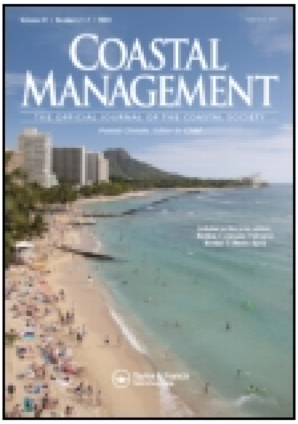

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Considering "Coastal Carbon" in Existing U.S. Federal Statutes and Policies

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Coastal ecosystems such as mangroves, salt marshes, and seagrasses provide important ecosystem services, including nursery habitat for fish, shoreline protection, and the recently recognized service of carbon sequestration and storage. When these wetland ecosystems are degraded or destroyed, the carbon can be released to the atmosphere, where it adds to the concentration of greenhouses gases (GHGs) that contribute to climate change. Many federal statutes and policies specifically require that impacts on ecosystem services be considered in policy implementation. Yet, no federal statute, regulation, or policy accounts directly for the carbon held in coastal habitats. There are a number of federal statutes and policies for which coastal carbon ecosystem services could reasonably be added to environmental and ecosystem considerations already implemented. We look at a subset of these statutes and policies to illustrate how coastal carbon ecosystem services and values might affect the implementation and outcomes of such statutes generally. We identify key steps for the inclusion of the ecosystem services of coastal habitats into the implementation of existing federal policies without statutory changes; doing so would increase the degree to which these policies consider the full economic and ecological impacts of policy actions.

Both Pendleton and Sutton-Grier contributed equally to this article.

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Introduction

Coastal ecosystems such as mangroves, salt marshes, and seagrasses provide important ecosystem services, and thus economic value. These services include nurseries for fish, shoreline protection, water purification, and recreation and tourism opportunities (Barbier et al. 2011). In the United States alone, there are more than 6 million acres of marine and estuarine wetlands (Dahl 2011). And, where valuation studies have been completed, the value of the services provided by these coastal habitats is significant. For example, a study of the storm protection against hurricanes provided by coastal wetlands along the Atlantic and Gulf coasts found that these habitats provided \$8,236 ha^{-1} yr^{-1} in reduced hurricane damages (Costanza et al. 2008), while another study in Thailand suggested that for every square kilometer of mangrove lost, an expected increase of \$585,000 in storm damages is expected (Barbier 2007). Barbier (2007) also determined that every hectare of mangrove increased offshore fishery production by \$708–\$987 in capitalized value. The high economic value of the ecosystem services these coastal habitats provide warrants attention to their protection from destruction and degradation (Beaudoin and Pendleton 2012). Nevertheless, these coastal systems are being degraded at a significant pace, with global losses of functioning coastal ecosystems estimated to be between 1% and 2% per year (Murray et al. 2011; Duke et al. 2007; Food and Agriculture Organization (FAO) 2007).

In addition to the other ecosystem services already described, there is a growing body of literature recognizing and quantifying the carbon sequestration and storage potential of salt marshes, mangroves, and sea grasses (Pidgeon, Herr, and Fonseca 2011; Sifleet, Pendleton, and Murray 2011). In these habitats, carbon is sequestered from the atmosphere and retained in living biomass and sediment. Because of its proximity to the ocean, the carbon in these habitats often is referred to as “coastal blue carbon.” Herein, we refer to this ecosystem service as simply “coastal carbon.” Unlike in-land forests, which typically store most of their carbon in aboveground biomass such as tree trunks, coastal carbon habitats store the majority of their carbon in the sediment, with carbon-rich sediments sometimes reaching depths of many meters. These ecosystems are changing due to both natural and anthropogenic forces and their coverage is somewhat dynamic. In the case of mangrove forests, for example, mangroves are currently being lost due to deforestation and degradation resulting from human activities; however, there is some mangrove expansion due to sea-level rise or increases in temperature (Giri, Long, and Tieszen 2011).

When these wetland ecosystems are degraded or destroyed, the carbon in the plant biomass and sediments can be released to the atmosphere, where it adds to the concentration of greenhouses gases (GHGs) that contribute to climate change (IPCC 2007). Recent estimates suggest that 0.15–1.02 Pg (billion tons) of carbon dioxide are being released annually due to destruction or degradation of coastal habitats (Pendleton et al. 2012). To put that amount of carbon into perspective, these emissions are equivalent to 3–19% of those from deforestation globally (Pendleton et al. 2012). Thus, when coastal habitats are lost, not only is their ability to sequester carbon lost, but past stored carbon is released, causing these habitats to become large sources of greenhouse gases.

