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Catching a wave? A case study on incorporating storm protection benefits into Habitat Equivalency Analysis

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ABSTRACT

Since Hurricane Sandy, there has been heightened attention to increasing the resilience of coastal communities to extreme events, including storm protection provided by coastal ecosystems. Storm protection benefits (SPB) are the ability of ecosystems, including wetlands, reefs, and beaches/dunes, to attenuate waves and storm surge. SPB are a topic of growing interest in the scientific and policy spheres, including discussions of how to incorporate SPB into existing policies. As an engine for restoration and a leading mechanism for the evaluation of ecosystem services, Natural Resource Damage Assessment (NRDA) provides a platform for better internalizing this and other services into decision-making particularly using Habitat Equivalency Analysis (HEA). HEA does not explicitly account for impacts to ecosystem services that flow from one habitat to an adjacent one. This study examines a hypothetical case study of an oil spill that impacts a marsh with resulting impacts on SPB to the adjacent upland forest. To more fully assess these impacts, a "nested HEA" was developed which accounts for cross-habitat ecosystem service flows. The nested HEA captures the impacts of the marsh loss on the forest due to wave and saltwater intrusion that would not be captured by a traditional HEA. By adapting the HEA approach with a nested HEA, NRDA could quantify direct ecosystem services losses as well as additional cross-service flows between habitats. However, additional data are needed in order to perform a nested HEA, and in the case of SPB, location-specific data likely will be needed to appropriately specify the model.

1. Introduction

In the wake of Hurricane Sandy, there is heightened interest in making coastal communities more resilient to extreme events and storm surge, with particular emphasis regarding the use of healthy coastal ecosystems to provide storm buffering services which can reduce the risk of erosion and flooding [1]. For example, a recent United States White House report entitled "Ecosystem-Service Assessment: Research Needs for Coastal Green Infrastructure", identified the need for more research on how natural ecosystems provide storm protection in order to better incorporate these benefits into policy and decision making [2].

At the same time, there has been increased attention to the broad importance of ecosystems to human health, well-being, and economic prosperity, including a U.S. White House Memorandum for Executive Departments and Agencies called "Incorporating Ecosystem Services into Federal Decision Making," released in October 2015 [3]. This memorandum directs agencies to incorporate ecosystem services into federal planning and decision-making, including potentially modifying some practices, policies, or existing regulations to address the evolving understanding of the value of ecosystem services, although it should be noted that the future implementation of this guidance is unclear with the change in administration.

When dealing with the impacts of oil and chemical spills, U.S. federal regulation already clearly incorporates ecosystem services. Under the Oil Pollution Act (OPA) of 1990, government entities, known as Trustees, act on behalf of the public to address the loss of natural resources or services that occurs when an incident like an oil spill harms ecosystems [4]. This process, called Natural Resource Damage Assessment (NRDA), also serves as a mechanism to restore many ecosystems that provide storm protection. As part of this process, a Habitat Equivalency Analysis (HEA) is often performed to determine the amount of restoration needed (see Section 2.4 for more HEA info).

However, scientific understanding of ecosystem services has expanded since OPA was passed, and society now more fully recognizes

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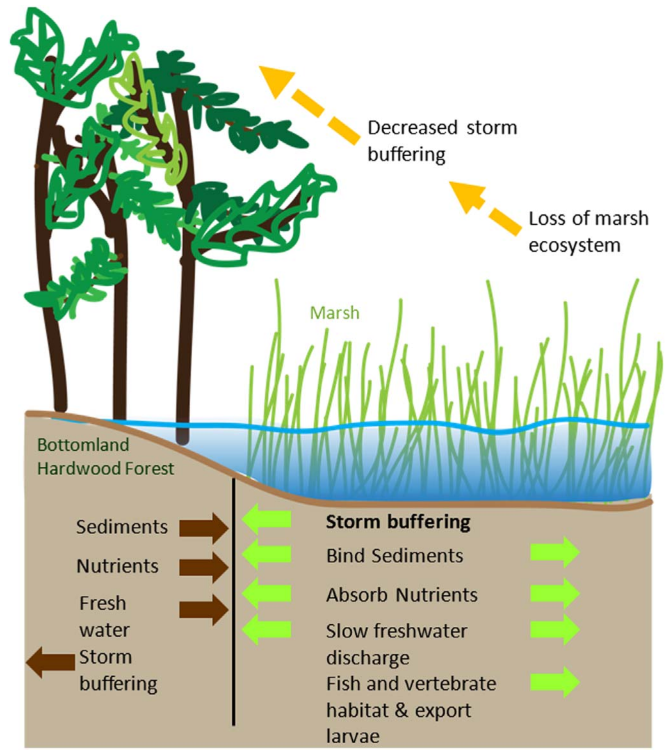

