, P. Menéndez, A. Espejo, S. Torres, P. Díaz-Simal, F. Fernández, S. Abad, N. Ripoll, J. García, S. Narayan, D. Trespalacios. 2017. Valuation of the Coastal Protection Services of Mangroves in the Philippines. World Bank, Washington, DC.

[25] See, Justin Charles G., and Emma E. Porio. "Assessing Social Vulnerability to Flooding in Metro Manila Using Principal Component Analysis." Philippine Sociological Review, vol. 63, 2015, pp. 53–80.

[26] http://edition.cnn.com/2009/WORLD/asiapcf/09/27/ Philippines. Floods/index.html

[27] Indirect impacts are defined as associated losses in production and other flows of the economy

[28] Global Facility for Disaster Reduction and Recovery. Philippines Typhoons Ondoy and Pepeng: Post Disaster Needs Assessment, Main Report. Ahttp://siteresources.worldbank.org/INTPHILIPPINES/Resources/PDNAVol1MainReport.pdf. Accessed December 18, 2017.

[29] Losada, I.J. et al. 2017.

[30] The World Bank. 2010.

[31] Ibid.

[32] See page 19 for reference to steps and tasks in the NOAA Framework

third of the most at-risk economies in terms of exposure to natural hazards, vulnerability, coping capacity, and adaptive capacity in 2017.[33] Manila's GDP, estimated at US$111.6 billion,[34] and over US$60 billion of value in buildings and infrastructure (in 2016) are subject to estimated disaster losses of 0.6% of GDP per year.[35]

As noted above, Metro Manila faces grave flooding and inundation risks from severe storms and the threat of climate change. Global analysis from major catastrophic risk insurers estimates that Metro Manila faces an average of US$6 billion in risks each year from windstorms (typhoons) alone, over the next 10 years.[36] Projecting that figure out, using GDP growth estimates[37] would result in economic risks from severe storms of US$20 billion annually by 2050. Manila's population of 12.8 million is also at risk. Estimates of 12.6 million at risk citizens each year will rise to more than 18 million by the year 2050, not taking into account increasing risks due to climate change and the accompanying sea-level rise. High population density (20,785 people/km^2)[38], and poverty levels (6.5% in Metro Manila[39]) further exacerbate that risk.

POTENTIAL BENEFITS OF NCI

[Step 2: Assess Flooding Scenarios without Green Infrastructure Tasks 1, 2, 3[40]]

This analysis assesses the value of coastal benefits by first assessing potential damages or economic losses, from severe storms (typhoons), on the Metro Manila area over the period from 2020-2050. Because storms vary in intensity, and impact, and are expected to increase in severity over time due to climate change, we describe three storm damage scenarios.

These scenarios are based on a 2008[41] analysis by the World Bank,[42] which use detailed climatology and hydro meteorological variables to estimate economic damages, vulnerability, and scenario analysis. The World Bank based its analysis on three "storm-year" frequencies, 1 in 10, 1 in 30, and 1 in 100 (aka "the 100-year storm"), and also varied those impacts with two different IPCC climate change scenarios that impact sea-level rise and resulting inundation levels. Since climate researchers have found that "100-year floods" may happen as frequently as every 3-20 years,[43] our base assumption is that the 10-year storm could become an annual event.

1. Baseline scenario: Using the economic impacts of a 1 in 10 years storm across the entire period (2020-2050);
2. 1 in 10 years storm with a 30-year storm, including the high-end IPCC scenario included every five years; and

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[33] Bundnis Entwicklung Hilft. 2017. World Risk Report, Analysis and Prospects 2017.

[34] Philippine Statistics Authority reports GDP of Metro Manila at 36.6% of total GDP for the Philippines in 2016, World Bank Reports total GDP of the Philippines as US$304.9B in 2016.

[35] Natural Disaster Risk Management in the Philippines: Enhancing Poverty Alleviation Through Disaster Reduction- 2005, World Bank

[36] https://www.lloyds.com/cityriskindex/locations/fact_sheet/manila

[37] Lloyd's City Risk Index estimates average GDP growth for Manila to be 3.46%

[38] Philippine Statistics Authority. https://psa.gov.ph/content/philippine-population-density-based-2015-census-population. Accessed December 19, 2017.

[39] https://borgenproject.org/latest-statistics-on-philippine-poverty/

[40] See page 19 for reference to steps and tasks in the NOAA Framework

[41] Dollar values from this report are translated to US$2014

[42] World Bank. 2008. Climate Risk and Adaptation in Coastal Asian Megacities.

[43] https://phys.org/news/2012-02-climate-today-year-years.html

3. 1 in 10 years storm with a 30-year storm, including the high-end IPCC scenario included every five years, plus a 100-year storm with the high-end IPCC scenario included once (in year 15).

Based on additional climatological analysis,[44] we assumed that a typhoon would hit Metro Manila once every two years. Table 3 shows that the potential expected damages range from approximately US$378 million to US$2.8 billion annually with existing levels of NCI, depending on the severity of the storm event.

The next step is to add the potential benefits that could be realized if Metro Manila were to implement a comprehensive NCI strategy, which would include the restoration of historical mangrove forests in areas designed to maximize protection from storm surge and flooding. The World Bank WAVES program[45] estimated that restoring mangrove forests to the levels that existed in 1950 would protect 267,000 people per year, and provide US$450 million in flood protection benefits annually, across the entire Philippines.[46] It assessed a value of US$3,200 per hectare in direct flood control benefits across the economy. This value, which would be conservative for Metro Manila, as they have more economic assets at risk, is used as the baseline value for the restoration scenarios described below.

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[44] World Bank. 2016. Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. M. W. Beck and G-M. Lange, editors. Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC.

[45] WAVES is a World Bank-led global partnership that aims to promote sustainable development by ensuring that natural resources are mainstreamed in development planning and central government economic accounts.

[46] Losada, I.J., M. Beck, P. Menéndez, A. Espejo, S. Torres, P. Díaz-Simal, F. Fernández, S. Abad, N. Ripoll, J. García, S. Narayan, D. Trespalacios. 2017. Valuation of the Coastal Protection Services of Mangroves in the Philippines. World Bank, Washington, DC.

