

Conceptual Model Series

Ecosystem Services Conceptual Model Application

Testing General Model Adaptability

Sara Mason and Lydia Olander

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Review

The work in this case study was conducted in collaboration with federal agency partners, but it has not undergone a formal review process.

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SUMMARY

This case study, a companion to “Ecosystem Services Conceptual Model Application: NOAA and NERRS Salt Marsh Habitat Restoration,” summarizes initial efforts to apply a general salt marsh ecosystem services conceptual model to specific sites.

We have proposed that developing a set of reference ecosystem services conceptual models for a constrained set of common management interventions would increase the efficiency and consistency of incorporation of ecosystem services in decision-making contexts.

This case study discusses efforts to test whether a generalized model can be adapted to specific sites. It describes three cases: a retrospective case, a prospective case, and a quantitative case. Integrated in these studies is a discussion of the considerations that arise and revisions that should be made to a general model applied to a particular site.



INTRODUCTION

Ecosystem service conceptual models (ESCMs) illustrate the way that a management intervention cascades through an ecological system to change ecosystem service and other human welfare impacts.¹ We proposed that developing a reference set of general ESCMs could provide a way to increase standardization, efficiency, and consistency in the way that ecosystem services are incorporated into management decisions (Olander et al. 2016; Olander et al. 2018). The reference set of models would consist of general ESCMs, which users could adapt to their sites, creating a specified ESCM (see sidebar). When adapting and specifying a general model, users extract elements of a general model that apply to their particular site, and they can add detail to the model when site-specific information provides necessary nuance (Figure 1).

Given a constrained set of ways in which managers manipulate the natural environment and a fixed number of effects such management can have on the environment and people, it appears possible to establish a reference set of evidence-based conceptual models that become a go-to resource, thereby providing desired efficiency and consistency in application (Olander et al. 2016). For example, typical national forest plans include goals such as fire risk reduction, wildlife support, timber productions, drinking water provision, healthy forest systems, and increased recreational opportunities. Each of these goals tends to have a related and often overlapping set of management activities; for example, healthy forest management may focus on invasive species and pest management, which can overlap with fire risk reduction and timber production activities. As a result, a fixed set of related conceptual models can potentially cover the most common management needs for national forest planning (Olander et al. 2016).

General models can help increase consistency in ecosystem service integration for a particular management context (e.g., managing forests to reduce fire risk, restoring salt marshes, installing solar farms) by providing a common set of services for consideration and a common set of indicators for monitoring. ESCMs can increase efficiency by reducing both duplication of effort (i.e., models don't need to be built from scratch) and required ecosystem service expertise. A general model provides a useful framework from which managers and stakeholders can develop a specified model that will be comparable to other ESCMs while still representing their unique decision context. If general models are accompanied by evidence libraries—compilations of evidence summaries and assessments of the strength of evidence for each link in a model (e.g., Mason et al. 2018; Warnell et al. 2018)—model users will begin development of specified models with a review of the relevant literature that supports each model linkage.

Our proposal that general models can be adapted and specified to represent site-specific contexts is tested here. We worked with the National Estuarine Research Reserve System (NERRS) to test our hypothesis that general ESCMs could be developed for habitats commonly found at NERR sites (e.g., salt marshes, mangroves, sea grasses, oyster reefs, coral reefs) then specified at local sites across the network on the basis of NERRS' needs.

General and Specified Conceptual Models

General conceptual models are designed to be the parent model for a type of intervention that can be adapted to different contexts of application. In addition to helping stakeholders and experts get on the same page, these general models are particularly useful as a foundation for consistency in application/implementation, providing a common starting place and often a key set of services and indicators to include in decision making. They also provide a user-friendly starting point for those not knowledgeable about ecosystem services and can increase efficiency of implementation. Accessible general conceptual models can ensure teams have access to the best available science and can reduce duplication of effort.

Specified conceptual models are adapted and specified for a particular place and decision context. These models are more likely to follow best practices and include measurable indicators. Adapting a general model to a local context should require less time and effort than developing a model from scratch, and it requires less expertise in ecosystem services. Specified conceptual models can be the foundation for further assessment of evidence for a particular site or context, construction of a predictive model, or monetary or non-monetary valuation.

