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Rethinking Our Global Coastal Investment Portfolio

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1. INTRODUCTION

Coastlines around the world are being reshaped as human populations concentrate in coastal areas (Kummu et al., 2016). Vast infrastructure networks including buildings used for commerce and dwellings; transportation systems such as roads, railways, bridges, and ports; and communication infrastructure are built and maintained to support these coastal populations. Coastal areas are also being managed and restored for conservation purposes, both for their own sake and to preserve the ecosystem services on which people depend such as fisheries, clean water, and coastal defense (Barbier et al., 2011). In addition, there is great interest in understanding how coastlines will be affected by climate change impacts including sea level rise and stronger storms, and in undertaking efforts to mitigate these threats (Woodruff, Irish, and Camargo, 2013; The White House, 2015; Cheong et al. 2013). For example, developed nations have committed to raising $100 billion (all amounts in USD) per year by 2020 to support climate change adaptation and mitigation efforts in developing countries (UNFCCC, 2011; UNFCCC, 2016).

Such investments will be critical in helping communities and nations adapt to climate change. However, while the most severe impacts of climate change are expected to take place over at least fifty to one hundred years, coastal developments are already dramatically reshaping our coasts. Far less attention is paid to understanding and predicting how coastlines will change in a more immediate timeframe of upcoming years and decades, and identifying ways to improve current investments to ensure the current and future wellbeing of coastal communities and ecosystems (Reguero et al., 2014; Kron, 2013; Brown et al., 2014). Gaining a more thorough understanding of financial investments in different coastal sectors, i.e., our “global coastal investment portfolio”, is an important first step toward identifying opportunities for improving both short- and long-term outcomes for people and nature. Like any investment plan, our coastal spending portfolio should be regularly reviewed and adapted as more knowledge becomes available and circumstances change.

To this end, we identify and discuss some of the major sources of funding for coastal green and gray infrastructure. Our purpose is two-fold: first, we aim to understand the relative scale of spending in these sectors. Second, we aim to consider if and how we might use these funds more strategically. We use data from a variety of sources to answer three key questions: 1) How much money is invested globally in coastal habitat conservation and restoration, i.e., green infrastructure? 2) How much money is invested globally to shape our coastlines for human use by building gray infrastructure? 3) What is the value of investments lost in coastal storms such as hurricanes and typhoons, and how much is spent on rebuilding damaged gray infrastructure? Based on our findings, we explore opportunities to shift the spending balance, i.e., to update our coastal investment portfolio, in ways that could save lives, protect property, and restore and conserve coastal habitats on which biodiversity and people depend.

2. METHODS

We analyzed funding for green and gray infrastructure over the 10-year period from 2004-2013. We also analyzed the costs of storms as these are a major source of re-investment and rebuilding, mainly of gray infrastructure, in the coastal zone. We chose a 10-year timespan to provide a broad perspective on spending in each category and overcome interannual variability due to differences in the severity of coastal storms in different years, global economic trends, and other factors. We chose the decade ending in 2013 because this was the most recent year for which international aid data were available in the AidData database, one of our primary data sources (Tierney et al., 2011). For all AidData funds, we used "committed" rather than disbursed amounts to be consistent with common practice in the foreign aid literature (Miller, 2014). We converted funding amounts from all data sources to constant 2011 U.S. dollars (www.usinflationcalculator.com) because this was the year and currency of the amounts in AidData.

2.1 Green Infrastructure Data: Coastal Conservation and Restoration

2.1.1 International Conservation Aid

We sought to identify international aid funds for coastal conservation and restoration using the AidData database (aiddata.org). To be consistent with the other funding categories, we aimed to identify funds spent directly on ecosystem recovery (stress reduction) and habitat rebuilding (restoration) and management; we did not focus on more general scientific research or natural resource management per se. We searched AidData projects in the sector General

Environmental Protection and downloaded all projects from 2004-2013 in which 1) the recipient countries have a coastline and 2) the project record in AidData contained one of the following keywords: coast(al), marine, ocean(s), estuary(ies/ine), atoll(s), shore(s), island(s), reef(s), coral(s), mangrove(s), seagrass(es).