Fig. 1. Cross-ecosystem service flow examples for bottomland hardwood forest and marsh ecosystems. Arrows indicate ecosystem service flows or connectivity including storm buffering. Impacts to the storm buffering cross-service flow due to loss of marsh habitat are shown in dashed arrows and for the purposes of this case, these dashed lines representing storm buffering from the salt marsh are the only service we are quantifying. Of note, the loss of forest habitat explored here could have similar repercussions on habitats, or human communities, behind the forest. If the forest loss were significant enough, there could be impacts to habitats behind the forest that would then be impacted by flooding as well.

that ecosystems provide a broad range of quantifiable benefits. For example, coastal ecosystems provide many services including, but not limited to, carbon sequestration and storage [5], water quality improvement [6], and storm buffering [1,7–9]. These latter two are cross-habitat ecosystem services, meaning that the benefits provided by the primary habitat accrue to an adjacent one. For example, marshes provide storm buffering to adjacent forested habitats (see Fig. 1). There is also recent research which has found that there may be new, additional beneficial connections, particularly between coastal and marine habitats, than previously thought including reducing the risk of disease [10] or providing buffering from ocean acidification [11]. Scientists are coming to understand both how coastal ecosystems provide these services, as well as the value of these services [12,13].[3]

Two other newer concepts in ecosystem service research are worth noting. The first is the concept of understanding and mapping ecosystem service flows, meaning where services are provided and who benefits from those services [see, for example, [14]]) as well as how changes in land-use affect service flows [15]. A second concept that is somewhat germane to the discussion of cross-ecosystem service flows is that of ecosystem service bundling. Bundles are defined as sets of ecosystem services which repeatedly co-occur spatially or temporally [16] This co-occurrence within a bundle can be a positive or negative association, resulting in a synergy or tradeoff respectively [17]. It is important to note that bundles involve ecosystem service interactions, not simply inventories [16]. Bundling is very much of interest to communities looking to Payment for Ecosystem Services (PES) as an opportunity to generate revenue for conservation. Bundling can, for example, capitalize on the co-occcurrence of carbon and water services with biodiversity to provide more revenue for habitat conservation [see, for example, [18]].

Bundling ecosystem services can be advantageous for policymakers and scientists by allowing predictions of commonly co-occurring services in similar ecosystems and reducing transaction costs through management of a bundle as opposed to multiple individual services [19]. Additionally, there are research efforts to understand what kinds of synergies and trade-offs exist in terms of land-use management for cultural and regulating services versus provisioning services [16,20]. However, assessing bundles in a manner useful for managers is currently still a challenge and difficult to implement. Nevertheless, additional information regarding the spatial and temporal co-occurrence of other coastal ecosystem services alongside the service of SPB could provide further information allowing the execution of nested HEAs. As understanding of ecosystem services grows, the current practice for scaling natural resource injury (the legal term that describes all the harm done) may not accurately (or potentially adequately) compensate the American public.

This study examines storm protection benefits (SPB) provided by coastal habitats and present a model, called a "nested HEA," which explicitly accounts for this cross-habitat ecosystem service flow. However, it is important to note that this model could be modified to work for other cross-habitat ecosystem services as well. Using SPB as an example, this "nested HEA" model builds on the traditional HEA to incorporate the growing scientific understanding of ecosystem services including how to model and incorporate cross-habitat ecosystem service flows.

2. Background

2.1. Ecosystem services: storm protection

Over the past two decades, scientific understanding of how ecosystems provide many services and the societal value of these services has grown. The storm buffering ability of ecosystems is a somewhat recently recognized service. Multiple studies have determined that coastal ecosystems can decrease the velocity and height of waves, and in some cases, storm surge [see, for example, [12,21–25]]. This wave attenuation capacity reduces the risk of erosion and flooding, and can provide protection from both high-energy storms and the erosion caused by high-frequency wave events [22,26].

In discussions about SPB, healthy coastal ecosystems are often referred to as "natural infrastructure" and approaches that combine natural features with some built or engineered features are called "hybrid infrastructure." These approaches contrast with "gray" or "built" infrastructure, which refers to the traditional approaches of coastal protection such as seawalls and dikes [1]. Although wetlands are often the most-discussed ecosystems in terms of SPB, mangroves [27], coral reefs [22], oyster reefs [28], and sandy systems such as beaches and dunes [9], all provide critical SPB.

Some benefits of using healthy coastal ecosystems as natural infrastructure to provide SPB are that ecosystems can be self-maintaining and self-repairing after storms, and can keep pace with sea-level rise [1,28]. In addition, they provide a number of co-benefits, such as water quality improvements and recreational opportunities that gray infrastructure cannot provide. One caution about natural infrastructure, however, is that there is more variability in the SPB provided due to many factors including ecosystem structure as well as storm characteristics and local tides, bathymetry, and topography [see 1 and references therein]. Thus, one of the challenges of quantifying and predicting SPB from natural ecosystems is that these benefits are localized, complex, and more variable compared to the benefits provided by gray

[3] It is worth noting that correct identification of ecosystem services presents other practical challenges in NRDA. Injuries must be scaled to avoid double counting, quantification must be limited to the injury caused by the incident and not other stressors on the ecosystem, changing baseline conditions over time must be addressed, and fundamentally, sufficient restoration options must exist to compensate for the injury.