Many federal statutes and policies specifically require that impacts on ecosystem services be considered in policy implementation and some federal policies directly include the economic value of certain ecosystem services in estimates of economic impact. For example, the Natural Resources Damage Assessment injury assessment process determines the loss of a natural resource or service compared to baseline conditions (French et al. 1996). These can include the loss of recreation opportunities or commercial fishing landings when fish habitats and stocks are impacted by an incident. To our knowledge, however, these assessments do not include the carbon services provided by ecosystems. In fact, we are aware of only one federal statute, regulation, or policy that suggests accounting for the carbon held in coastal or terrestrial habitats and that is the recently released "Principles and Requirements for Federal Investments in Water Resources" (herein "P&G") policy that was released by the White House in March 2013. The revised P&G now state that "carbon storage" is one of the ecosystem services that could be included in evaluations of federal water resources projects. Also, in recent draft guidance about the National Environmental Policy Act (NEPA) and climate change and greenhouse gas (GHG) emissions, the Council on Environmental Quality seeks public comment on "the appropriate means of assessing the GHG emissions and sequestration that are affected by Federal land resources management decisions" because there is no "established Federal protocol" for assessing the impacts of land management techniques (including land use or management strategies) on atmospheric carbon release and storage (Sutley 2010). Thus, currently there is no specific method for including coastal or terrestrial carbon in the implementation of federal policies.

In this analysis we have chosen to focus on coastal carbon due largely to a growing interest both in the United States and abroad for the importance of coastal carbon stores. Ideally, the implementation of more federal policies would include carbon held in both terrestrial and coastal ecosystems like the recent P&G guidelines. Explicitly accounting for coastal carbon could change the outcome of federal policy actions for variety of federal statutes and policies, including the NEPA, Clean Water Act, and others. These statutes and policies allow for agency discretion in deciding which ecosystem services to include when considering alternative policies, plans, actions, and even assessments of the economic costs of damages to coastal ecosystems. Coastal carbon is an ecosystem service that could be included.

The Relevance of Coastal Carbon to U.S. Federal Statutes and Policies

Scarlett and Boyd (2011) highlight the many ways in which existing federal policies could promote the quantification, management, analysis, and even payments for ecosystem services. We take a different approach. We look at how a better accounting of one ecosystem service, coastal carbon, could affect the implementation and outcomes of selected federal statutes and policies.

Most recently, the 2012 Draft National Ocean Policy (NOP) Implementation Plan contains an action item that directs federal agencies to pay special attention to coastal carbon in public policies regarding coastal management and conservation (NOC 2012). To implement this action, agencies will need to re-examine existing policies, possibly develop additional protocols or guidelines for how to incorporate coastal carbon services into federal policies, and prepare for the implications of considering these services in federal decision-making. This article considers the possible opportunities and potential implications of implementing the NOP action and increasing the attention paid to coastal carbon values in the implementation of specific policies. This article does not suggest or recommend a proper path for action. Ultimately, agencies will decide how best to account for coastal carbon values in federal policymaking, planning, and action.

Scope of Analysis

Our analysis considers federal environmental statutes and policies exclusively. While state policy regarding coastal management and protection is obviously important, these policies vary from state to state and are beyond the scope of this review. Federal policy, on the other hand, is applied in a relatively uniform manner throughout the nation. Thus, this article examines how several *existing* federal statutes and policies could be affected by a more complete accounting of coastal carbon values. We do acknowledge that federal policies considered in this article *are* influenced by state action and state discretion. Therefore, the lessons learned here may also reveal lessons for state policies.

Opportunities for Including Coastal Carbon in Existing U.S. Federal Statutes

There are a number of federal statutes, policies, and authorizations for which coastal carbon ecosystem services could reasonably be added to environmental and ecosystem considerations already well implemented by the federal agencies. We look at a subset of these statutes and policies to illustrate how coastal carbon ecosystem services and values might affect the implementation and outcomes of such statutes generally.

For each statute or policy, we provide (1) a short description of the statute, regulation, or authorization and (2) a description of the current status for the inclusion of coastal carbon in the implementation and assessment of the policy. In the discussion we examine the common findings, limitations, and opportunities for including coastal carbon in the implementation of these federal policies. We conclude with a summary of findings.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) was signed in 1970 by President Richard Nixon. The Act requires all federal agencies to analyze the impacts of their actions on the human environment and encourages public involvement in the decision-making process. There are three types of documentation for analysis. Categorical Exclusion documents are for federal actions with no to minimal impacts. Environmental Assessments (EAs) are prepared to determine whether a federal Action will result in one or more significant effects. Environmental Impact Statements (EIS) are prepared for federal actions that are expected to have significant effects. The Council on Environmental Quality (CEQ) coordinates federal environmental efforts and works closely with federal agencies and other White House offices in the development of environmental policies and initiatives. CEQ was established within the Executive Office of the President by Congress as part of the National Environmental Policy Act of 1969 (NEPA) and additional responsibilities were provided by the Environmental Quality Improvement Act of 1970.

Much of the discretion regarding what impacts are considered and which alternative is chosen lies with the agencies.

Current Status

Based on analysis of NEPA guidelines and interviews with agency specialists, it appears that coastal carbon sequestration and storage services are not considered in NEPA analysis despite the need for consideration of impacts on ecosystem services. We could not find any case in which the consideration of carbon services of coastal habitats has been included in NEPA analysis concerning federal actions in coastal areas. Terrestrial carbon stores also are not currently considered in NEPA analyses, but whether to include them and how to include them is a matter under consideration by the Council on Environmental Quality (Sutley 2010).

Opportunities and Implications

If a federal agency would like to institutionalize carbon as an important impact for inclusion in an EA or EIS analysis recommended in the NEPA process, it can develop a policy or a set of guidelines for use by regulatory offices when considering actions that will affect the human environment. As a result, the inclusion of coastal carbon values in NEPA analysis and statements could occur immediately.