The initial list of projects had a wide range of conservation-related goals, and we used the following guidelines to determine which projects to include in our estimates. To be consistent with the types of funds we considered for gray infrastructure, we focused when possible on funding that was clearly tied to actions on the ground (e.g., habitat restoration). We included funding for basic scientific research only if there was a clearly described link between the research and a specific conservation objective. Similarly, we only included projects related to fisheries management, natural resource management, coastal management, and climate adaptation if the project description clearly described habitat or ecosystem conservation objectives. For some projects related to threatened species management and conservation, it was not possible to separate spending on single species vs. habitat conservation. Consequently, we included these projects under the assumption that some or most of the funds were used to protect the habitats of threatened species. We included education and capacity building projects that directly linked to conservation goals, for example, training park guards to enforce laws within a protected area, but excluded more general environmental education projects aimed at the general public. Finally, we excluded projects whose primary goals were pollution mitigation (including oil spill cleanups) and invasive species detection and control.

We used the project descriptions in the database and the guidelines listed above to classify each project into one of three categories: conservation aid (the project's only objective was conservation or restoration); mixed aid (the project had conservation objectives as well as other objectives, such as economic development or education); or not relevant (there was no clear conservation objective in the project description).

2.1.2 U.S. Conservation and Restoration Funding

In addition to the large national and multi-national funding sources above, we analyzed two sources of green infrastructure spending in the United States: conservation- and restoration-related spending by the National Oceanic and

Atmospheric Administration (NOAA), and voter-approved ballot measures for conservation projects. NOAA is the world's largest marine management agency with direct responsibility for coastal habitat conservation and restoration. We use it as an estimator of the scale of funding from public agencies for these purposes, but acknowledge that there are other very large agencies in the world we do not account for here such as CSIRO in Australia (CSIRO, 2016) and the European Commission (European Commission, 2016).

We analyzed the annual budgets of two NOAA agencies: The National Ocean Service (NOS) and the National Marine Fisheries Service (NMFS). Both of these agencies are responsible for stewardship of the natural resources of U.S. oceans and coasts. We identified the budget lines within each agency that were most directly associated with conservation and restoration of coastal habitats (Table S1). As with international conservation aid, in some cases we were unable to distinguish spending on threatened species from that on habitat conservation, so some projects include more explicit species conservation goals in addition to ecosystem-related objectives. We summed the enacted budget values for each year from 2004-2013, and inflated or deflated the annual values to 2011.

We were not able to analyze state budgets for conservation and restoration similar to federal funding alone; however, conservation bonds provide a good proxy for the scale of funding for these purposes, particularly for investments in on-the-ground projects. The Nature Conservancy maintains records of U.S. conservation-related ballot measures in which citizens vote on the use of tax dollars for environmental purposes. We used these records to identify voter-approved conservation ballot measures at town, city, county, and state levels from 2004-2013. We included all town, city, and county ballot measures that were approved in coastal municipalities, with 'coastal' defined as all locations within 100 km of a coastline. We included all statewide measures for Rhode Island and New Jersey because all points in these states lie within the coastal zone. We excluded statewide measures in Maine, Oregon, and Pennsylvania because we were unable to determine the portions of these measures that were directed to coastal versus inland locations (less than or more than 100km from the coast, respectively). For one large statewide measure in California (2006), we were able to track a small portion of the funding specifically to coastal conservation. For this measure, we included only this portion of the total amount in our analysis. Similarly, a measure passed in San Diego County, California (2004) directed

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funding to both environment- and non-environment-related projects, and we included only the amount that had clearly been designated for environmental conservation.

2.2 Data: International Gray Infrastructure Aid

2.2.1 Building Infrastructure

We sought to identify international aid funds for building coastal gray infrastructure using the AidData database. We included four aid sectors in AidData that relate directly to infrastructure: Water Supply and Sanitation; Transport and Storage; Energy Generation and Supply; and Industry, Mining, and Construction.

