Chapter 11
Coastlines Caught in the Middle: How Development Policy and Sea Level Rise Are Eroding Coastal Ecosystems in the United States

Chad J. McGuire

Abstract Coastal ecosystems provide a tremendous amount of value to human well-being. Not only do they yield a wealth of services that benefit humans, such as acting as hatcheries and nurseries for commercially valuable fish species, but they also provide more indirect benefits like protecting nearshore development from coastal storm surges. Climate induced sea level rise presents a unique challenge to coastal ecosystems as the natural attributes between the sea and land are impacted through rising waters. Under ideal conditions, coastal attributes would be able to migrate landward as sea levels rise. But in many areas of the United States, coastal ecosystem migration is prevented by both existing and planned coastal development. In essence, there is no place for the coastline to migrate. In the United States of America, current national and state policies that favor both the creation and protection of coastal development at the expense of protecting coastal ecosystems is playing a significant role in exacerbating this problem. The purpose of this paper is to overview the importance and value of coastal ecosystems, show the impact of sea level rise on coastal ecosystems, and examine the role of current coastal development policy in the United States in exacerbating coastal ecosystem decline in an era of climate change. The goal is to show how existing policies, some aligned to mitigate the impacts of climate change, can have the effect of disturbing—and even eradicating—important coastal ecosystems.

Introduction

Human health and wellbeing are intricately linked to ecosystem health and functioning. As Li (2017) notes, intact ecosystems provide the foundation for the services that provide humans worldwide with basic necessities for survival: food, clean air, clean water, productive soils. And this is certainly true of coastal ecosystems worldwide. The literature over the past fifty years shows that coastal ecosystems provide

C. J. McGuire (✉)
Department of Public Policy, University of Massachusetts, Dartmouth, MA, USA
e-mail: cmcguire@umassd.edu

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important services to humans. When coastal ecosystems are harmed, the literature also shows the harm accrues to both human and planetary health.

In 1997, two seminal works came out that attempted to identify and quantify all of the values of nature. An edited book by Gretchen Daily attempted to introduce the concept of ecosystem services and natural capital (Daily 1997). And in conjunction with this work, Robert Costanza and colleagues published an article in *Nature* on the value of the world's ecosystem services and natural capital (Costanza et al. 1997). Covering 17 ecosystem services for 16 biomes, the analysis suggested the natural assets of the Earth provided humans somewhere between 2 and 3 times the global gross national product in direct and indirect services. The book and article expanded on earlier research that attempted to combine the disciplines of ecology and economics (see Ehrlich and Ehrlich 1981; Ehrlich and Mooney 1983; Westman 1977). This collective work was an earnest attempt to understand the value of what nature offers humans; not only what we take from nature, for example commercial fishing, but also important regulating services such as clean air, clean water, and natural storm protection.

From 1997 to the present, there have been continuing efforts to better understand the scope of nature's capital, quantify it, and then link it to human behaviors and decision-making processes. In the early 2000's the Millennium Ecosystem Assessment attempted to identify and quantify the earth's ecosystem services, and then place them into a conceptual and decision-making framework for policymakers (MEA 2005). This effort coincided with the work of the Intergovernmental Panel on Climate Change to understand the causes and impacts of a changing climate, including impacts on the Earth's natural capital (IPCC 2014). Applications of this work have included, among others, attempts to place a price on the cost of carbon emissions relative to their impacts on natural capital (Nordhaus 2017). And recently, Costanza et al. (2017) have provided a 20-year update on the state of ecosystem services since their original published work, including a summary of research that has been undertaken on this topic since 1997.

An important part of this effort to quantify the value of nature includes work that has been done on the value of coastal ecosystems. While the ecology and defining characteristics of coastal ecosystem components (coral reefs, seagrass meadows, salt marshes, mangroves, sand beaches and dunes) is well understood, less understood are how these habitats, individually and collectively, lead to human benefits as defined in an economic sense. The traditional economic definition of benefits for environmental goods and services is the sum of what all members of society would be willing to pay for those goods and services (Mendelsohn and Olmstead 2009, p. 326). There is some disagreement on how to calculate these services (for example, see Boyd and Banzhaf 2007; Polasky and Segerson 2009). Even with disagreement on calculation methods, there is general consensus that the underlying functions of these coastal ecosystems provide a wide array of values to human wellbeing (Braat and De Groot 2012; Gomez-Baggethun et al. 2010).