The reliance on individual agency discretion also means a reliance on individual agency capacity for including coastal carbon in NEPA documents. This would involve using methods for quantification and tools for valuation such as MIMES or InVEST (see the section in Discussion on "Tools and Next Steps"). Before agencies take action regarding the incorporation of coastal carbon into NEPA analyses, including EAs or EISs, they will likely need to possess adequate scientific expertise to assess the carbon sequestration, storage, and emissions that may be affected by the proposed action. Methods will be needed for estimating the amount of carbon that could be lost or gained under the range of reasonable alternatives.

When a benefit–cost analysis is included or associated with NEPA analysis, the economic value of differences in coastal carbon value could be included directly in the benefit–cost analysis.

In order to facilitate the ability of individual agencies to include coastal carbon in their EISs and EAs, the Council for Environmental Quality (CEQ) could provide additional guidance regarding the inclusion of carbon into NEPA analysis to all agencies. CEQ already provides guidelines to federal agencies regarding the calculation and reporting of GHG emissions in "Federal Greenhouse Gas Accounting and Reporting Guidance," but there is no mention of coastal carbon (NOAA 2011b; CEQ 2010).

Natural Resources Damage Assessment (CERCLA and OPA)

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Oil Pollution Act (OPA) authorize federal, state, and tribal trustees to assess the environmental consequences of pollution events and to seek compensation, remediation, or mitigation for damages caused. The process is routinely referred to as Natural Resources Damage Assessment (NRDA). Parties responsible for the destruction or degradation of the ecosystem must not only work toward restoring the contaminated site, they must also provide compensatory mitigation for the interim loss of the functionality of that site (DARRP 2006).

Current Status

NOAA's Damage Assessment, Remediation and Restoration Program often assists the "trustees" of public natural resources in the estimation of damages caused by and the required mitigation needed to offset the impacts of pollution events. Calculating the level of compensatory mitigation is often accomplished through Habitat Equivalency Analysis (HEA). This method seeks to replace an equivalent level of ecological services for services lost. Another concept used to account for damages is the "discounted service acre years"

(DSAYs). DSAYs take into account the time it takes the injured area to recover as well as the mitigated area needed to create new ecological services that are comparable to those originally provided by the damaged site (DARRP 2006). Ecological services could include bird or fish habitat, shoreline protection, and recreation, among other types of services.

When deciding how much habitat restoration is required to offset habitat damage, the trustees can implement a "scaling approach" that could include resource-to-resource or service-to-service scaling. The trustees may also utilize a valuation approach that attempts to identify habitat equivalence that will result in a value-to-value scaling or a value-to-cost approach.

Coastal carbon values have not been included in NRDAs to date.

Opportunities and Implications

Coastal carbon functions and value could be included directly in the estimation of habitat equivalency and scaling as well as in estimates of DSAYs. If coastal carbon values were included in service-to-service or value-to-value scaling approaches, new habitat would have to achieve a level of carbon sequestration and storage equivalent to that of the affected habitat, prior to damage. The vast majority of carbon value in salt marshes, sea grasses, and mangroves is in sediments that may contain 500 to 1,500 metric tons of CO_2 equivalents per hectare per meter of depth (Sifleet, Pendleton, and Murray 2011). Existing, historically long-lived coastal habitats may protect up to ten meters of sediment beneath their living biomass. When coastal ecosystems are disturbed, the vast stores of carbon in these sediments could be released to the atmosphere. Restored habitat, however, may not protect the large carbon stores associated with carbon-rich sediments because sediments may start off being carbon-poor. Since sequestration rates are on the order of tens of metric tons (CO_2 equivalents) per hectare, it is likely to take many decades before restored habitats sequester and protect equivalent amounts of sediment carbon as undisturbed habitats. Therefore, the scaling needed to offset lost carbon storage by restored habitat could be very large (e.g., 100), even measured in DSAYs.

The NRDA process ultimately is one of negotiation and teamwork (DARRP 2012). As a result, parties responsible for damages could propose innovative ways of offsetting lost carbon, including the protection of existing habitat elsewhere rather than the restoration or creation of new habitat. This could be a viable alternative because carbon gases are globally mixed and distributed. While such an offsite approach may be appropriate for compensating for lost carbon services, it may not be appropriate for compensating for other types of lost coastal habitat services in an NRDA context.

404(b) Compensatory Mitigation Requirements (Clean Water Act)

Section 404 of the Clean Water Act (CWA) is administered by both the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (EPA) and provides a process by which landowners can apply for permits for activities that would result in the discharge of dredged fill material into water of the United States, including wetlands. The USACE coordinates the review of permit applications with state and federal Agencies, including NOAA and the U.S. Fish and Wildlife Service, who provide information on the environmental impacts of specific proposals and recommendations for avoiding, minimizing, and compensating for those impacts.