AidData only includes geographic locations for a small portion of the projects in the database, which made it impossible to identify all coastal infrastructure projects. Given this limitation, we used a combination of strategies to account for as many coastal projects as possible. Complete georeferenced project data are available for seven coastal countries (Bangladesh, Colombia, Honduras, Nigeria, Senegal, Somalia, and Timor-Leste), as well as for all World Bank-funded projects globally and for all aid given from China to any African country. For these datasets, we used Geographic Information Systems to identify projects located within 100 km of a coastline. The precision of location information in AidData varies, with some projects only referenced to the country level. We only included projects with sufficiently fine-scale resolution to ensure they fit our definition of "coastal" (AidData precision codes 1-4; see Strandow et al., 2011).

We also included in our analysis all aid funds committed to infrastructure projects in nations that are: 1) part of the United Nation's group of Small Island Developing States (UN Department of Economic and Social Affairs 2016), or 2) small coastal or island countries or territories in which all points lie within 100 km of the coastline. The combined list includes 71 nations and territories (Table S2).

Finally, we identified 127 coastal gray infrastructure projects in AidData that were not accounted for in any of the categories described above and for which location information was available. There were an additional 70,210 infrastructure projects during the relevant timeframe for which no location information was available, many of which were likely coastal, but we had no way of determining how many projects or how much infrastructure aid we were unable to account for. Thus, our analysis undoubtedly underestimates the total amount of international aid for building coastal infrastructure. However, until more projects in AidData are georeferenced, we are unaware of any other methods for tracking this funding.

2.2.2 Public Storm Relief and Reconstruction

We also sought to estimate (re)investments in coastal gray infrastructure by identifying international aid funding for emergency aid and reconstruction after coastal storms. This rebuilding represents a major (re)investment in coastal infrastructure. We searched the AidData database for projects in four sectors: Humanitarian Aid, Emergency Response, Reconstruction Relief, and Disaster Prevention and Preparedness. While the humanitarian aid and emergency response categories do not strictly reflect infrastructure investments, we included them because they represent damage and financial expenditures incurred as a result of coastal storms; these are comparable to the total loss category of private funding (described below). We downloaded all projects in these categories from 2004-2013 in which: 1) the recipient countries have a coastline (Tables S2 and S3) and 2) the project record in AidData contained one of the following keywords: hurricane(s), cyclone(s), typhoon(s), flood(s), or coast(al).

We also searched for projects in which the aid recipient was a regional or global institution (e.g. the United Nations and the World Bank; Table S3). We coded each of the resulting international aid projects for inclusion or exclusion from our estimates by reading the project descriptions and determining whether the aid was directly intended for emergency response and reconstruction due to damage from coastal storms. In cases where the cause of damage was unclear, for example, flooding in coastal countries where a specific coastal storm was not listed in the project description, we searched online news sources and documents from aid agencies to gather additional information about the cause of damage. In this way we determined whether aid projects were related to coastal storms such as hurricanes, or to unrelated events that were not explicitly coastal, such as annual monsoons or inland flooding due to other weather patterns. We excluded projects for which we were unable to determine whether funds were used for recovery after a relevant coastal storm.

2.3 Data: Private and Public Rebuilding after Storms

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One of the most significant sources of coastal investments is post-storm payouts, both public and private. We sought to estimate insured and total financial losses from coastal storms including typhoons, hurricanes, tropical storms, and winter storms. Insured losses are assumed to represent funds invested back in coastal areas, mostly to rebuild insured properties, while total losses are assumed to often represent funding by governments (e.g., the U.S. Federal Emergency Management Agency (FEMA) and the Department of Housing and Urban Development (HUD)) for rebuilding. The reinsurance company MunichRe publishes annual summaries of the world's most damaging and expensive natural disasters, and we used these reports to estimate insured and total financial losses from storms from 2004-2013. For the years 2008-2014, the annual MunichRe reports list the top 50 most expensive disasters of the year, and we identified all coastal storms in these lists. Prior to 2008, the reports did not summarize the year's events in a single table so we searched the text of each report to identify all relevant coastal storms.

3. RESULTS

3.1 Green Infrastructure: Coastal Conservation & Restoration

International aid for conservation and restoration was the smallest spending category in our study. We identified \$0.8 billion in international aid funds committed solely for coastal and marine conservation purposes during the decade we analyzed. We identified an additional \$1.2 billion committed for mixed conservation and development purposes. Summing these estimates, we conclude that total international aid for coastal conservation from 2004-2013 was between \$0.8-2 billion (Figure 1).