—Adapted from Olander et al. (2018)

¹ Some of this section has been adapted from Olander et al. (2018) and Mason et al. (2018).

Figure 1. Illustration of how a general model might be adapted for different NERR sites, with each site only using the parts of the model relevant to its individual context



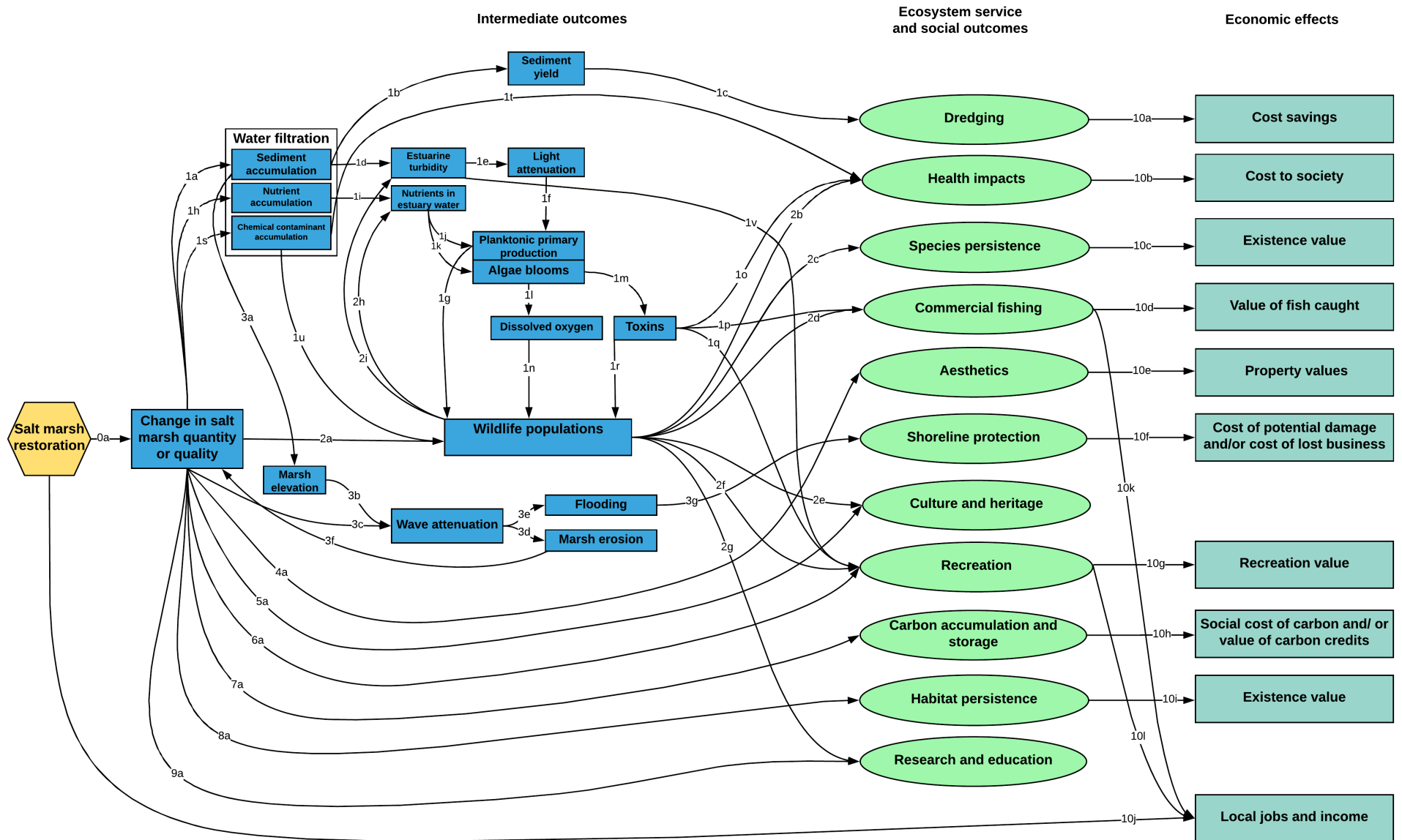
Source: The map is from <https://coast.noaa.gov/nerrs/>.