Table 3. Potential Economic Damages to Metro Manila based on three storm scenarios (in US$000s)

Year	1 in 10 year/baseline	1 in 10 year baseline - with the 30 year high end IPCC every 5 years	1 in 10 year baseline - with the 30 year high end IPCC every 5 years plus 100 year storm added once (2035)
2020	377,678	1,705,023	1,705,023
2021	377,678	377,678	377,678
2022	377,678	377,678	377,678
2023	377,678	377,678	377,678
2024	377,678	377,678	377,678
2025	377,678	1,705,023	1,705,023
2026	377,678	377,678	377,678
2027	377,678	377,678	377,678
2028	377,678	377,678	377,678
2029	377,678	377,678	377,678
2030	377,678	1,705,023	1,705,023
2031	377,678	377,678	377,678
2032	377,678	377,678	377,678
2033	377,678	377,678	377,678
2034	377,678	377,678	377,678
2035	377,678	1,705,023	2,766,317
2036	377,678	377,678	377,678
2037	377,678	377,678	377,678
2038	377,678	377,678	377,678
2039	377,678	377,678	377,678
2040	377,678	1,705,023	1,705,023
2041	377,678	377,678	377,678
2042	377,678	377,678	377,678
2043	377,678	377,678	377,678
2044	377,678	377,678	377,678
2045	377,678	1,705,023	1,705,023
2046	377,678	377,678	377,678
2047	377,678	377,678	377,678
2048	377,678	377,678	377,678
2049	377,678	377,678	377,678
2050	377,678	1,705,023	1,705,023
Total Damages 2020-2050	**11,708,020**	**20,999,431**	**22,060,725**

Sources: Nathan Associates Inc.

[Step 5: Estimate Benefits and Costs Task 2, 3[47]]

Table 4. Cumulative Averted Damages to Metro Manila (2020-2050) based on Mangrove Restoration Scenarios

Mangrove Restoration Scenario	Cumulative Averted Damages (2020-2050) from Coastal Protection Services
10 km2 restored annually	$171,318
20 km2 restored annually	$330,038
30 km2 restored annually	$488,758
40 km2 restored annually	$647,478
10 km2 restored annually with 5% growth increase benefit	$298,915
20 km2 restored annually with 5% growth increase benefit	$580,131
30 km2 restored annually with 5% growth increase benefit	$861,347
40 km2 restored annually with 5% growth increase benefit	$1,142,563

Sources: Nathan Associates Inc.

This case study uses four scenarios based on different levels of annual mangrove restoration, 10 km^2 mangroves restored per year, 20 km^2 mangroves restored per year, 30 km^2 mangroves restored per year, and 40 km^2 restored per year. Because the value of mature mangrove forests is expected to provide greater storm protection benefits than young or newly restored mangrove forests, scenarios were also developed that included a 5% increase in coastal protection benefits annually, once the mangroves had been restored for five years. This 5% is based on anecdotal evidence, as there is very limited quantitative research available on the increase of these benefits over time.

Table 4 shows the potential **cumulative** averted damages, or value for coastal protection benefits, for each mangrove restoration scenario. The potential value of protection services from mangroves for these scenarios ranges from approximately US$171,000 to over US$1.1 million. It is important to note that these values only represent the coastal protection services provided by mangrove forests. Mangroves provide many additional services that can be valued, including recreation and ecotourism, wood and thatch for local communities, and fish habitat benefits. Researchers have found that the total value of mangrove services in Bohol and Palawan exceeded PHP $33 million in 2012, which provides some perspective for the potential value in Metro Manila.

CONCLUSIONS

[Step 6: Identify and Communicate the Desired Green Infrastructure Strategy (modified)[48]]

Natural coastal infrastructure is a potent and critical tool in mitigating risk from severe storms, flooding, and climate change in Metro Manila. Mangroves can potentially avert

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[47] See page 19 for reference to steps and tasks in the NOAA Framework

[48] Ibid.

US$1.7 billion in damages for a 50-year storm, and also provide significant benefits for more frequent, lower intensity events[49] over the entire Philippines. This study estimated the potential expected damages from typhoons hitting Metro Manila between 2020 and 2050, which range from approximately US$378 million to US$2.8 billion annually with existing levels of NCI, depending on the severity of the storm events. The potential value of protection services from the restoration of mangroves in Metro Manila ranges from approximately US$171,000 to over US$1.1 million, over the same time period, for the scenarios developed for this report. It is important to note that these values only represent the coastal protection services provided by mangrove forests.

While this case study focused on the protective services provided by mangroves, Metro Manila also has other types of NCI that can provide coastal protection services, including coral reefs that fringe the opening of Manila Bay, and sea grasses, which attenuate waves; enhance sedimentation; and prevent erosion.[50] In addition, this report analyzed only the protection value of mangroves, as that was the only NCI that had high quality valuation data, however, research shows that when valuing NCI, the combined value of services for different types of NCI may be greater than the sum of the individual parts.

Because the coastal protection services provided by mangroves, coral reefs, salt marshes, and other types of natural coastal infrastructure are "non-marketed," their benefits are not often considered in commercial and economic development decisions. These values are rarely measured explicitly, resulting in the continued deforestation of mangroves across the globe and policy makers will be unable to consider these means of coastal protection as part of coastal economic development policies. In addition, mangroves provide many additional services that can be valued, including recreation and ecotourism, wood and thatch for local communities, and fish habitat benefits. However, valuing those additional benefits was outside the scope of this report.

Communication of the increasing risk from severe storms and climate change, as well as the potential benefits of NCI to a wide range of partners and stakeholders, is critical, including local businesses; communities; and decision-makers. Local businesses are often overlooked partners and as over 70% of the economic damages from severe storms and flooding in Manila impact buildings,[51] they are a critical component to any comprehensive NCI strategy. Incorporating the concepts of natural coastal infrastructure into business decisions is a strategic, multi-objective, community- and business-oriented approach that can reduce risk, increase revenue, enhance branding, and increase ecological and economic resiliency.

As noted previously, these case studies use a modified version of the NOAA Guide because certain elements of the Guide, such as hydrological modeling; modeling the costs of implementing natural coastal infrastructure solutions, and stakeholder engagement are outside the scope of this paper. However, to maximize the potential value of coastal protection and additional services that can be provided by NCI, full implementation of the NOAA Framework to develop an overarching strategy for assessing the costs and benefits of natural infrastructure, including extensive stakeholder engagement is recommended. As described previously, the World Bank "Managing Coasts with Natural Solutions[52]" can then be used to provide additional scientific, economic and technical

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[49] Losada, I. J., et al. 2017.

[50] Marjolijn J. A. Christianen, et al. 2013. Low Canopy Seagrass Beds Still Provide Important Coastal Protection Services.

[51] World Bank. 2008. Climate Risk and Adaptation in Coastal Asian Megacities.

[52] World Bank Group. 2016. Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. WAVES Technical Paper; World Bank, Washington, DC

guidance in terms of how to undertake the hydrologic modeling, and coastal protection service valuation aspects within the strategy.