Estimates of the value of coastal ecosystems vary. Costanza et al. (1997) provided an early estimate of marine contributions to human welfare at equal to global GNP in the late 1990s, with 60% of that total estimated to come from coastal and shelf systems, with the remaining 40% attributed to open ocean resources. This estimate was updated significantly in the past ten years. de Groot et al. (2012) and Costanza et al. (2014) calculated coastal ecosystems account for a multiple of global GNP: somewhere between 2 and 3 times. The change between 1997, 1999, and 2014 can be attributed, in large part based on climate change impacts and projects, to revising the value of these coastal resources for storm surge protection, biodiversity, and early life nurseries for commercially important marine species.

By all measures, coastal ecosystems are seen as important to humans not only for direct human use, but also in how they support human wellbeing. And while climate change is heightening the value of coastal ecosystems in terms of what they provide to humans, it is also threatening their continued existence. Climate change is causing seas to rise, while also increasing the frequency and intensity of coastal storms worldwide (IPCC 2014). It is increasing acidity of surface water temperature and acidity, placing critical habitats like mangroves, seagrasses, and coral reefs at-risk (He and Silliman 2019; Hewitt et al. 2016) All of this, and more, demands a public policy response. But are our public institutions responding? If they are, what does that response look like? And if not, what factors are influencing a lack of response?

The United States of America (US) is doing a poor job overall of protecting its coastal ecosystems, mainly due to preexisting policy initiatives that prioritize and incentivize coastal development. A history of coastal development, policy incentives for continued coastal development and redevelopment after disaster, and a path-dependence that favors protecting built resources at the expense of coastal ecosystems collectively creates a policy environment that neither properly accounts for nor protects coastal ecosystems. Solutions to this current policy conundrum include removal of subsidies that obfuscate the risk of coastal living to provide a proper context for development and hard armoring choices and, as a consequence, reprioritizing proactive retreat and non-development options as ways of balancing coastal asset resource protection against incentivizing and protecting coastal development.

This paper provides a case study of how existing US policies influence coastal ecosystem protection in an era of climate change. It begins by defining and interpreting the value of coastal ecosystems. It then provides an overview of the influence of sea level rise and climate change on coastal ecosystem integrity. A discussion and interpretation of current US policies that frustrate coastal ecosystem protection follows. The examination, while limited to US policies, helps provide a framework for examining coastal nation policies as a way of determining their ability to proactively protect coastal ecosystems in an era of climate change.

The Importance and Value of Coastal Ecosystems

Coastal ecosystems provide an abundance of benefits to humans (Barbier et al. 2011). The benefits provided vary, in economic terminology, based on how humans derive the value out of what coastal ecosystems provide. Generally speaking, there are direct benefits (the goods provided by coastal ecosystems directly sought by humans), indirect benefits (the services ecosystems provide that lead to human benefits), and non-use benefits (the spiritual, religious, and heritage values of coastal ecosystems). All of these kinds of benefits are generally classified as ecosystem services (Barbier 2007).

Coastal ecosystems can generally be categorized into five distinct regions. Beginning at the nearshore and moving towards the ocean, the five regions are as follows: sandy beach and dunes, mangroves, salt marshes, seagrass meadows, and finally coral reefs (Alongi 2020). Each of these regions have distinct and defining characteristics, but also share characteristics and functions with other regions. A summary of the kinds of ecosystem services (benefits to humans) provided by each coastal ecosystem is provided in Table 11.1.

From a policy standpoint, it is generally the raw material, tourism, and, to some extent, wildlife services that are most regularly associated with coastal ecosystems. When one thinks of coastal regions, the use of these areas for tourism and recreation pursuits generally comes to mind. Beaches and nearshore waters are popular destinations for many coastal areas of the United States of America (US), bringing in important revenue for local and coastal state economies. In addition, commercial and recreational fishing and other extractive practices of coastal resources provide direct economic benefits.