The test model explored here focuses on salt marshes and starts with the generalized management intervention of salt marsh restoration, leading to a change in salt marsh quantity or quality (Figure 2). See Mason et al. (2018) for a detailed description of how the model was created.

Endpoints for ESCMs are the social or economic (welfare) changes linked to changes in the provision of ecosystem services. These endpoints can be measured using benefit-relevant indicators (BRIs)—indicators that reflect changes in ecological condition that are relevant to people (NESP 2016; Olander et al. 2018b). Although the endpoints listed in the general ESCM here are not BRIs (green ovals in Figure 2), they represent categories of services or benefits that could be specified to BRIs that are relevant to a particular site. If economic effects of ecosystem services are important, the model can be extended to include economic or monetary indicators (teal boxes in Figure 2).

We applied the salt marsh general model in three pilot test cases. First, a retrospective case in Great Bay New Hampshire applies the model to a previous ecosystem services assessment, testing whether the model aligns with one example of ecosystem services considerations already made by a NERR site. The second prospective case, in San Francisco Bay, tests whether a group of stakeholders could satisfactorily adapt the general model to represent their system. The third case extends the San Francisco example and tests whether a specified ESCM can be used as a framework for a Bayesian ecosystem services predictive model.

Figure 2. Generalized salt marsh ecosystem service conceptual model



ESCM TEST CASE APPLICATIONS

Retrospective Case: Great Bay, New Hampshire

Case Description

The Great Bay NERR site is on the Great Bay Estuary in southern New Hampshire. The estuary contains salt marsh, eelgrass beds, mudflats, and rocky intertidal zones (State of New Hampshire 2011). Great Bay faces development pressures related to population growth, marine transportation, boat moorings, invasive species, eutrophication, and climate change (NOAA OCM et al. 2016). Local management goals created in 2010 aimed to mitigate these threats and protect habitat, and investments were made in salt marsh, eelgrass, and oyster habitat restorations (NOAA OCM et al 2016).

In 2013, local conservation partners decided to complete a Great Bay ecosystem services assessment (GBESA) to more fully understand the benefits that people are receiving from the Great Bay Estuary and to help inform decision making that would affect Great Bay natural resources (NOAA OCM et al. 2016). The assessment was designed to assess future ecosystem scenarios, test an ecosystem services valuation approach, and identify opportunities to improve management and maximize ecosystem services (NOAA OCM et al. 2016).