The top three donors for the \$0.8 billion in pure conservation aid we identified were the Global Environment Facility (GEF; 47% of funds), the World Bank (24%), and Germany (12%) (Figure 2). The top five donors for conservation projects (GEF, World Bank, Germany, Asian Development Bank, and the United States) provided 92% of international aid funds for conservation.

Within the United States, we identified \$7 billion in NOAA funds designated for conservation-related purposes, and \$5 billion in conservation bonds and voter-approved ballot measures. Together, these investments total roughly \$12 billion spent on coastal and marine conservation in the U.S. from 2004-2013 (Figure 1).

3.2 International Gray Infrastructure Aid

3.2.1 Building Infrastructure

We identified $198 billion in international aid funds designated for building and maintaining coastal gray infrastructure (Figure 1). As described in the Methods, our ability to estimate the total global aid designated for such purposes was limited by a lack of georeferenced project data in AidData. Thus, our analysis underestimates the total amounts.

The top three donors for coastal gray infrastructure aid were the World Bank (68% of funds), China (12%), and Japan (5%) (Figure 3). Our analysis may overestimate China's relative importance as a donor of infrastructure aid globally because the China-to-Africa dataset was one of the few complete geocoded datasets available.

3.2.2 Public Storm Relief and Reconstruction

We identified $3.5 billion in international aid funds for immediate humanitarian relief due to damages and losses as well as longer-term reconstruction after coastal storms (Figure 1).

3.3 Private and Public Rebuilding After Storms

Our analysis of MunichRe's annual reports indicates that total losses from coastal disasters from 2004-2013 exceeded $514 billion; of this amount, $214 billion were insured losses (Figure 1).

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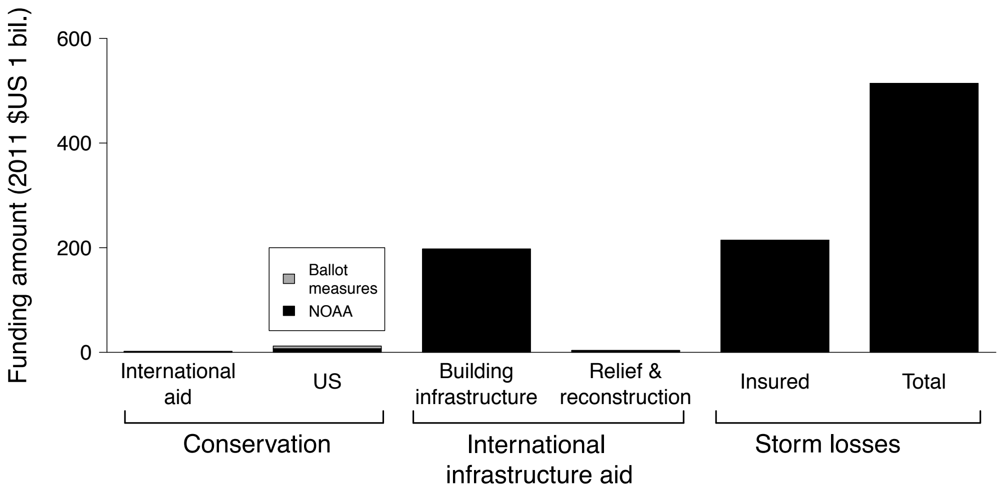

Figure 1. Estimated global investment in coastal green infrastructure (conservation), and gray infrastructure in aid and post-storm rebuilding from 2004-2013 (2011).