CASE STUDY PEARL RIVER DELTA/ GUANGZHOU

[Step 1: Define the Flooding Problem
Task 1: Choose a Watershed Study Area [53]]

The Pearl River Delta (PRD) is located in the central coastline of Guangdong Province in southern China. Formed as a vast flood plain (42,657 km^2) of the Pearl River it hosts eleven major cities, including the mega-city formed by Hong Kong, China; Shenzhen; and Guangzhou. Estimates in 2015 put the population at over 108 million, with projections estimating over 120 million residents by 2050.[54] Historically a center of Chinese commerce and culture, the City of Guangzhou was the start of the Silk Road on the Sea, the maritime trade route linking East and West. Thousands of years later, the PRD is one of the world's most successful economies, with an estimated GDP of US$690 billion. In the 1980s, PRD's designation as a special economic zone drew thousands of manufacturing businesses and, as a result, PRD became one of the largest consumer markets. Today PRD's economic base has shifted to high-tech sectors, such as telecommunications; biotechnology; and new energy industries. However, the geographic features that make it so attractive to commerce— a central coastal location, and a large, low-lying delta that allows easy access to maritime commerce— also put it at risk for natural disasters.

[Step 1: Define the Flooding Problem
Task 2: Characterize Flooding Issues and Causes[55]]

Storm surge and related tidal flooding impacts are the primary cause of natural disasters in the Guangdong coastal regions. The Swiss RE report "Mind the Risk"[56] estimates over 12 million people in the delta are exposed to windstorms (typhoons) and flood risk, ranking this area as the most highly exposed for both categories (Figure 7). The annual mean precipitation in the Guangdong Province is about 1800 mm with 85% of this precipitation occurring between April and September.[57] A 2004 report estimated that 66% of the tropical cyclones that made landfall in China entered through the Guangdong Province. At that time, the Guangdong government estimated that on average the economic loss caused by each tropical cyclone landing was over 300 million yuan[58].

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[53] See page 19 for reference to steps and tasks in the NOAA Framework

[54] Flood risk appraisal and management in mega-cities: a case study of practice in the Pearl River Delta, China, F. K. S. Chan, G. Mitchell, A. T. McDonald, Published December 2012, 7 (4) wpt2012060; DOI: 10.2166/wpt.2012.060, Water Practice and Technology

[55] See page 19 for reference to steps and tasks in the NOAA Framework

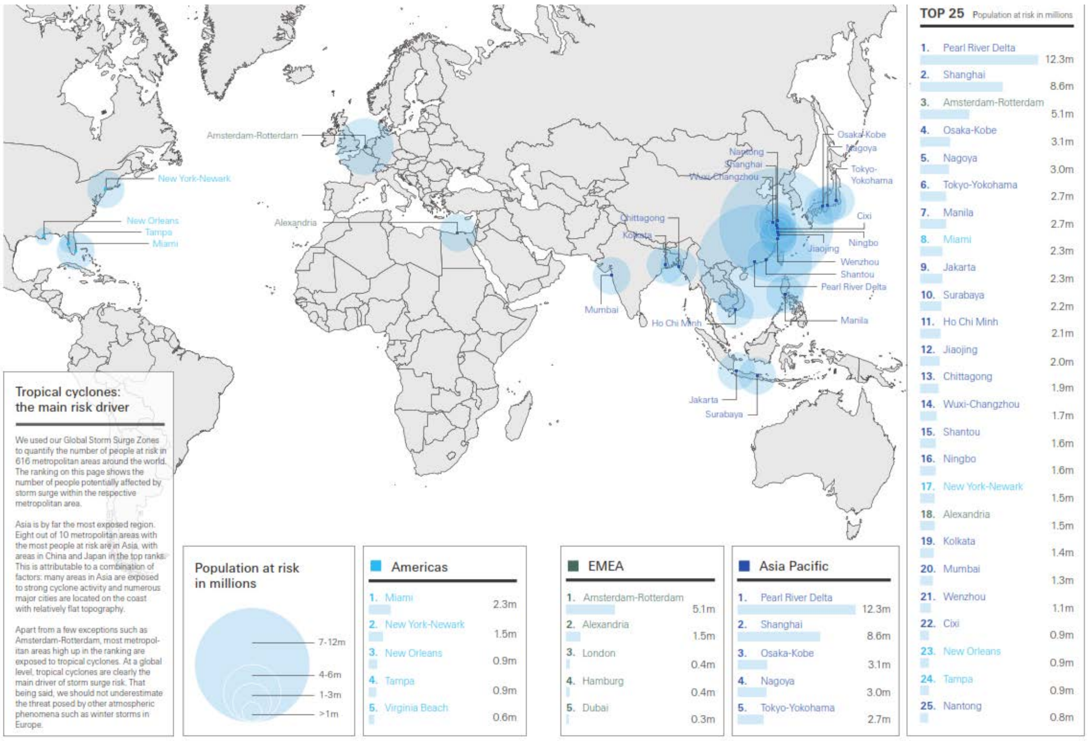
[56] Sundermann, Lukas, Schelske, Oliver and Hausmann, Peter. 2013. "Mind the risk – A global ranking of cities under threat from natural disasters" 2013. Swiss Re.

[57] Yang, L., Scheffran, J., Qin, H., & You, Q. (2014). Climate-related flood risks and urban responses in the Pearl River Delta, China. Regional Environmental Change, 15(2), 379-391.

[58] Tender AM02 – 316, Provision of Service for Characterizing the Climate Change Impact in Hong Kong; China Final report submitted to the HKSAR – Environmental Protection Department, Written by: Miss Fung Wing Yee, 2004

The City of Guangzhou, in the Guangdong province, in China was identified as a suitable candidate for the evaluation exercise. This was based on several factors including urban land cover overlapping with the flood zone, potential risk recognized by policymakers, and most importantly the presence of extensive NCI adjacent to the city. Figure 8 shows the extensive salt marshes (in yellow) that protect the entrance to Guangzhou's port via the Pearl River.

Figure 7. Swiss RE Global Storm Surge Zones
Accessed at http://www.swissre.com/rethinking/climate_and_natural_disaster_risk/first_global_storm_surge_zones.html



Tropical cyclones: the main risk driver

We used our Global Storm Surge Zones to quantify the number of people at risk in 616 metropolitan areas around the world. The ranking on this page shows the number of people potentially affected by storm surge within the respective metropolitan area.

Asia is by far the most exposed region. Eight out of 10 metropolitan areas with the most people at risk are in Asia, with areas in China and Japan in the top ranks. This is attributable to a combination of factors: many areas in Asia are exposed to strong cyclone activity and numerous major cities are located on the coast with relatively flat topography.

Apart from a few exceptions such as Amsterdam-Rotterdam, most metropolitan areas high up in the ranking are exposed to tropical cyclones. At a global level, tropical cyclones are clearly the main driver of storm surge risk. That being said, we should not underestimate the threat posed by other atmospheric phenomena such as winter storms in Europe.