What is often less well understood are the more indirect and non-use benefits provided by coastal ecosystems. In particular, the role of these regions in purifying and retaining fresh water as part of water resource management in coastal areas is not well understood (Carter 1990; MEA 2005). Nutrient cycling and biodiversity protection are other services that help to ensure productive and healthy oceans. These services are also marginally understood. And the critical roles of carbon sequestration, erosion control, and coastal protection that most of these coastal ecosystems provide are becoming ever more valuable in an era of climate change. This is particularly so in low-lying coastal areas of the US where large financial investments in development have occurred. These investments are increasingly under threat due to effects and impacts of climate change (USGCRP 2018). As these threats increase,

Table 11.1 Ecosystem services provided by different coastal ecosystem regions (Barbier et al. 2011)

Service provided	Sandy beach and dunes	Mangroves	Salt marshes	Seagrass meadows	Coral reefs
Raw material	X	X	X	X	X
Coastal protection	X	X	X	X	
Erosion control	X	X	X	X	
Fresh water protection	X	X	X	X	
Nutrient cycling					X
Wildlife	X	X	X	X	X
Carbon sequester	X	X	X	X	
Tourism, etc.	X	X	X	X	X

the US is spending more to remediate their impacts through redevelopment efforts and measures to replicate these mitigation functions.

There are ongoing efforts to quantify the value of coastal ecosystems as a whole and within specific regions. The goods, as compared to the services, provided by coastal ecosystems are generally easier to quantify. Many of the goods derived from our coastlines, say commercial fisheries for instance, are already imbued into our economic system. This is also true for tourism and recreation dollars spent on traveling to and using coastal ecosystems. However, this measure is a bit more difficult because many of the coastal resources act as support systems for the more direct activities. If one wishes to sunbathe on a beach, then sand dunes are incredibly important in maintaining the sandy beach characteristics in many coastal areas. Equally important for maintaining sandy beach characteristics are the coastal storm protection characteristics of mangroves, salt marshes, seagrass meadows, and coral reefs. But these kinds of services are indirect. Mangroves, saltmarshes, and the like are not directly sought by sunbathers who wish to bathe on a sandy beach. However, they are critical to ensuring the sandy beach's continued existence. In this way, these services are much like human infrastructure projects. No one really wants a highway or a sewer system for its own sake. They are necessary to provide what humans really want: efficient and fast transportation and removal of waste products.

Calculations based on assumptions suggest the panoply of services provided by coastal ecosystems is a multiple of total global economic output (Costanza et al. 2014; de Groot et al. 2012). These calculations are reasonable when seen as logical extensions of known market values and methods for determining indirect service provisions. It is difficult to have consistent and reliable estimations because so much of what coastal ecosystems provide are dynamically linked to supporting other human activities and benefits. Without fully understanding the dynamics of an ecosystem, including all of the inputs and interactions that can affect the ecosystem stability, it is hard to accurately connect how the ecosystem operates with the values that flow to humans from that operation (Polasky and Segerson 2009).

One example might be a watershed that naturally purifies drinking water for a local municipality. A relative value for that watershed may be calculated by substituting the cost of building and operating a water purification system providing the same purity and quantity of drinking water as the watershed. But understanding the biological, chemical, and physical nuances of the watershed that ensure it can act as a reliable water filter is more dynamic and difficult to assess. However, these ecological components that help the watershed to function for this purpose are critical to quantifying its value. And even if this can be accurately calculated, the value derived only speaks to the watershed as a filter for water. It does not speak to other services it may provide, known and unknown, that benefit humans.

Aside from the nuances and difficulties in understanding total valuations, coastal ecosystems are valuable to humans. And that value is such that it likely exceeds the current economic activity being accounted for in our global coastal regions. But coastal ecosystems are under threat from climate change and, in particular, the impacts of climate-induced sea level rise.

The Impact of Sea Level Rise on Coastal Ecosystems

Direct human activities have been negatively impacting coastal ecosystems for well over the past century. As Barbier et al. notes (2011), 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of seagrasses are either lost or degraded worldwide (citing FAO 2007; MEA 2005; Orth et al. 2006; UNEP 2006; Valiela et al. 2001; Waycott et al. 2009) The United States of America (US) is no exception in this regard. Historical actions like reclamation projects, coastal agricultural operations, and flood control have aided in removing between 30 and 50% of the historical coastal wetlands in the US (Zedler 2004).