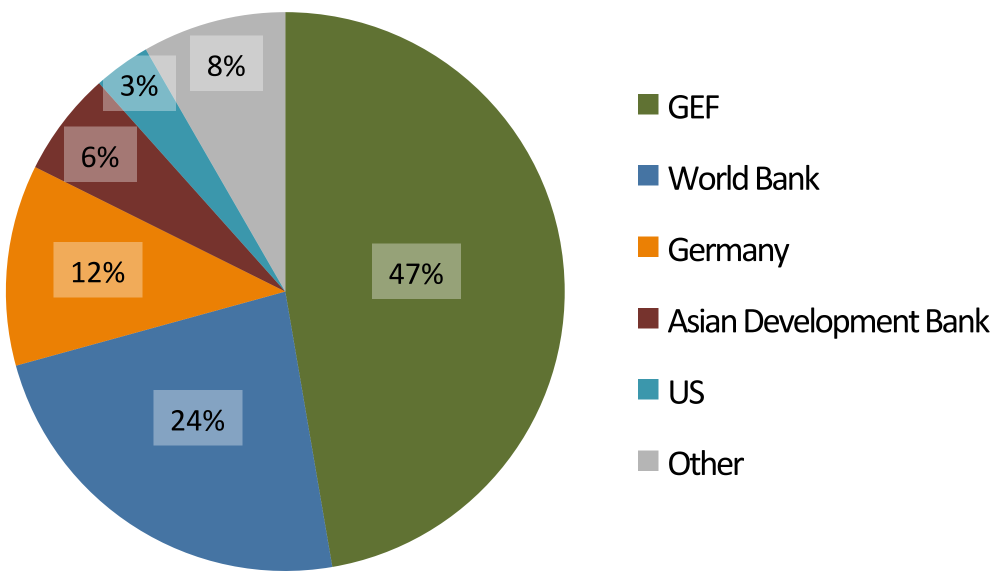

Figure 2. Top donors of international aid for coastal conservation, 2004-2013.

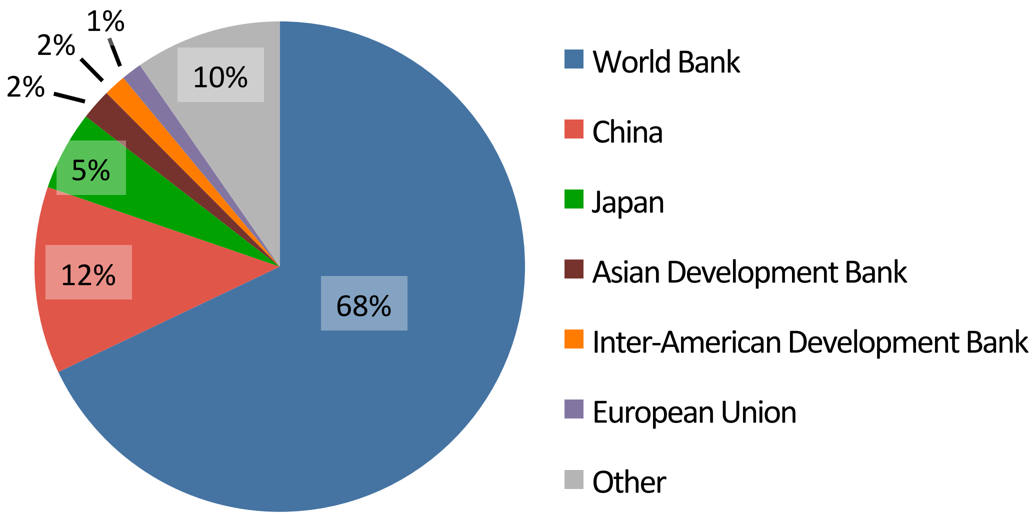

Figure 3. Top donors of international aid for coastal gray infrastructure, 2004-2013.

3.4 Combined Totals

The total global investment in gray infrastructure during the decade we analyzed, including the totals from infrastructure aid, storm relief and reconstruction aid, and insured losses, was $416 billion. The total investment in green infrastructure, including international aid and U.S. conservation funding, was $14 billion; this is 3.4% of the total amount spent on gray infrastructure ($416B), and 2.7% of the total estimated financial losses from coastal storms ($514B).

4. DISCUSSION

Our results show that funding for green infrastructure (conservation and restoration) makes up roughly 3% of global financial investments along coastlines. In other words, our global coastal investment portfolio is heavily weighted toward gray infrastructure. The biodiversity conservation community spends tremendous time and effort deciding where and how to invest this relatively small amount of conservation funding to maximize benefits to biodiversity (e.g. Klein et al. 2010, Giakoumi et al., 2015). Our study suggests that these conservation funds may have relatively minor impacts, given the extent to which they are dwarfed by infrastructure funding.