Americas	
1. Miami	2.3m
2. New York-Newark	1.5m
3. New Orleans	0.9m
4. Tampa	0.9m
5. Virginia Beach	0.6m

EMEA	
1. Amsterdam-Rotterdam	5.1m
2. Alexandria	1.5m
3. London	0.4m
4. Hamburg	0.4m
5. Dubai	0.3m

Asia Pacific	
1. Pearl River Delta	12.3m
2. Shanghai	8.6m
3. Osaka-Kobe	3.1m
4. Nagoya	3.0m
5. Tokyo-Yokohama	2.7m

TOP 25	Population at risk in millions
1. Pearl River Delta	12.3m
2. Shanghai	8.6m
3. Amsterdam-Rotterdam	5.1m
4. Osaka-Kobe	3.1m
5. Nagoya	3.0m
6. Tokyo-Yokohama	2.7m
7. Manila	2.7m
8. Miami	2.3m
9. Jakarta	2.3m
10. Surabaya	2.2m
11. Ho Chi Minh	2.1m
12. Jiaojing	2.0m
13. Chittagong	1.9m
14. Wuxi-Changzhou	1.7m
15. Shantou	1.6m
16. Ningbo	1.6m
17. New York-Newark	1.5m
18. Alexandria	1.5m
19. Kolkata	1.4m
20. Mumbai	1.3m
21. Wenzhou	1.1m
22. Cixi	0.9m
23. New Orleans	0.9m
24. Tampa	0.9m
25. Nantong	0.8m

WHAT IS AT RISK?

[Step 1: Define the Flooding Problem Task 3: Determine what is at Risk[59]]

Located on the Pearl River about 120 km (75 mi) north-northwest of Hong Kong, China; and 145 km (90 mi) north of Macau, Guangzhou has a history of over 2,200 years and was a major terminus of the maritime Silk Road and continues to serve as a major port and transportation hub today. In 2015, the city's administrative area was estimated to have a population of 13,501,100,[60] and its GDP is estimated at approximately US$272 billion.[61]

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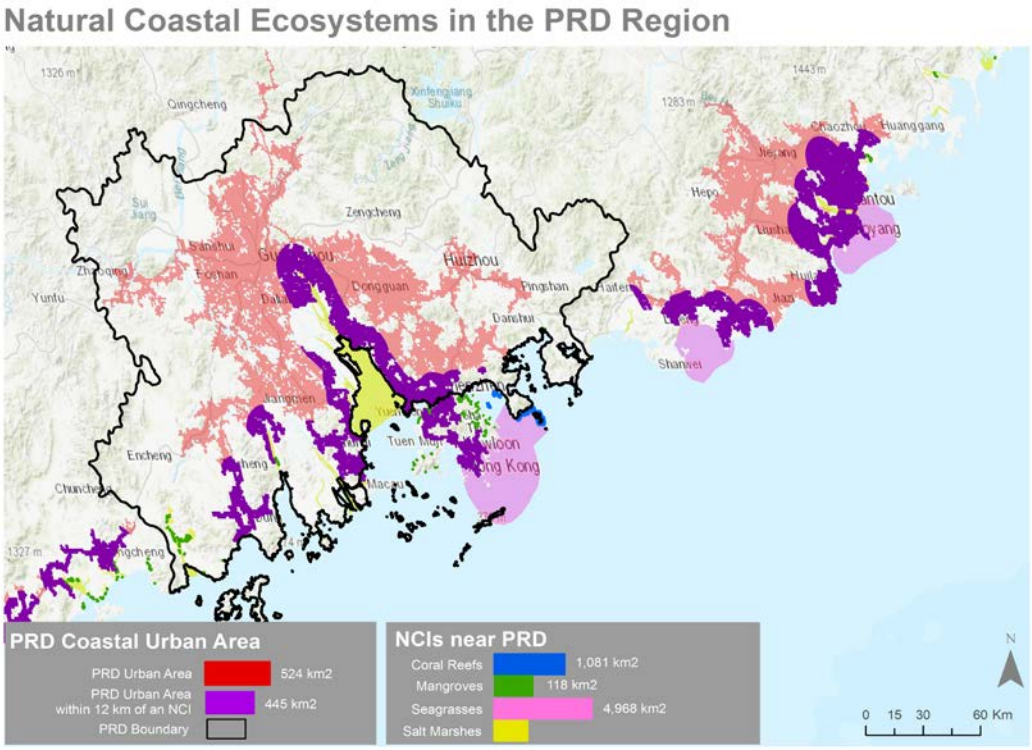
[59] See page 19 for reference to steps and tasks in the NOAA Framework
[60] http://www.iccsct.org/about.html
[61] data.stats.gov.cn. Retrieved 2017-08-25

Figure 8. Natural Coastal Infrastructure in the PRD Region



As noted above, Guangzhou faces grave flooding and inundation risks from severe storms and the threat of climate change. Global analysis from major catastrophic risk insurers estimates that Guangzhou faces an average of approximately US$16 billion in risks each year from windstorms (typhoons) alone, over the next 10 years.[62] Projecting that figure out, using GDP growth estimates[63] would result in economic risks from severe storms of over US$118 billion annually by 2050. Guangzhou's population is also at risk. Estimates of 12.3 million at risk citizens each year will rise to more than 20 million by the year 2050, not taking into account increasing risks due to climate change and the accompanying sea-level rise.

Natural disasters impact commerce, as well as livelihoods, and as the key port of the Pearl River Delta, and one of China's primary import/export locations, a typhoon that damaged critical port infrastructure could have impacts that ripple far beyond those of the local economy. In 2010, the Port of Guangzhou handled 410 million tons of cargo, including 12.6 million TEUs, making it the fifth busiest port in the world for non-containerized cargo and seventh in the world for containerized cargo.[64] The Port of Guangzhou is the busiest port for loading and unloading automobiles in South China and the biggest base for imports and exports of automobiles. Other key industries include automobile manufacturing,

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[62] https://www.lloyds.com/cityriskindex/locations/fact_sheet/guangzhou

[63] Lloyd's City Risk Index estimates average GDP growth for Guangzhou to be 8.4%

[64] http://www.worldportsource.com/ports/commerce/CHN_Port_of_Guangzhou_403.php

petrochemicals, and electronics. The Xinsha Automobile Terminal is the export point in the Port of Guangzhou for Honda (China) and the import point for Toyota, Hyundai, and BMW vehicles. The Port of Guangzhou is one of four ports that have been appointed by China's General Customs for foreign trade auto importing. In 2010, the Guangzhou Port Group handled 431,000 automobiles. The Xinsha Coal Terminal in the Port of Guangzhou operates with outstanding efficiency and is a leading coal-handling facility for South China. The Port of Guangzhou is the largest port in South China for loading and unloading one of the region's major energy sources. In 2010, the Guangzhou Port Group handled 42.5 million tons of coal.