General ESCM Application

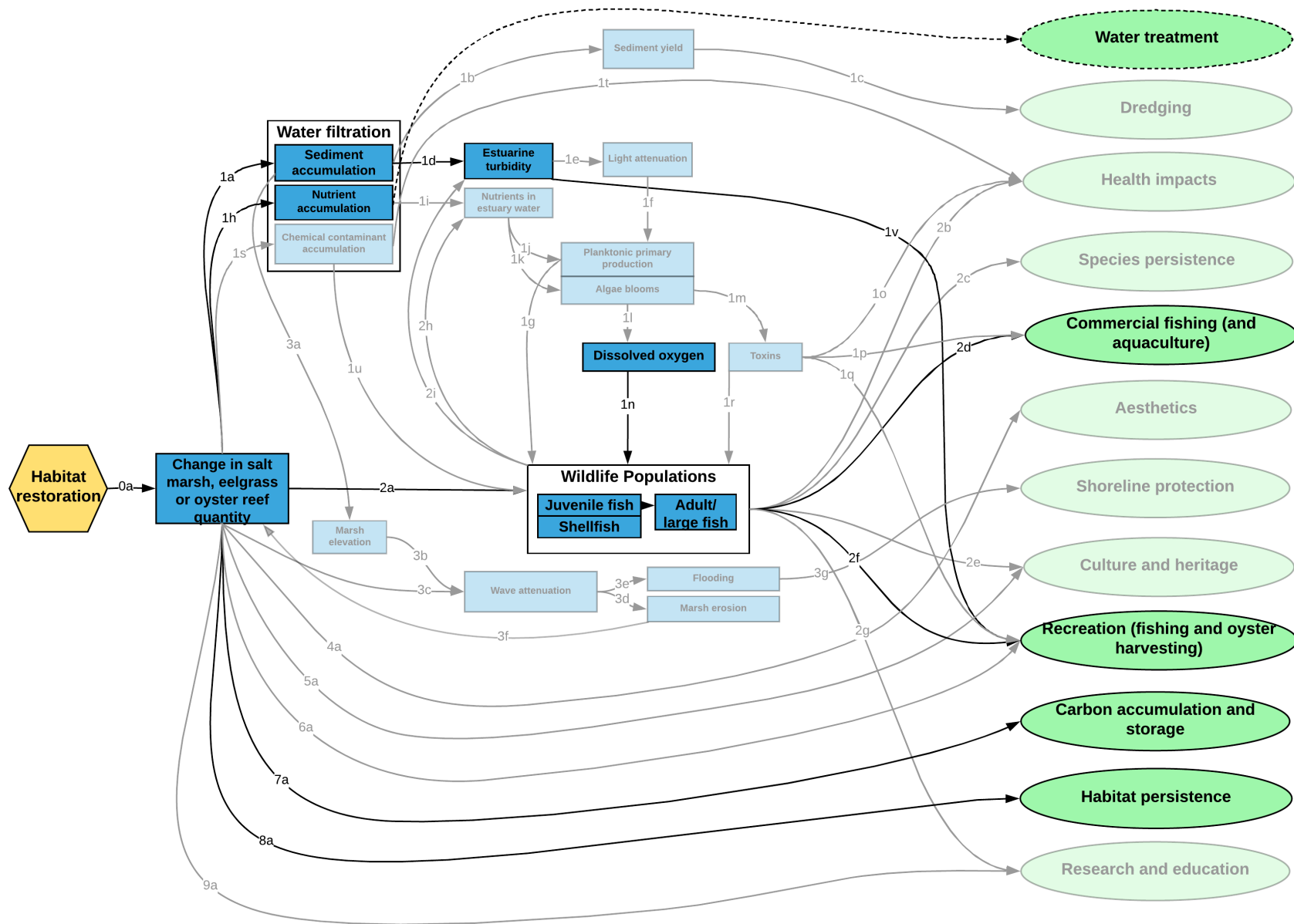
The GBESA provided a unique opportunity to test the generalized salt marsh ESCM on a project that had already been completed. It allowed us to assess whether the general model could be adapted to a local site, and whether the model would match up with the kind of assessments in which a NERR was already engaged.

After reading the GBESA and extracting the methodology used to quantify each ecosystem service, we were able to align the GBESA methodology with our generalized model and indicate which parts of the model were included in the assessment. We found that the linkages included in the generalized model did align with the GBESA; however, the GBESA did not assess all of the services included in the generalized model (and added one service, water treatment). Wildlife populations considered in the GBESA were specified in this version of the model. We had to alter the original intervention (change in salt marsh quantity or quality) to match the scenarios that the GBESA had analyzed. The adapted intervention had to encompass changes in salt marsh, eel grass, and oyster reef habitat areas. Figure 3 shows the generalized ESCM as a faded base model, with only linkages and services included in the GBESA highlighted in bold color. The additional linkage and service are shown with dashed lines to show how the GBESA aligns with the original model. Notably, the general salt marsh model framework still applied despite the need to encompass other habitat types, suggesting tsignificant overlap in the models for different ecosystems. We would like to explore this finding in future applications.