Current Status

Compensatory mitigation options for wetlands include restoration, enhancement, establishment and preservation (USACE and EPA 2008). The USACE and EPA regulations governing compensatory mitigation emphasize a watershed approach that focuses on sustaining or improving aquatic resources, functions, and services at a landscape scale (USACE and EPA 2008). The USACE and EPA regulations governing compensatory mitigation provide examples of the contribution wetland mitigation can make to carbon sequestration and sea-level rise, but do not incorporate carbon sequestration as a variable that should be considered when designing wetland mitigation projects (USACE and EPA 2008). When measuring wetland degradation, the USACE guidance mentions a need to look at hydrology, vegetation, and soils for wetlands (White and Meager 2008). While carbon is not mentioned explicitly, it clearly is an important component and characteristic of both soils and vegetation.

Opportunities and Implications

In principle, the 2008 compensatory mitigation rule provides an opportunity to consider carbon in coastal wetland habitats when determining required compensatory mitigation (USACE and EPA 2008).

The USACE and EPA recognize wetland compensatory mitigation crediting as the accrual of aquatic functions. Such aquatic functions represent the chemical, biological, and physical integrity of a wetland (USACE 2008). However, the guidelines also mention performance criteria based on the ecological performance of the site. If an individual conducting compensatory mitigation lists as an objective the restoration of carbon sequestration and storage in a coastal wetland, the project could certainly be held accountable to this objective.

Areas within the regulation that could be influenced by a more thorough accounting of coastal carbon involve the compensation ratio method of determining credits and the temporal aspect of this calculation. The EPA and USACE encourage higher compensation ratios (more compensation required per unit lost) to compensate for temporal loss of wetland function. If restoration occurs after degradation, more restoration is required to meet this temporal loss. Accounting for lost carbon could increase this temporal loss as the carbon lost in the soils of a degraded wetland likely would take longer to be restored than other physical or biological processes.

The method used for calculating restoration credits could yield different results if carbon sequestration and storage functions were considered (USACE 2012). If the USACE considered carbon sequestration and storage as an additional attribute that must be mitigated for, then restoration or preservation ratios would likely be higher to account for carbon losses. The change in ratios would likely be greatest for restoration projects given that restoration sites tend to have low soil carbon (Clewell and Lea 1989; Bruland et al. 2006; Taylor et al. 2002).

The inclusion of coastal carbon values could affect the implementation of the 404 permitting process even in the short term. Specifically, federal agents could require estimates of carbon sequestration and storage (e.g., GHG fluxes) for all assessments of project impacts and compensatory mitigation proposals, since carbon sequestration, storage, and emissions represent biological and chemical processes within a wetland.

Mitigation bankers already face monitoring requirements to ensure that a project's promised level of restoration, enhancement, establishment, or preservation occurs. If carbon sequestration and storage were included as biological and chemical processes for which compensation must be provided, monitoring would have to demonstrate how carbon sequestration and storage was being achieved by the restored/enhanced/ established/protected habitat.

Greater costs may accrue to those who seek coastal wetland mitigation credits if the USACE updates compensatory mitigation requirements to include carbon loss. This update may require substantially greater amounts of land restored or protected to compensate for not only carbon stored in the wetland's soil, but also the temporal gap between degradation and compensatory mitigation.

Coastal Zone Management Act

The Coastal Zone Management Act (CZMA) was enacted in 1972 by Congress to allow states to protect their coastal resources while allowing for continued development. NOAA's Office of Ocean and Coastal Resource Management administers the Act, but states have full sovereignty in their decision to participate and the extent to which they do (HSS 2011). CZMA provides the framework for a partnership between the federal government (through NOAA) and coastal states (NOAA 2011a). Through the Act, states are required to develop coastal zone management plans if they accept coastal zone management funds from NOAA. NOAA in turn provides implementation funding, advice, and mediation with stakeholders (NOAA 2007). This means that the bulk of actions under the CZMA are undertaken by individual states.

Current Status

Currently, we are unaware of any guidance from NOAA that directly addresses coastal carbon. The Coastal and Estuarine Land Conservation Program previously provided funding to acquire coastal land that could include areas of high coastal carbon function and value, but that program has been defunded. There is ongoing research at NOAA and within the National Estuarine Research Reserve System to better understand coastal carbon functions in coastal habitats, sponsored by the NERRS Collaborative Science Initiative.

Opportunities and Implications

Because states develop and implement coastal plans, *states* must decide whether coastal carbon is an important ecosystem service to consider in making coastal plans and assessing coastal development proposals. Nevertheless, NOAA provides advice to the states regarding ecosystem outcomes the agency deems to be most important. For example, NOAA's climate change planning guide for coastal managers identifies climate adaptation as an important outcome in coastal planning (NOAA 2010).

As coastal carbon rises in importance as a component of NOAA's mission to promote healthy coastal systems, NOAA may begin to encourage a focus on coastal carbon through its funding of coastal restoration, research, and stewardship. While NOAA technically has the capacity to offer preferred funding to projects that protect coastal carbon, it currently does not prescribe such specific action for grant applicants.

Funding mechanisms through the CZMA have two main channels: the National Estuarine Research Reserve System (NERRS) and the Coastal Zone Management Program. The NERRS program focuses predominately on the local research needs of the 28 coastal reserves in its system. In 2009, the NERRS program saw approximately $30 million in funding for projects and land acquisition. Already, the NERRS Science Collaborative currently funds coastal carbon research in the Waquoit Bay NERR (Massachusetts) (WBR 2011). The Collaborative currently works on research regarding local stakeholders and climate change; further research regarding coastal carbon would be a natural fit.