Table 5. Potential Economic Damages to Guangzhou due to Severe Storms

Year	GDP at Risk (2014 US$B)
2020	15.81
2021	15.81
2022	15.81
2023	15.81
2024	15.81
2025	15.81
2026	17.14
2027	18.58
2028	20.14
2029	21.83
2030	23.66
2031	25.65
2032	27.81
2033	30.14
2034	32.67
2035	35.42
2036	38.39
2037	41.62
2038	45.11
2039	48.90
2040	53.01
2041	57.46
2042	62.29
2043	67.52
2044	73.20
2045	79.34
2046	86.01
2047	93.23
2048	101.07
2049	109.56
2050	118.76

POTENTIAL BENEFITS OF NCI

[Step 2: Assess Flooding Scenarios without Green Infrastructure Tasks 1, 2, 3[65]]

As described in the previous section on Economic Valuation Methodology, the preferred approach to determine the potential benefits of NCI is to first assess potential damages or economic losses from severe storms (typhoons), and then assess how the impacts change in the presence or absence of additional NCI over the study time period (2020-2050). However, because there are some existing protections afforded by the salt marsh in the PRD outside of Guangzhou, and because recent data on economic losses from storm damage in the PRD is difficult to find, this case study also integrates a benefits transfer approach to assess the potential benefits of NCI.[66] This involves "transferring" the baseline economic benefit for salt marshes from another area, and using it as a baseline value in the calculations for Guangzhou. Projecting out the GDP at risk determined by Lloyds City Risk Index the estimates of potential economic damages from severe storms are presented in Table 5.

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[65] See page 19 for reference to steps and tasks in the NOAA Framework

[66] The benefit transfer method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context. Thus, the basic goal of benefit transfer is to estimate benefits for one context by adapting an estimate of benefits from some other context. Also See Table 2.

An exhaustive literature search uncovered only three studies that were appropriate for consideration for the benefits transfer. Two of the studies provided similar estimates for the protective value of salt marshes, US$82.36/km^2/year[67] and US$93.64/km^2/year,[68] the third estimated a significantly lower value of US$10.96/km^2/year.[69] Considering the third number as an outlier, the second number was chosen as it was from a study that was published in 2017. Using the value of US$93.64/km^2/year, and the existing extent of salt marshes surrounding Guangzhou (932 km^2), we set a baseline value for the salt marsh restoration scenarios below.

[Step 5: Estimate Benefits and Costs Task 2, 3[70]]

This case study uses four scenarios based on different levels of annual salt marsh restoration as a percentage of existing salt marshes, additional 25% salt marshes restored per year, additional 50% salt marshes restored per year, additional 75% salt marshes restored per year, and additional 100% salt marshes restored per year. Because the value of mature salt marshes is expected to provide greater storm protection benefits than young or newly restored salt marshes, scenarios were also developed that included a 5% increase in coastal protection benefits annually, once the salt marshes had been restored for five years. This 5% is based on anecdotal evidence, as there is very limited quantitative research available on the increase of these benefits over time.

Table 6 shows the potential cumulative averted damages, or value for coastal protection benefits, for each salt marsh restoration scenario. The potential value of protection services from mangroves for these scenarios ranges from approximately US$13.5 million to over US$80 million. It is important to note that these values only represent the coastal protection services provided by salt marshes. Salt marshes provide many additional services that can be valued, including recreation and ecotourism, improving water quality and sediment retention, and fish habitat benefits.

Table 6. Cumulative Averted Damages to Guangzhou (2020-2050) based on Salt Marsh Restoration Scenarios

Salt Marsh Restoration Scenario	Cumulative Averted Damages (2020-2050) from Coastal Protection Services
25% restored annually	$13,527,234
50% restored annually	$24,349,022
75% restored annually	$35,170,809
100% restored annually	$45,992,597
25% restored annually with 5% growth increase benefit	$22,974,480
50% restored annually with 5% growth increase benefit	$42,148,244
75% restored annually with 5% growth increase benefit	$61,322,008
100% restored annually with 5% growth increase benefit	$80,495,772

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[67] Costanza, 2008.

[68] Costanza, 2017.

[69] Tong 2007.

[70] See page 19 for reference to steps and tasks in the NOAA Framework

CONCLUSIONS

[Step 6: Identify and Communicate the Desired Green Infrastructure Strategy (modified)[71]]

Natural coastal infrastructure is a potent and critical tool in mitigating risk from severe storms, flooding, and climate change in Guangzhou. Salt marshes can potentially avert up to US$80 million in damages annually, and provide significant benefits for more frequent, lower intensity events over the entire PRD. This study estimated the potential expected damages from typhoons hitting Guangzhou between 2020 and 2050, which range from approximately US$16 billion to US$118 billion annually with existing levels of NCI, showing how much is at risk. The potential value of protection services from the restoration of salt marshes in Guangzhou ranges from approximately US$13 to US$80 million over the same time period for the scenarios developed for this report. It is important to note that these values only represent the coastal protection services provided by salt marshes.

While this case study focused on the protective services provided by salt marshes, Guangzhou also has other types of NCI that can provide coastal protection services, including coral reefs, and mangroves, which attenuate waves; enhance sedimentation; and prevent erosion. In addition, this report analyzed only the protection value of salt marshes, however, research shows that when valuing NCI, the combined value of services for different types of NCI may be greater than the sum of the individual parts.

Because the coastal protection services provided by salt marshes, mangroves, and coral reefs and other types of natural coastal infrastructure are "non-marketed," their benefits are not often considered in commercial and economic development decisions. These values are rarely measured explicitly, resulting in the continued reclamation of salt marshes across the globe, and policy makers will be unable to consider these means of coastal protection as part of coastal economic development policies. In addition, salt marshes provide many additional services that can be valued, including recreation and ecotourism, improving water quality and sediment retention, and fish habitat benefits. However valuing those additional benefits was outside the scope of this report.

When developing a strategy for planning and implementing natural infrastructure, communication to a wide range of partners is critical. Those partners may include local businesses, municipal planners and decision makers, and residents of communities that may be impacted by flooding. Local businesses are an often overlooked partner, for instance, given the extensive and valuable industrial infrastructure present in Guangzhou, those who plan for or manage physical infrastructure or local ports would be a critical component to engage in any comprehensive NCI strategy. Integrating natural coastal infrastructure into business decisions can reduce risk, increase revenue, enhance branding, and increase ecological and economic resiliency.