Sea level rise is responsible for the majority of coastal wetland degradation today. For example, between 2004 and 2009, it has been estimated that US coastal wetland environments—mainly saltmarsh ecosystems—have been lost at an average rate of approximately 80,160 acres per year. This loss is due almost entirely to observed sea level rise, with over 70% of that loss occurring in the Gulf of Mexico. And based on future predictions, it is probable that the US will lose an additional 16% of its remaining coastal wetlands by 2100 (USGCRP 2018).

Climate change impacts coastal ecosystems in multiple ways. Sea level rise can occur at a rate that is too fast for mangrove, saltmarsh, and beach/dune ecosystems to migrate landward (Sandi et al. 2018). Alternatively, humans can respond to observed sea level rise by constructing hard barriers to protect built assets along the coastline. In these instances, even if the rate of sea level rise is slow enough to allow coastal ecosystem attributes to migrate, the building of seawalls and other hard structures prevent migration (McGuire 2017). Seagrasses and corals, although submerged, are subjected to increased ocean acidity and higher temperatures that impact their ability to function (Wilkinson and Salvat 2012). Combined, climate change creates a set of cascading effects that place coastal ecosystems at-risk and, as a consequence, diminish the services they provide in support of human wellbeing.

Sea level rise will have differential impacts on the five categorical coastal ecosystem regions described earlier. Coastal sand/dune ecosystems, as the interface between land and sea in many coastal regions, provide the conditions for ocean-related recreational activities. Whether using the beach directly, or as a staging ground for water-based recreation, the sand/dune ecosystem is the "infrastructure" through which those activities occur. Thus, the relative value of its existence as a medium for ocean-related recreation can be determined. For example, the vast majority of the US population and international travelers visits a beach during a planned vacation representing US$285 billion in direct spending in 2017 (Houston 2018).

The coastal sand/dune ecosystem has a multitude of benefits beyond recreation that it provides to human wellbeing. For millennium, it has been a source of raw materials for humans. Sand is regularly harvested for its silica and feldspar components. It is used as fill and as a basic ingredient in cement and other construction materials. And more recently, sand from beach areas with large dune systems (which provide natural renourishment) has been transported to other coastal areas suffering from erosion as a form of nourishment to reinforce the recreational values of other coastal areas.

There are numerous values humans get out of coastal resources (see Table 11.1), but one of the more important values for sand/dune regions is acting as a buffering nearshore and inland development from coastal storm activity. For many areas around the world, and certainly for US coastlines, climate change and sea level rise are increasing the intensity and frequency of coastal storms (IPCC 2014; USGCRP 2018). Beaches associated with sand dunes generally provide substantial protection because they attenuate the storm surge and wave activity due to their unique morphology (Ruggerio et al. 2010). Dunes tend to congregate landward of sandy beach areas and are often connected to vegetation that is endemic to the sand dune environment. The dunes not only replenish sand along the beach area through normal wind action, but they also provide natural breaks from the storm surge and are supported by the vegetative communities that thrive in the dune ecosystem (Hacker et al. 2011; Hesp 1989).

In areas of significant coastal development, coastal sand/dune ecosystems are integral in protecting human assets from existing and emerging risks of coastal storm damage. And they provide a natural defense (through dune renourishment) to the effects of erosion brought on by climate change and sea level rise. Without this ecosystem, humans would have to provide renourishment if they wanted to maintain the sandy beach attributes of the coastline, and armoring or breaks if they wanted to achieve the storm surge dissipation attributes of the sand/dune ecosystem. Mangroves serve a similar function for storm surge dissipation and erosion prevention landward of the mangrove ecosystem (Valiela et al. 2001; Wilkinson and Salvat 2012). The same can be said for saltmarshes (Sandi et al. 2018). As the impacts of climate change progress and aggregate, it is reasonable to assume the value of coastal protection these ecosystems provide will increase.

It is apparent that coastal ecosystems are valuable, by most reasonable estimates a multiple of total global economic output. Attaching that value to human wellbeing is, in some cases, relatively easy. Many people directly interact with coastal beaches for, at least, recreational purposes. In this way, they can attach their recreational preferences to their spending. In other cases, it is harder to show the value of coastal ecosystems, particularly their more indirect provisioning services like coastal storm protection, nursery habitat for commercially and recreationally valuable fish species, nutrient cycling and filtration, and more recently carbon sequestration. And because it is hard to attach these important provisioning values to human spending, it is hard to see how private actions can be relied upon to protect these resources.