The Coastal Zone Management Program provides funding beyond the NERRS and supports the implementation of states' coastal management plans (NOAA 2012). In 2011 the program provided $65 million to states. Both of these funding streams could feasibly direct funds to coastal carbon research and protection. Based on recent reviews (Sifleet, Pendleton, and Murray 2011; McLeod et al. 2011), some of the most important research needs for coastal carbon which need to be addressed include:

1. Understand the driving forces affecting carbon sequestration rates. This includes mapping the spatial and regional variability of carbon sequestration rates in and among blue carbon sinks, and relating them to ecological and environmental characteristics. We also need indicators to scale up measurements from sites to regions.
2. Improve quantification of carbon sequestration (and other benefits) associated with preservation and restoration of these habitats and the carbon emissions from destroyed or modified habitats.
3. Improve data on the areal coverage of each of these habitat types as well as the areas most at risk of further loss. This will help identify priority areas for protection and restoration in order to maximize carbon sequestration and storage.
4. Develop standardized methods for improving measurements of carbon sequestration estimates in order to better understand the spatial and regional variability in carbon sequestration and storage.
5. Improve understanding of how climate change affects carbon sequestration rates and storage.
6. Improved methods of valuing the carbon sequestered and stored in these habitats will help us better manage and conserve these habitats.

Another practical change could come from the key outcome metrics that NOAA provides through the CZMA, including funding and general "success" criteria. When NOAA reports its funding, it could specifically highlight funding for coastal carbon protection and the amount of carbon protected if relevant. In such a scenario, the value of this carbon could be used in its expression of the economic benefit provided by the work. NOAA also reports performance measures for both the Coastal Zone Management Program and NERRS (NOAA 2007). Future performance metrics could include metrics that reflect coastal carbon.

Endangered Species Act Executive Order 13563

The economic assessments required by the Endangered Species Act, too, could be influenced by an accounting of the carbon value of coastal habitats. The assessment of costs and benefits of designating critical habitat has been required since the 1970s, but these assessments are not always completed concurrently. In President Obama's Executive Order 13563 of January 18, 2011, and the Presidential memo of February 28, 2012, the Fish and Wildlife Service (FWS) is directed to consider the costs and benefits of designating critical habitats of endangered species concurrently with the development of designations of such habitats needed to ensure species recovery. The Order and memo urge that actions taken to recover an endangered species impose the least burden on society and also maximize net benefits (Obama 2012).

Earlier, a memo from the FWS Director (October 26, 2005) instructed the agency to include a broader array of benefits from habitat protection in the calculation of economic and policy benefits associated with critical habitat designation. Traditionally the economics of land use have focused on the lost opportunity costs of the land, but these analyses also could look at the opportunity gained by the protection of the habitat—for instance, the carbon sequestration and storage services provided by coastal habitats. However, we do not know that anyone has ever exercised this option.

Current Status

Coastal carbon has not been included in the assessment of the economic impact of any critical habitat designation.

Opportunities to Incorporate Coastal Carbon

If "economic impact" in ESA economic assessments is interpreted to include ecosystem service values, as it has been in other new guidance coming from the White House, carbon values could be included as benefits. Such an acknowledgment of the economic value of preserving coastal carbon could reduce the estimated net costs of critical habitat designation in coastal areas by including coastal carbon values in the potential ancillary benefits of that designation.

Water Resources Development Act and the Proposed Revised Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G)

The Water Resources Development Act and the Proposed Economic and Environmental Principles and Guidelines for Water and Related Land Resource Implementation Studies (P&G) provide guidance for assessing federal investments in water resource development projects in the United States. The U.S. Army Corps of Engineers (USACE) established the current revised P&G document in March 2013; the previous version had not been updated since 1983. The purpose of the principles and guidelines is to support consistent evaluation of water-related projects conducted by the USACE, Bureau of Reclamation, Tennessee Value Authority (TVA), and the Soil Conservation Service (now Natural Resources Conservation Service or NRCS) (USACE 1983). While the previous version of the P&G guidance from 1983 considered both economic and environmental objectives, plan selection criteria retained a strong focus on net economic benefit of a project primarily from a market-based perspective (USACE 1983). This is largely due to the predominant emphasis on national economic development (NED) as the underlying policy objective (Brezack & Associates 2011).

Current Status

With the 2007 Water Resources Development Act, Congress requested the development of an updated P&G. Under the Obama administration, the White House's Council on Environmental Quality (CEQ) proposed an update to the P&G that expands this guidance to cover all federal agencies working in federal waters. The revised policy released in March 2013 seeks to expand the current measures of net economic benefit (usually interpreted as market effects) that ignore environmental and certain other social goals, towards a more inclusive measure that places these latter factors on an equal footing (CEQ 2009). The recently revised P&G includes a focus on ecosystem services and includes specific language about carbon: "Services and effects of potential interest in water resource evaluations could include, but are not limited to: water quality; nutrient regulation; mitigation of floods and droughts; water supply; aquatic and riparian habitat; maintenance of biodiversity; carbon storage; food and agricultural products; raw materials; transportation; public safety; power generation; recreation; aesthetics; and educational and cultural values" (CEQ 2013, 7). To our knowledge, this is the first federal policy to explicitly include language that acknowledges the carbon services of habitats in the policy and in the agency implementation guidance.