This paper is intended only to assess the potential benefits of natural coastal infrastructure, and the hydrological modeling; modeling the costs, and extensive stakeholder engagement that is recommended in the NOAA Guide is outside the scope

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[71] Ibid.

of this effort. However, full implementation of the NOAA framework is recommended, including extensive stakeholder engagement, to maximize the potential value of coastal protection and additional services that can be provided by NCI in Guangzhou. The NOAA Guide can be used in concert with the World Bank "Managing Coasts with Natural Solutions"[72] which provides detailed scientific, economic and technical guidance on how to undertake the hydrologic modeling and coastal protection service valuation aspects within the strategy.

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[72] World Bank. 2016. Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. M. W. Beck and G-M. Lange, editors. Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC.

DISCUSSION AND POLICY RECOMMENDATIONS

A TALE OF TWO CITIES

There are comparisons and contrasts that can be made between the case studies of Manila and Guangzhou. Both Manila and Guangzhou are at extremely high risk from natural disasters. The World Risk Index ranked the Philippines third of the most at risk economies in terms of exposure to natural hazards, vulnerability, coping capacity, and adaptive capacity in 2017.[73] Similarly, SWISS RE estimates that 12 million people are at risk from wind storms and floods in the PRD, ranking this area as the most highly exposed in both categories.[74] The main difference being that the population of Guangzhou is considered as highly exposed to natural disasters, but records lower social vulnerability scores because of their relatively high coping capacity, and adaptive capacity.[75] [76] [77] This is contrasted with Metro Manila, where the high population density and poverty levels in Manila further contribute to increased social and economic risk.

Manila's GDP, estimated at US$111.6 billion[78], faces an average of US$6 billion in risks each year from typhoons, over the next 10 years,[79] and potentially faces economic risks from severe storms of US$20 billion annually by 2050. Manila's population of 12.8 million is also at risk. Estimates of 12.6 million at risk citizens each year will rise to more than 18 million by the year 2050, not taking into account increasing risks due to climate change and the accompanying sea-level rise. Approximately US$16 billion of Guangzhou's current GDP of US$272 billion is at risk from storms, and that risk could potentially rise to over US$118 billion by 2050, with more than 20 million people at risk.

In terms of the presence of NCI there are notable differences between the two cities. Manila historically was protected from coastal storms by extensive mangrove forests, but retains very few mangroves. Manila also has a sizable amount of seagrasses in Manila Bay, and corals at the mouth of the bay that can provide protective capacity. Guangzhou, still has a relatively sizable acreage of salt marshes along the banks of the Pearl River, and throughout the delta. However, it lacks other types of NCI to provide protection from storm surge, flooding and to attenuate waves. Given the current levels of protective NCI in each city, Guangzhou could seek to maintain and restore its existing salt marshes, while Manila could seek to undertake restoration activities to regrow the protective NCI.

INTEGRATION WITH EXISTING DISASTER RESILIENCE FRAMEWORKS

It is not always feasible to undertake massive restoration projects; rather decision makers should be cognizant of the potential benefit streams provided by NCI and look for opportunities to integrate natural coastal infrastructure with ongoing and new recovery

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[73] Bundnis Entwicklung Hilft. 2017. World Risk Report, Analysis and Prospects 2017.

[74] Swiss RE, 2013. Mind The Risk: A Global Ranking Of Cities Under Threat From Natural Disasters.

[75] Su, S., Pi, J., Wan, C., Li, H., Xiao, R., & Li, B. (2015). Categorizing social vulnerability patterns in Chinese coastal cities. Ocean & Coastal Management, 116, 1-8.

[76] Coping capacity is inferred by the ability of the population to cope with external harms during emergency situations and is assessed using metrics including levels of poverty, percentages of elderly and children, and strength of communities. .

[77] Adaptive capacity reflects the potential of implementing adaptation measures, and is correlated with deliberate anthropogenic attempts to cope or adapt. It is assessed using metrics including available technology, knowledge and skills, education, infrastructure, and social capital.

[78] Philippine Statistics Authority reports GDP of Metro Manila at 36.6% of total GDP for the Philippines in 2016, World Bank Reports total GDP of the Philippines as US$304.9B in 2016.

[79] https://www.lloyds.com/cityriskindex/locations/fact_sheet/manila

efforts from severe storms. To take advantage of events that have already caused economic damages (recovery from storms), NCI should be considered part of the toolkit in existing Disaster Risk and Resilience Frameworks. In the APEC context, the APEC Disaster Risk Reduction Framework was developed by the Emergency Preparedness Working Group. Further details of the APEC DRRF are below.