Because many of the coastal ecosystem services provide benefits that are not priced in a private market, and because those benefits are distributed and available to humankind generally, they may be categorized as public goods and thus require government action for protection (Loomis and Paterson 2014). One way of looking at what government is doing to protect coastal ecosystems is to identify and analyze policies enacted specifically for this purpose. Another way, and the one explored in the following section, is to examine existing government policies that impede the ability to protect these coastal ecosystems. What follows is an exploration of key national policies in the US that support and protect coastal development and redevelopment in ways that contribute to the decline of these coastal ecosystems.

United States Coastal Development Policy and Coastal Ecosystem Decline

The current effects of climate change already pose a significant threat to coastal ecosystems (He and Silliman 2019; IPCC 2014; USGCRP 2018). This threat presents itself equally to developed and undeveloped coastlines sharing similar geospatial and geomorphological attributes. However, developed coastlines have considerations beyond the background risks associated with climate change. The effects of existing and planned coastal investments, as well as the tendency to protect those investments, create additional risks.

The United States of America (US) has a long history of subsidizing coastal development. Today, over 50% of the population lives in a coastal county, encompassing an area that is less than 20% of the contiguous US land mass and having a population density over four times that of the continental average (NOAA 2020). And coastal population is increasing. Overall, the greatest increases are being seen in the Gulf Coast region, an area that is disproportionately at risk to both sea level rise and climate-related storm activity, particularly hurricanes (KC et al. 2020). These trends create pressure for new coastal development, redevelopment after damage, and protecting existing development in some of the most at-risk regions.

Policies Favoring Development and Redevelopment

The US has supports, through various subsidies, the development of coastal areas (Onda et al. 2020). There are historical reasons for developing along coastlines. Early settlement by Europeans from sailing vessels and marine shipping as a main source of commerce between regions (see McGuire 2020). The effect of incentivizing coastal development, mainly through infrastructure, created a kind of path-dependence for coastal living that has led to the majority of its population living in and around coastal regions.

In more recent times, support for coastal development and redevelopment in the US has taken the form of disaster economics: a complex set of federal policies aimed at mitigating the impacts of increasing risk associated with coastal living. As Knowles and Kunreuther (2014) summarize, the US has been providing disaster assistance since its founding as a nation in 1776. The concept of disaster assistance is to provide federal assistance—mainly financial—to those who have suffered from harm caused by a “natural” phenomenon. Sometimes the definition of a natural phenomenon is clear, like an earthquake, flood, or hurricane; it is an event caused by natural forces. Sometimes the concept of natural is less clear, for example a wildfire initially caused by human negligence. What is common among federal disaster assistance declarations is the notion of no-fault; the event causing harm is not seen to be the fault of those who have suffered the harm.

One issue with federal disaster assistance is that it provides a financial backstop for coastal risks. Those developing and living in coastal areas can effectively discount the risks of loss as federal disaster assistance is made readily available when a coastal storm occurs and causes damage. This assistance helps to make both the coastal municipality and private homeowner whole. In effect, federal assistance diminishes the need to consider the risk of loss when making local decisions about coastal development. All of the benefits of allowing development accrue to the local community, while the risk of loss can be mitigated by federal assistance (McGuire 2015).

The effects of federal disaster assistance can be seen in relation to increased population densities in coastal regions of the US, particularly risky regions along the Gulf of Mexico, and the increasing influence of climate change and sea level rise. According to the Congressional Research Service (CRS 2020), between 1964 (when records began) and 2020, the federal government has spent a total (adjusted to 2020 dollars) of US$435 billion on disaster assistance. US$200 billion, approximately 46% of the total, has been spent in the last decade. When observed in terms of numbers of disasters declared and amounts spent for disasters the picture becomes clear; more money is being spent today on disasters, and each disaster is becoming more expensive by an inflation adjusted comparison.

Elliott and Clement (2017) have provided some context on the dynamics of disaster relief and its impacts on local development. The have found that federal disaster relief not only provides an economic impetus for redevelopment, but it also incentivizes new development in the very same coastal areas. A mix of direct government relief funding, subsidized development loans, and government-backed guarantees on private mortgages—along with a ready-made building workforce brought in for redevelopment—helps to create the conditions for both redevelopment and new development. Ouzad and Kahn (2019) have added to this research by looking at financing activity in coastal areas immediately after a disaster. They note loan originations for coastal development *increases* after a disaster. The rate of private mortgage origination is higher post-disaster than its equilibrium rate in the years preceding the disaster event.