Understanding current spending breakdowns is an important first step toward identifying opportunities to re-balance our investments and improve long-term outcomes for nature and people. For example, if 10% of international aid funds spent on building and rebuilding coastal gray infrastructure were instead used to conserve and restore coastal ecosystems (i.e., green infrastructure), total international aid for conservation would increase by at least ten-fold. Similarly, if 10% of the total global infrastructure investments we identified were redirected to conservation and restoration projects, global investments in coastal environmental protection would nearly triple; indeed, the increase in conservation funds would likely be much greater, as there are large portions of infrastructure spending we were unable to account for here. The funds freed up for conservation could then be invested strategically, for example to restore coral reefs and oyster reefs near high-density areas with a high risk of flooding.

If implemented carefully, such investments would provide long-term benefits not just for coastal ecosystems but also for human communities and infrastructure that would benefit from improved coastal defense and other services (Ruckelshaus et al. 2016; Narayan, Beck, Wilson, et al., 2016; Barbier et al., 2011). In many cases, investing in the conservation or restoration of coastal ecosystems represents a highly effective approach to helping communities adapt to the impacts of climate change (Ferrario et al. 2014; Gedan et al. 2011, World Bank, 2016). The overall benefit and the cost-effectiveness of coastal ecosystems or "green infrastructure" is highly dependent on site-specific parameters (Reguero et al. 2014); gray infrastructure such as seawalls and dykes will thus remain an important component of coastal defense, both alone and in combination with green infrastructure in "hybrid" approaches (Spalding et al. 2014). Hybrid solutions present opportunities to capitalize on the benefits of both green and gray approaches while counteracting their respective limitations (Bouma et al., 2014; National Science and Technology Council, 2015). For example, mangrove restoration projects in Vietnam have been integrated with sea dykes over more than 100 km of the coastline, to provide more effective coastal protection (World Bank, 2016). These projects have generated measureable benefits, as the damage from recent storms to dykes and other infrastructure was less than the damage from storms before the restoration projects took place (World Bank, 2016).

Interest in such projects is growing: multiple public and private institutions including the European Commission, the World Bank, USAID, the U.S. Army Corps of Engineers and the Department of Housing and Urban Development (HUD), and the Caribbean Catastrophe Risk Insurance Facility (CCRIF) have recognized the importance of investing in green and hybrid approaches to increase the resilience of coastal communities (European Commission, 2013; National Science and Technology Council, 2015; USAID, 2015; Wittenberg, 2017; CCRIF, 2010).

There are many sources of funding for both green and gray infrastructure that we were unable to account for here. Coastal conservation around the world is funded by government agencies and partnerships such as CSIRO and the European Commission, as well as by private organizations and donors. However, even if we could include these additional funds, it is likely that we would underestimate gray infrastructure spending to a greater extent than we do conservation spending. Several lines of evidence support this assumption. First, our estimates of international aid for gray infrastructure are likely far lower than the true amounts since we were unable to identify many coastal projects in AidData. Second, even the insurance data on total losses do not include all public funds spent on rebuilding infrastructure after coastal storms, for example, the $120 billion paid by the U.S. Government for recovery after Hurricane Katrina (Plyer 2016). Finally, we did not include any financial losses or aid related to tsunamis; this was because, in many cases, we were unable to distinguish damage from coastal earthquakes from that caused by the associated tsunamis.

Consequently, we did not account for large amounts of tsunami damage (e.g. the 2004 Indian Ocean tsunami [Telford, Cosgrave, and Houghton, 2006] and the earthquakes and tsunamis in Chile [2010] and in Japan [2011]). Our data sources indicate these would add an additional $4.2 billion in coastal relief and reconstruction aid, $48 billion in insured losses, and $193 billion in uninsured losses to our estimates. We also did not account for additional rebuilding funds, such as the construction of hundreds of miles of seawalls in Japan after 2011, which represents an estimated $10 billion in coastal infrastructure spending in that country alone (The Economist, 2014). Thus, we believe our central point, that global coastal gray infrastructure funding vastly outweighs conservation and gray infrastructure funding, would hold true, probably even more dramatically, if we could include all relevant funding sources.