Figure 9. APEC Disaster Risk Reduction Framework

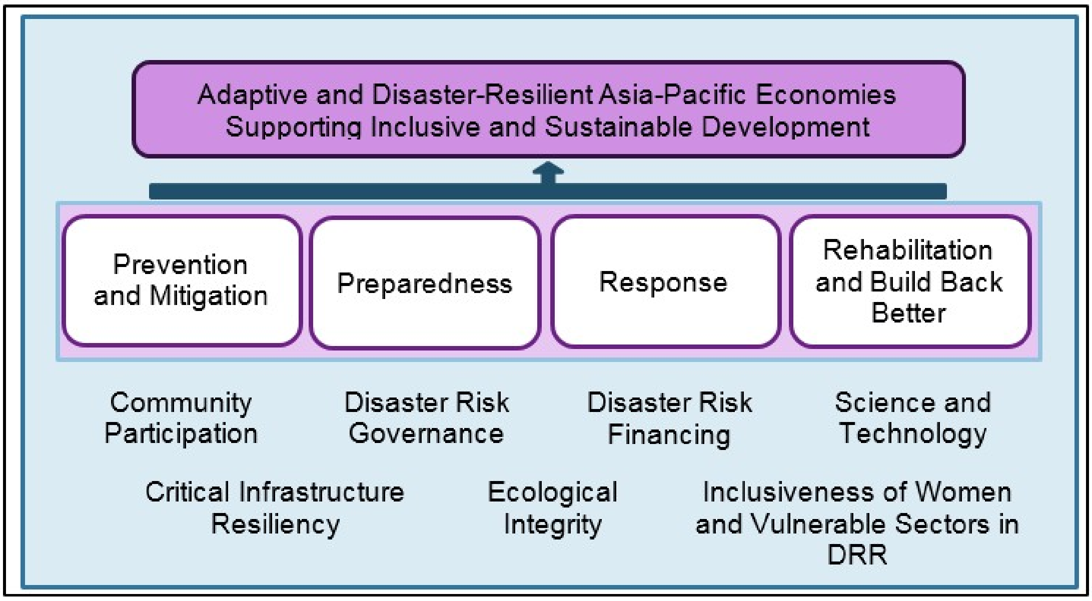

Figure 9 illustrates the current APEC Disaster Risk Reduction Framework developed and endorsed by the Emergency Preparedness Working Group. According to APEC, "The core of this Framework is the clear recognition that addressing the impacts of disasters requires holistic, more proactive, multi-stakeholder, multi-sectoral and strategic interventions to make APEC economies more resilient. Under this Framework, the APEC community can collectively identify and explore areas for enhanced cooperation.[80]" The principles that underpin the framework –which those of holistic, proactive, multi-stakeholder, multi-sectoral, and strategic interventions are the same principles that are used to develop an effective NCI implementation strategy. Decision-makers should look for key decision points, or "on ramps," for integrating NCI into this existing framework. NCI approaches could be integrated into the Prevention and Mitigation, Preparedness, and Rehabilitation and Build Back Better stages in the framework. An effective NCI strategy also works within the same enabling environment as the APEC Disaster Risk Reduction framework (anchored in Community Participation, Disaster Risk Governance, Disaster Risk Financing, Innovations on Science and Technology, Critical Infrastructure Resiliency, Ecological Integrity, and Inclusiveness of Women and Vulnerable Sectors), and the NCI Economic Valuation Framework, used in this report (Figure 5) and detailed in Annex II provides opportunities for several key linkages (i.e. Community Participation, Disaster Risk Governance, Disaster Risk Financing, Critical Infrastructure Resiliency, and Ecological Integrity).

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[80] Ibid.

It is increasingly well understood that natural ecosystems play a crucial role in determining the well-being of human populations,[81] however information about ecosystem services, and the protective benefits they can provide has yet to fundamentally change decision-making and suggest a path forward.[82] The successful integration of NCI approaches within the APEC Disaster Risk Reduction Framework will require collaborative efforts between public sector officials, business, and civil society to develop the information necessary, integrate the appropriate frameworks, and change policy and practice to better align private short-term goals with societal long term goals.

LIMITATIONS

The case studies presented in this report are intended to show the process of integrating NCI approaches and a framework into existing Disaster Risk Reduction Frameworks and the potential for NCI to contribute positively to risk and resilience efforts. They are not intended to support specific decision-making and only present illustrative, order-of magnitude-estimates for the potential benefits of NCI to the cities of Manila and Guangzhou. This is largely due to data limitations, time, and scope restraints. Further, the potential benefits illustrated in the two case studies do not include the additional benefits that can accrue with the restoration of natural systems. Those benefits can include recreation and ecotourism, improving water quality and sediment retention, directly marketable products such as wood and thatch, and habitat for commercial and recreational fisheries. When comparing the costs and benefits of natural infrastructure versus engineered solutions, it is important that all the benefits (ecosystem services) of using natural coastal infrastructure approaches be included in the assessment.

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81 Rao et al. 2015. Global values of coastal ecosystem services: A spatial economic analysis of shoreline protection values

[82] Guerry et al. 2015. Natural capital and ecosystem services informing decisions: from promise to practice.

ANNEX I: VISUALIZATION DATA SOURCES, METHODOLOGY, AND OUTPUTS

VISUALIZATION DATA SOURCES

The data required to undertake the NCI visualization and spatial calculations was attained from a wide variety of sources. This data represented a range of critical demographic and natural/physical variables with their respective geographic locations and extents. Most of the GIS data used in this activity was attained in polygon, ESRI shapefile format, but was originally created based on 'raster' data, which is the data format corresponding to satellite imagery. With that in mind, the degree of "spatial accuracy" of the data used is dependent on the resolution of the images used to produce this data. Other data were attained in raster format (i.e. the "seagrass" layer), which was converted into a shapefile format in order to match it with the format of the other layers that were analyzed.

In terms of spatial accuracy, the resolution of the data sources is low, due to the scale at which the visualization was undertaken (in all of the APEC Economies). At such continent-size scale, data representing the features that were analyzed in this visualization activity is only available at low resolutions (ranging from 30 meters to 1km resolutions). Due to the low resolution of the datasets utilized for this activity, it must be noted that a margin of error in the spatial accuracy of the area calculations that were made using GIS software, was relatively high (approximately 15% at the scale/geographic extent at which the calculations were made). Therefore, the results from this visualization activity are presented as estimates and users of this information should be aware of the relative uncertainties tied to the data. The table below lists the data included in the visualization and calculations along with their respective sources and spatial accuracy characteristics:

Table 7: Data Sources of Features Included in the Visualization Activity

GIS Data	Source / Year of Data	Spatial Resolution (indicator for spatial accuracy)
Mangroves Biomass Distribution	UNEP[i] / 2011	1km x 1km
Coral Reefs Distribution	WRI[ii] / 2011	1km x 1km
Salt Marshes[83]	UNEP[iii] / 2015	1km x 1km
Seagrass	UNEP[iv] / 2015	1km x 1km
World Land Features	Natural Earth[v] / 2017	1:10m Scale
Urbanized Areas	Land Scan[vi] / 2012	1km x 1km

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[83] While salt marshes are a type of coastal wetland, the organizations that prepared and make the above data available separate the two classes of NCI, and geographic overlap between the two datasets is marginal.

VISUALIZATION METHOLOGY

As shown in the visualization results section, the visualization outputs include maps showing the extent of five different types of NCI (coral reefs, mangroves, sea grasses, and salt marshes) located within 100km of a coast in APEC Economies, contiguous urban land cover adjacent to the coast, and urban land cover located within 12km of an NCI.

Additionally, as the result from running the InVEST model, an additional map displays the shoreline segments in APEC Economies that have the highest degree of coastal vulnerability. A list of cities that are adjacent to these highly vulnerable shoreline segments, is included. Since most of the layers' attributes did not include the area of the features, the area in km2 was calculated for each type of feature using ArcGIS. To minimize distortions in area calculations at a continental scale, all layers were projected into the Equal Area projection Eckert IV.

However, layers in the visualization maps are displayed using the WGS 84 PDC Mercator Coordinate Reference System (CRS) so that all APEC Economies can be shown at once. It is also important to note that for the purpose of making the NCI layers visible from a continental scale, each NCI layer was augmented using a 0.4 point outline for maps of all APEC Economies, and a 0.2 point outline for the zoomed-in regional maps using ArcGIS.[84] While such augmentation distorts the actual size NCI displayed, it allows the viewer to see how each type of NCI is distributed throughout the APEC Region in relation to other types of NCI. The NCI area calculation results displayed in the map legend reflect the real area without the visual augmentation. The urban area within 12km of an NCI was mapped with the purpose of visualizing densely populated areas that would benefit most from disaster risk reduction services of one or more NCI. This 12km threshold distance parameter was attained from the InVEST model, which recommends using such distance as the maximum distance to separate sheltered and exposed areas. In order to map these urban areas, a 12km buffer around all NCI was generated, and then intersected with its overlapping coastal urban areas using ArcGIS.