The mix of direct payments, loan guarantees, and other aid reinforces the concept of coastal areas as desirable places to live regardless of the risk. The public spending creates a safety net for coastal development, and the government guarantees help to spur new and expanded private investment in low-lying coastal areas highly sensitive to the influences and impacts of climate change. In such a situation, it is hard to see how coastal ecosystems, and their services, can complete from a policy prioritization standpoint. The more that is invested in coastal areas for development purposes, the easier it is to prioritize protecting those investments over coastal ecosystems and the services they provide.

Climate Mitigation Policies and Coastal Ecosystem Decline

Federal subsidies collectively act to tip the scales of a benefit–cost analysis towards coastal development by externalizing the risks of coastal living. And in doing so, they make it more difficult to prioritize protection of coastal ecosystem resources as they come into conflict with coastal development priorities. This balance in favor of prioritizing development while deprioritizing risk yields additional perverse outcomes when public policies, under the guise of climate adaptation, are enacted to mitigate the impacts of climate change to the built coastal environment.

As already discussed, current policies in the US favor coastal development and redevelopment. These policies, taken as a whole, move significant capital towards coastal development. And as emerging research shows, this movement positively influences demand for coastal real estate by making capital readily available at discounted rates with reduced underwriting requirements due to government guarantees (see Bakkensen and Barrage 2017; Ortega and Taspinar 2018; Zhang and Leonard 2019). This can lead to coastal climate adaptation and mitigation policy being operationally prioritized as human-built asset protection above other competing interests. As summarized below, where sandy beaches are identified as a significant economic driver for a particular coastal area, nourishment tends to be identified as a policy solution. Otherwise, for built areas, armoring is often the preferred policy solution. It is only for undeveloped coastal areas that non-invasive adaptation responses (allowing landward migration for example) are often identified.

Coastal armoring is the process of placing physical structures (seawalls, bulkheads, revetments, jetties, groins, breakwaters, etc.) at the shoreline to limit the influence and impact of the ocean on dry land. There are generally two categories of armoring: hard and soft. Hard armoring provides a solid structure, like a seawall, to provide a substantial barrier between the sea and land. Soft armoring is made of less resilient, often organic materials that attempt to mimic the shoreline's natural contours. Soft armoring is generally favored in lower energy areas like bays and inlets. Hard armoring tends to be used in high energy areas, particularly coastlines directly facing the open ocean (McGuire 2013).

Hard armoring leads to both active and passive erosion. Under conditions of sea level rise, the area in front of a seawall experiences active erosion as the ocean approaches and contacts the wall (CRS 2016). Passive erosion occurs by preventing migration of coastal features landward (Dugan et al. 2008). The cumulative effects of hard armoring diminish and degrade sandy beach, saltmarsh and mangrove ecosystems. They can also impact seagrass meadows and coral reefs through nutrient flow interruption.

Coastal armoring, particularly hard armoring, is favored as an adaptation strategy for most of the built areas along the coastline of the US. As shown by Peterson et al. (2019), armoring is highly correlated with coastal development and climate change adaptation strategies in a positive feedback. The more demand for coastal development, the more likely it is that hard armoring will be chosen as a method to protect those assets from the effects of climate change. McGuire (2017) analyzed hard armoring in the coastal state of Massachusetts in the US. Over 27% of the ocean-facing coastline was found to have some form of public or private hard armoring protection. Preferences for hard armoring was even shown in low energy bays and estuarine rivers. Many of these projects were private and done in conjunction with single-family developments. Most were limited in scale and thus not subject to stricter environmental review requirements under US federal law. But when linked together, they created a substantial "wall" stretching hundreds of miles of inner coastline across the State.

Beach nourishment is another method actively employed in coastlines where shoreline attributes, particularly sandy beaches, are desired (Armstrong et al. 2016). The US has employed beach nourishment as a main strategy to combat coastline erosion and protect coastal assets since the 1970s (NRC 2014). It has regularly been used to protect and reinforce coastal development. Nourishment can have the same impacts as hard armoring, even in undeveloped areas. If the nourishment takes the place of natural seascape migration landward, then the normal coastal features, including mangroves and saltmarshes, are inhibited from migration through the depositing of new sand. Otherwise, for developed coastlines, nourishment buffers the rising tides and their effects—at least for a time—from development.