Opportunities and Implications

The revised P&G have the potential to change how agencies assess investments in federal water projects that provide ecosystem benefits, such as recreation or carbon sequestration and storage. Under the previous (unrevised) P&G, a coastal wetland enhancement project would not have generated large net economic benefits if it did not directly contribute to jobs or local business activity. Under the revised P&G, which include consideration of the value of ecosystem services, such a project will potentially be seen to yield higher net benefits because coastal carbon and other ecosystem service benefits may be included in the assessment.

Another example of how the revised P&G can enable agency consideration of coastal carbon is through preemptive mitigation activities. The draft "Revised P&G" encourage federal agencies to compensate for the loss of ecosystem services before an activity takes place (CEQ 2009). Carbon lost from degraded coastal sediments could take years to restore through the creation of new coastal habitat. Agencies with an expressed interest in coastal carbon would not just have an incentive to mitigate their impacts, but could choose to mitigate such impacts far ahead of the actual degradation—through protection, stewardship, or other forms of proactive management.

Findings, Limitations, and Opportunities

There were a number of similar findings from our analysis of these six regulations. First, coastal carbon could be incorporated into the implementation of all of these regulations (NEPA, NRDA, 404(b) Compensatory Mitigation, CZMA, ESA, and WRDA) without statutory changes. These regulations do not have language that would prohibit the inclusion of coastal carbon in their implementation. Thus, no new regulations are needed.

Second, even though it is not prohibited, to the best of our knowledge coastal carbon is currently not included in the implementation of any of these regulations. For NEPA, coastal carbon is not included in documents and analyses, including EISs or EAs. It is not included in NRDA assessments or 404(b) actions or assessments. In the CZMA process, coastal carbon is not included in CZMA documents or as a target of scientific research in the CZMA-related, NOAA coastal science initiatives (e.g., NERRS Science Collaborative, although the one exception to this is the current, unique project at the Waquoit Bay NERR site in Massachusetts, examining how wetland projects can reduce greenhouse gas production (WBR 2013). It is not included in the analysis of the economic impacts of designating critical habitat for species listed under the ESA or of proposed federal water projects. It should be noted that we do not know of any cases where terrestrial carbon has been included

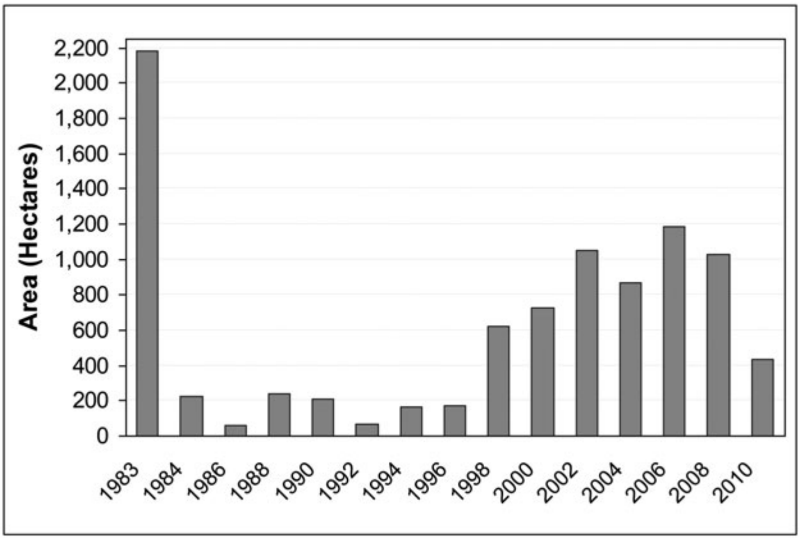

Figure 1. Mangrove forest area of Louisiana from 1983 to 2010 derived from Landsat.

in the implementation of any of these regulations either but the CEQ is considering including ecosystem carbon in NEPA activities (Sutley 2010).

Third, there are some key limiting factors that need to be overcome in order for coastal carbon to be included in the implementation of these regulations. One major limitation across all the regulations we examined is a lack of guidance and procedures for estimating and valuing coastal carbon. A second common limitation was a lack of capacity and expertise needed to quantify impacts of projects on carbon storage and sequestration. For NRDA, for example, there need to be agreed-on methods for valuing coastal carbon, and capacity and expertise needed to quantify the counterfactual (i.e., without damage) levels of carbon storage and sequestration. For 404(d) permits, there need to be quantitative methods for calculating the carbon function lost at project sites and gained at compensatory mitigation sites (gained through restoration, enhancement, establishment, and preservation). Better monitoring methods are needed to monitor the carbon function of these habitats. For CZMA, current limitations include a lack of methods for weighing the tradeoffs between coastal carbon functions and other ecosystem services, and a lack of capacity and expertise needed to quantify the impact of current and proposed coastal zone management policies on carbon storage and sequestration. For ESA, there is a lack of agreed-on methods for valuing coastal carbon and a lack of capacity and expertise needed to quantify the impact of critical habitat designation on carbon values.