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[84] Referring to the outline point scale in the ArcGIS software layer symbol selector options.

ANNEX II: NCI VALUATION METHODOLOGY

As noted in the body of the report, the analysis in this report is conducting using as a guiding framework "A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction85" which was developed by NOAA. This presents a useful decision making and analytical framework to assess the costs and benefits of natural coastal infrastructure. The Guide covers the full spectrum of the natural coastal infrastructure decision framework, from identifying the area at risk and the problems it faces, to performing hydrological modeling, comparing costs and benefits of natural infrastructure solutions, and placing the results within the context of a comprehensive natural coastal infrastructure strategy — all while communicating and engaging with an appropriate group of stakeholders.

However, the study uses a modified version of the Guide because certain elements of the Guide, such as hydrological modeling, modeling the costs of implementing natural coastal infrastructure solutions, and stakeholder engagement are outside the scope of this paper. The analysis draws mainly on steps 1, 4, 5, and 6, while including some tasks from steps 2 and 3 (see Figure 5). Steps 1 and 2 (defining the flooding problem, and assess flooding scenarios without green infrastructure) are described in the previous sections, while the remaining steps are described below.

In addition, the study on "Managing Coasts with Natural Solutions[86]" provides a basic framework for assessing the valuation of natural infrastructure. It recommends similar steps, including offshore and nearshore hydrodynamic modeling, understanding the interactions between different types of coastal structures, and estimating flooding scenarios, however, it provides additional guidance on the most appropriate methods for valuing expected damages from coastal storms and averted damages, or benefits, from natural coastal infrastructure. By valuing the services provided by natural coastal infrastructure, we are assessing their value as a "productive input" to the economy. Barbier[87] notes that this is a "viable methodology" for policy analysis. This approach assumes that the NCI yields a benefit in terms of reducing the severity of economic damage from storms, and values the protective services of mangroves by estimating their ability to mitigate damage costs.

The two frameworks used in this analysis, are very similar in intent and process, however one focuses more on the critical process of community and stakeholder engagement, the other provides a more technical overview of techniques for modeling hydrodynamics and valuing coastal protection benefits.

The NOAA Guide titled "A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction" can be accessed via the following link:

https://coast.noaa.gov/data/docs/digitalcoast/gi-cost-benefit.pdf

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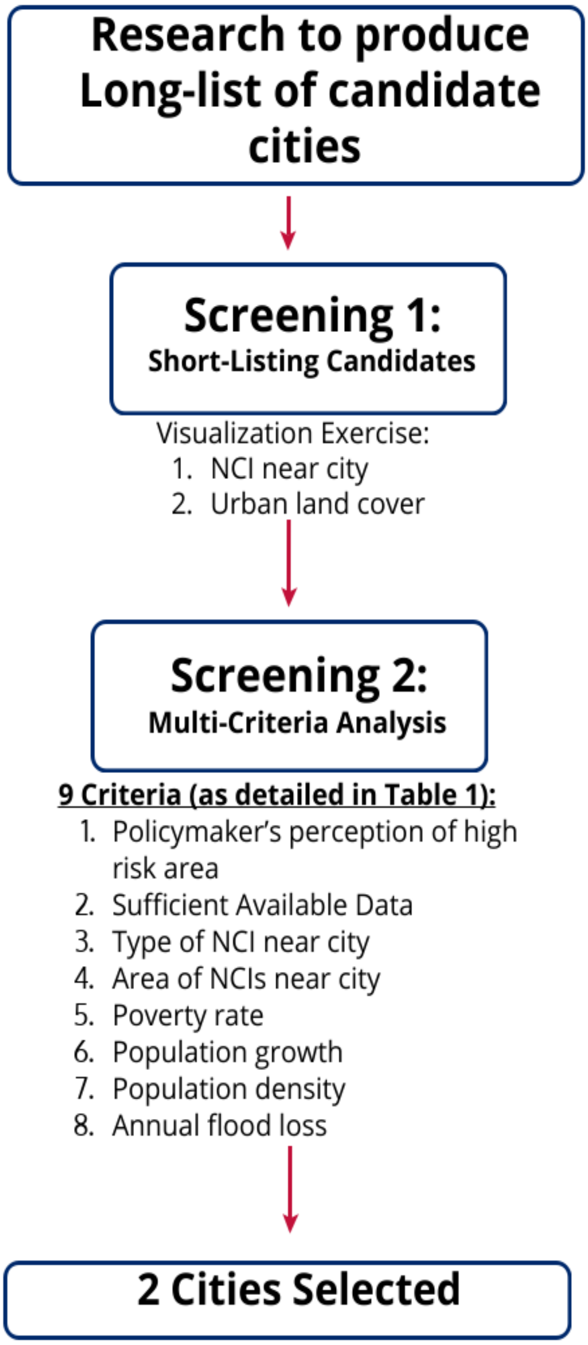
85 https://coast.noaa.gov/data/digitalcoast/pdf/gi-cost-benefit.pdf

86 World Bank. 2016. Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. M. W. Beck and G-M. Lange, editors. Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC.

87 Barbier 2007. Valuing Ecosystems as productive inputs.

ANNEX III: CITY SELECTION PROCESS[88]



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[88] *Source: Nathan Associates Inc.*

ANNEX IV: NCI VISUALIZATION DATA REFERENCES

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[i] C. Giri [1]*, E. Ochieng [2], L. L. Tieszen [3], Z. Zhu [4], A. Singh [5], T. Loveland [3], J. Masek [6] and N. Duke [7]
[1] ARSC Research and Technology Solutions, contractor to US Geological Survey (USGS) Earth Resources Observation and Science Center (EROS), Sioux Falls, SD 57198, USA,
[2] United Nations Environment Programme, United Nations Avenue, Gigiri, PO Box 30552, 00100, Nairobi, Kenya,
[3] US Geological Survey, Earth Resources Observation and Science Center (EROS), Sioux Falls, SD 57198, USA,
[4] US Geological Survey, Reston, VA 20192, USA,
[5] United Nations Environment Programme, Washington, DC 20006, USA,
[6] Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD 20771, USA,
[7] Centre for Marine Studies, Marine Botany Group, c/-Gehrmann Building (60), Level 8, The University of Queensland, Brisbane, QLD 4072, Australia

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[v] Natural Earth. 2017. URL: http://www.naturalearthdata.com/downloads/

[vi] Kelso, N.V. and Patterson, T. (2012). World Urban Areas, LandScan, 1:10 million (2012). Made with Natural Earth, online at http://www.naturalearthdata.com.