Besides inhibiting the natural movement of nearshore coastal features, nourishment has a similar effect as armoring on public perceptions of risk as measured through development. Numerous studies have shown that nourishment protection for coastal properties spurs additional coastal development (see Gopalakrishnan et al. 2011; McNamara et al. 2015; Nordstrom 2000). So, while less directly intrusive as hardscapes such as seawalls, nourishment as a mitigation measure for climate adaptation can lead to increases in coastal development in the very areas that are most at-risk in experiencing the impacts and effects of climate change.

Conclusions

Coastal ecosystems provide a tremendous amount of value to humans. Conservative estimates place that value, in monetary terms, as a multiple of global economic output on an annual basis. Some of that value is captured in our economic accounting in the form of direct and, to some degree, indirect human uses. We value sandy beaches not only for the sand and other resources that we find, but also for the many commercial and recreational activities we enjoy that beaches help supply.

There are many other supporting services coastal ecosystems provide that are less well understood. The sands of beaches help purify and store fresh water for human consumption. Salt marshes, mangroves, seagrass meadows, and coral reefs all provide critical nursery habitat for many of the marine species we value commercially and recreationally. All serve as important nutrient uptake and distributions systems that are critical to biodiversity. And all play an increasingly important role in mitigating the effects of climate change. These lesser understood functions, by most estimates, provide the greatest amount of value in service of human wellbeing.

Coastal ecosystems around the globe, and certainly in the United States of America (US), are under threat from climate change. Storms are getting more frequent and intense while seas are rising. Moving carbon from stored locations within the Earth is warming our surface waters and increasing their acidity. These climate-induced changes pose risks to global coastal ecosystems. The US, like many other coastal nations, is aware of the causes, effects and impacts of climate change. Like others, it is developing and implementing mitigation and adaptation strategies. But do these plans take full account of coastal ecosystem values and, as such, prioritize their wellbeing in existing policy instruments. At present that answer is no.

Current US policies, particularly those supporting coastal development and disaster assistance, are prioritizing development over coastal ecosystem protection. The current paradigm incentivizes the discounting of existing and emerging coastal risks. When coastal disasters occur, federal assistance subsidizes relief efforts with direct payments, redevelopment loan guarantees, and other financing for projects including hard armoring, soft-armoring, and beach nourishment. As has been shown in the literature and explained in this paper, these mechanisms not only lower the perception of risk, but they also induce additional demand and new development in risky coastal areas. More development and financing yield a greater overall investment in these coastal regions. This supports higher property valuations, prioritizing adaptation and mitigation policies towards protection of these assets through seawalls and nourishment projects that collectively lead to coastal ecosystem degradation. In many ways, the US is caught in a cycle of investment and reinvestment that blinds itself to meaningful coastal ecosystem protection.

It is clear that if the US is to break this cycle of coastal investment and reinvestment, it must fundamentally alter its current policies that, collectively, discount the evolving risks at its coastlines. It may be difficult to fully internalize the multitude of values of coastal ecosystems into policy development. It will certainly be difficult to gain support from an ill-informed public. But much can be achieved by removing the externalization of risk in current policy through the multitude of subsidies overviewed in this paper. By doing so, market forces free from distortions can better aid policymakers in balancing risk-adjusted demand for coastal living with the valuable services provided by coastal ecosystems.

The examination of US coastal policy provided here creates a template for examining coastal policies in other nations that exhibit similar characteristics of prioritizing development over coastal ecosystem protection. Similar among the US experience for most nations is the inability to fully internalize the values—particularly provisioning services—provided by coastal ecosystems. Different from the US experience will be the history of coastal development, the cultural dimensions, and the expectations of those who live along the coasts. In some cases, it may be easier to implement more proactive protection strategies in other coastal nations than is experienced in the US. And in some cases, it may be more difficult. While differences in analysis will likely occur, the framework of looking at existing policies as either barriers or pathways for coastal ecosystem protection is an important means of protecting planetary and human health under conditions of climate change.

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