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Unfortunately, we have no better mechanisms in place for recording and tracking spending on green and gray infrastructure, even just for coastal defense and climate adaptation. A few institutions have recently initiated such efforts. For example, the Pilot Program for Climate Resilience (PPCR), a joint initiative of several multilateral development banks (Climate Investment Funds, 2016a), separates and tracks investments in ecosystem-based (green) defenses, gray infrastructure, and other resilience strategies (e.g. Caribbean Community Climate Change Centre, 2012; Climate Investment Funds, 2016b). Similarly, in the U.S., rebuilding efforts after Hurricane Sandy struck the Northeast in 2012 include separate tracking of investments in green and gray infrastructure (Hurricane Sandy Rebuilding Task Force, 2014). As natural infrastructure solutions become more mainstream in national, regional, and global efforts to build coastal resilience, mechanisms for tracking spending in green, hybrid, and gray infrastructure should be incorporated into management and implementation plans. This must be a priority for all entities working on funding and implementing resilience strategies including governments, multilateral institutions, non-profit organizations, and the insurance sector.

Improving the balance in our global coastal spending portfolio—both under current circumstances and as additional funds are committed for climate change mitigation and adaptation (UNFCCC, 2011; UNFCCC, 2016)—will require long-term commitments and collaborations between a wide range of actors both within and between nations. The U.S. government has recognized the importance of such collaborations. For example, in 2014 the Executive Branch hosted a meeting of several government agencies (the Treasury Department, NOAA, and HUD), as well as leaders in the insurance and reinsurance industries, to discuss ways to reduce disaster risk and reduce current and future costs (The White House, 2016). At the international level, aid funds are committed and disbursed by numerous bilateral and multilateral donors and implemented by myriad in-country institutions and organizations. Such transactions require complex long-term negotiations and agreements. USAID and the Climate Investment Fund program have both committed to incorporating green infrastructure into aid and development programs in coastal nations (Climate Investment Funds, 2016b; USAID, 2015). In addition, our results suggest that the World Bank and the GEF, in particular, have important roles to play as the leading donors of aid for green and gray infrastructure.

A variety of financial mechanisms are being developed or adapted for investing more strategically in coastal green infrastructure and resilience. Public incentives for these efforts include traditional municipal bonds as well as post-disaster spending such as that provided by FEMA in the U.S., which can encourage the use of funds for green and hybrid infrastructure. A variety of incentives are built into existing risk reduction tools such as traditional insurance, reinsurance, and catastrophe bonds and these could be used to invest more significantly in green infrastructure. Resilience bonds represent a new approach for incentivizing risk reduction measures through decreases in bond payments (Vajjhala and Rhodes, 2015).

Moving forward, it will be important to include natural infrastructure in national accounts, policy decisions, and industry risk models. The end result of devoting such funding sources to conserving and restoring ecosystems such as marshes, reefs, and mangroves would likely be dramatic reductions in future losses of human life and property due to rising seas and coastal storms (Ferrario et al., 2014; Narayan, Beck, Reguero, et al., 2016; World Bank, 2016). Such investments would also save money in the long run by averting future rebuilding costs (Narayan, Beck, Wilson, et al., 2016). Quantifying the benefits and costs of green infrastructure investments is difficult and has rarely been undertaken (The White House, 2015; but see Reguero, Bresch, Beck, et al., 2014), although a case study of mangrove restoration revealed benefit:cost ratios ranging from 3:1 to 68:1, without considering additional ecological benefits (World Bank, 2016). Indeed, the insurance industry already finds that investments in coastal habitats can be particularly cost effective for climate adaptation and risk reduction (CCRIF, 2010; The White House, 2016).

More work remains to be done before we fully understand our global coastal investment portfolio and how it can be improved. Much of this work will depend on improving efforts to track spending on coastal green, gray, and hybrid infrastructure, as well as strengthening collaborations between the conservation, international aid, and insurance sectors. All of these sectors stand to benefit by identifying situations in which coastal environmental protection and human well-being are closely linked. Establishing these cross-sector partnerships now will help ensure that future coastal investments benefit biodiversity, prevent billions of dollars of damage, and protect the lives and livelihoods of coastal residents.

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