A third limitation is the need for better information on present condition, historical status, and dynamics of these ecosystems in order to quantify the change of carbon stocks and its value. This is particularly important in the coastal regions where ecosystems are highly dynamic. For example, one case study in Louisiana by Giri et al. (2011) using satellite imagery demonstrated how mangrove and salt marshes change resulting in changes in ecosystem services. When the winter is mild, mangrove expands to salt marshes, but with the occasional winter hard freeze, mangrove is destroyed and is replaced by salt marshes (Figure 1).

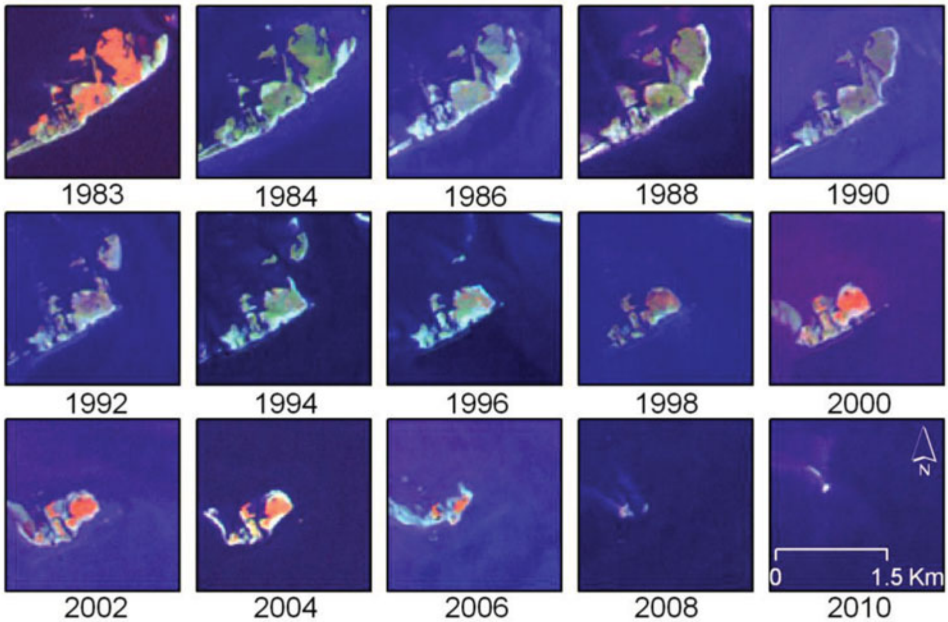

Figure 2. Mangrove forest (dark red) was destroyed by winter freeze in 1983–1984, recovered afterward, but completely vanished by 2010 due to erosion and subsidence of the island (color figure available online).

During the severe winter freezes (Figure 1, see 1983–1984, when mangrove cover was reduced by approximately 90%, and then 1989 and 2009 when hard freezes also occurred) mangrove cover was reduced and replaced by salt marsh. Major changes in mangrove cover are strongly correlated to winter freeze, but specific causes of mangrove forest cover change vary spatially and temporally. Besides winter freeze, other factors such as erosion and land subsidence also affected Louisiana's mangrove extent. For example, on East Timbailer Island (29° 04′ 43" N and 90° 16′ 46" W; Figure 2), mangrove completely disappeared during the winter of 1983–1984. In subsequent years, mangrove colonized and reestablished; however, the barrier island started eroding, and by 2010 nearly the entire island vanished, resulting in total loss of mangrove cover at this site. This case study highlights the importance of understanding the present condition, historical status, and dynamics of these ecosystems in order to better understand the carbon services these ecosystems provide.

A fourth limitation is that, for some of these regulations, such as the NRDA process, the ESA process, and P&G, precedent is especially important. In the NRDA case, a current limitation is the lack of precedent for valuing coastal carbon in binding damage assessments, agreed-on methods for valuing coastal carbon, and capacity and expertise needed to quantify the counterfactual (i.e., without damage) levels of carbon storage and sequestration. For ESA, there is no precedent for valuing coastal carbon in ESA economic assessments or similar forms of litigation-quality economic analysis. For P&G, there is a lack of precedent for valuing coastal carbon in federal cost-benefit analyses. Therefore there is a need for a pilot effort to establish a precedent for including coastal carbon in any of these processes.

But none of these limitations are insurmountable with the right tools, data and information, methodologies, and expertise, and all of the regulations offer opportunities for doing more to protect coastal habitats. All of these regulations offer exciting conservation opportunities for coastal habitats if the implementation of these regulations included coastal carbon. For example, in the 404(d) process, inclusion of coastal carbon could redirect mitigation efforts away from de novo creation of new wetlands toward the preservation of "at risk" wetlands and the restoration of wetlands that still contain carbon-rich soils. Incorporating the economic value of coastal carbon in the economic impact analysis of ESA critical habitat designation actions, would offset the perceived negative economic costs usually associated with designating critical habitat (e.g., job loss or loss of access) when such designation leads to the protection or restoration of coastal ecosystems that include salt marshes, seagrasses, or mangroves. Incorporating the economic value of coastal carbon into the economic impact analysis of federal water projects, would increase the estimated net economic value of projects that improve the protection or restoration of coastal habitats and increase the costs of projects that negatively impact these habitats, thus hopefully leading to additional coastal ecosystem conservation.

Tools and Next Steps

As identified through our examination of these regulations, the biggest challenges to the incorporation of carbon services into federal policies are: (1) quantifying the carbon in the system (determining a baseline for each system), (2) quantifying the loss of carbon that occurs due to human activities, and (3) quantifying the value of the carbon. There are efforts to develop standardized methods for quantifying carbon in these systems (Kauffman and Donato 2012), but more such efforts are needed. Availability of data and information on the condition and dynamics of these ecosystems is also needed.

In terms of *valuing and mapping* the carbon in these systems, several tools are available including Mimes, Aries, and InVEST, all tools that help visualize ecosystem services in order to support policy and decision-making. Mimes (Multi-scale Integrated Models of Ecosystem Services) is an integrated set of models that asses the value of ecosystem services and are designed to produce results that are easily interpretable to support decision-makers and natural resource managers (*AFORDable Futures* 2013). The ecological and economic models integrate our understanding of ecosystem functioning, ecosystem services, and human well-being (Boumans and Costanza 2007). ARIES stands for ARtificial Intelligence for Ecosystem Services and is a visualization tool for mapping benefits, beneficiaries, and service flows in order to better value and manage ecosystems (ARIES 2012). By mapping both the provisioning and usage of ecosystem services, ARIES helps scientists and policy and decision-makers understand the value of ecosystem services in order to make more effective environmental decisions (Villa et al 2009). InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a family of tools for mapping and valuing the goods and services humans get from nature (Natural Capital Project 2012a). This tool includes both a terrestrial and a coastal and marine component and allows the user to visualize the outcomes of different scenarios in order to support decision-making. The terrestrial version already includes carbon sequestration and storage as one model option (Natural Capital Project 2012b), and in the next version of Marine InVEST, which will hopefully be coming out in the next few months, carbon storage will be one of the new modules that will be able to be modeled using Marine InVEST (Anne Guerry, personal comminication, March 18, 2013). All of these tools are helpful in the valuation of ecosystem services but may need to be tailored to help support the implementation of specific policies.

Conclusions

The federal family of agencies that protect, steward, and monitor the coast is moving rapidly to include more ecosystem services "thinking" in its policies. For example, a recent report by the President's Council of Advisors on Science and Technology (2011) provides clear guidance regarding steps federal agencies can take to improve the productivity and resilience of the nation's ecosystem services. Additionally, the newly formed National Ecosystem Services Partnership recently met at Resources for the Future in Washington, D.C. (May 8, 2012) to help the federal agencies move forward in the incorporation of ecosystem services into agency policy.

Coastal ecosystems provide a large number of ecosystem services, including the sequestration and storage of carbon that might otherwise enter the atmosphere. Recognition of "coastal carbon" as an important and valuable ecosystem service could influence the outcomes of federal statutes and policies that affect coastal ecosystems.

We find that

1. Existing regulatory and policy frameworks require and promote consideration of ecosystem services.
2. Federal agencies routinely consider a range of ecosystem services in policymaking and implementation, but in general there is little or no explicit consideration of coastal carbon services, or terrestrial carbon services, for that matter.
3. The carbon sequestration and storage services of coastal habitats could be incorporated into the implementation of existing federal policies without statutory changes; doing so would increase the degree to which these policies consider the full economic and ecological impacts of policy actions.
4. Key steps needed in order for coastal carbon to be included in federal policy implementation include:
   - Setting a precedent by including coastal carbon functions in an assessment by federal regulation (e.g., EIA),
   - Setting a precedent by including coastal carbon economic value in a formal cost-benefit analysis or other economic impact analysis required by federal statute or regulation (e.g., an NRDA or cost benefit analysis), and
   - A peer-reviewed protocol for quantifying existing and lost carbon functions as well as rigorous methods for estimating or monitoring carbon function in restored, protected, or mitigated coastal ecosystems
   - Availability of spatiotemporal data on the status and dynamics of mangroves, saltmarshes, and seagrasses

If federal agencies incorporate coastal carbon functions and values into policy decisions and implementations, this could:

- Increase the net economic benefits attributed to projects that protect or restore carbon habitats (and thus the likelihood that such projects will be approved or chosen),
- Influence how and where agencies decide to invest in coastal management, and
- Result in a more accurate assessment of fines or amount of habitat required for NRDA and wetland mitigation.

Coastal carbon is an important, and integrated, component of a larger suite of coastal ecosystem services provided by salt marsh-, sea grass-, and mangrove-dominated ecosystems. As a result, coastal carbon will ride the coattails of the increased attention to ecosystem services generally. Unlike many other ecosystem services that depend mostly on the condition and quality of the living component of the ecosystem, the value of coastal carbon lies mostly in the sediments that are held intact, and below the surface of the water. Healthy and resilient coastal ecosystems are essential to keeping this carbon in these sediments and out of the atmosphere. As a result, the inclusion of coastal carbon functions and values in federal policy implementation could lead to outcomes that might be significantly different from those that focus only on living biomass.

The degree to which coastal carbon values ultimately influence the outcome of the implementation of statutes and policies will depend on the discretion of the implementing agencies or pressure from their constituencies, including pressures brought to bear through litigation.

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