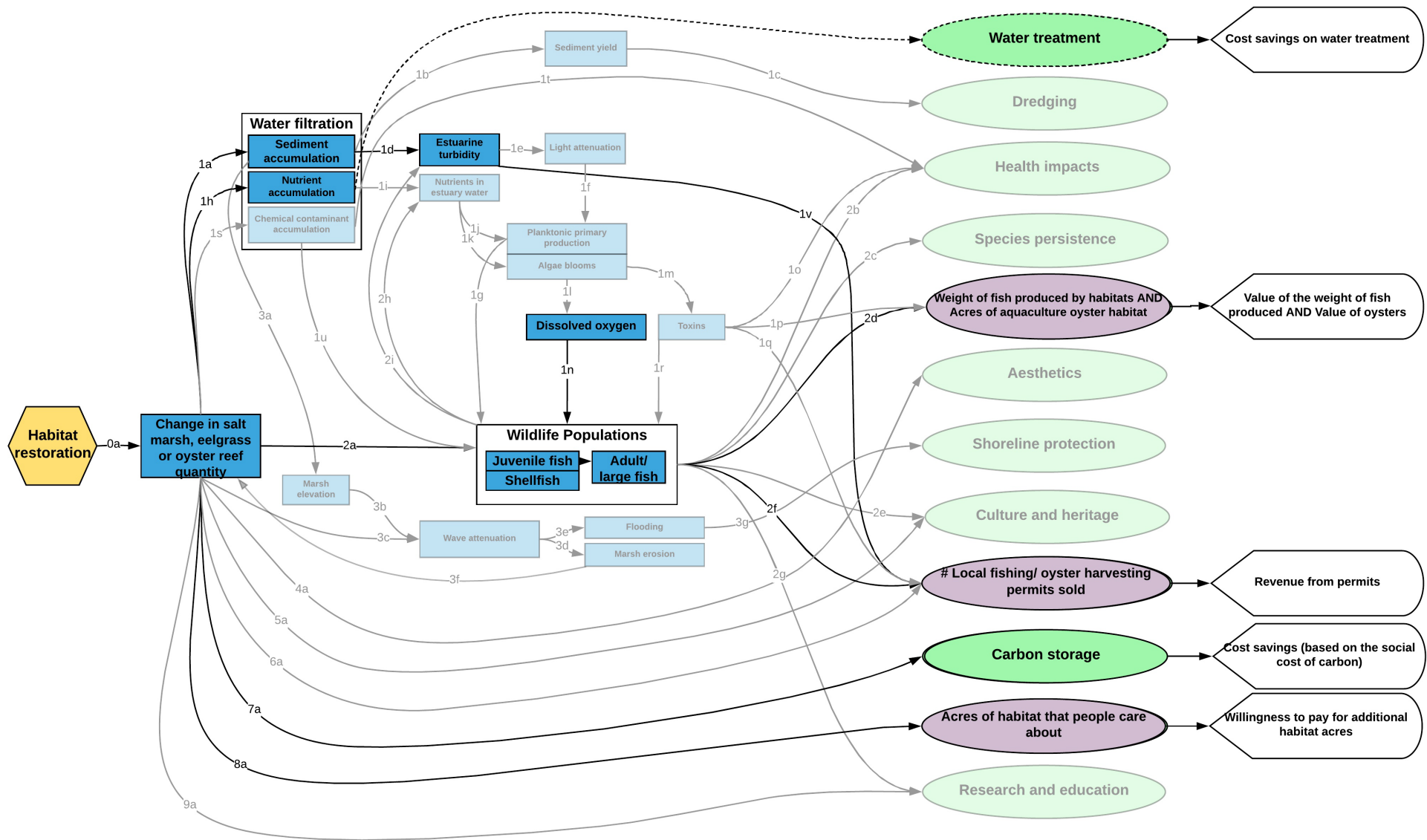
We were able to align the unique indicators used by the GBESA, including the economic valuation measures used to quantify each service in Great Bay, with the endpoints in the general ESCM (Figure 3b). The BRIs are shown in purple; economic valuation measures are shown in white.

Figure 3. Generalized ESCM highlighting (a) linkages and services and (b) benefit-relevant indicators and economic values included in the GBESA

(a) Adapted salt marsh ESCM, highlighting linkages and services assessed in the GBESA



(b) Adapted salt marsh ESCM, highlighting benefit-relevant indicators (purple) and economic values (white) included in the GBESA



Note: This figure shows the generalized ESCM as a faded base model highlighting only linkages and services included in the GBESA. The new linkage and service added to the generalized model are shown with dashed lines. In the model shown in (b), benefit-relevant indicators (purple) and economic values (white) have been added.

Prospective Case: San Francisco Bay, California

Case Description

The San Francisco NERR sites are tidal marsh habitats (SF Bay NERR 2012). This reserve collaborates with many environmental organizations and research institutions in the Bay Area to promote stewardship of and research on coastal sites within the San Francisco Bay. Marsh restoration in the Bay Area is considered an important way to increase resiliency along the coast, and a regional agency, the San Francisco Bay Restoration Authority, was specifically designed to allocate resources to tidal marsh restoration projects (SFBRA n.d.).

One such restoration is the McInnis Marsh Restoration Project, supported by Marin County Parks, the California State Coastal Conservancy, and the Marin County Flood Control and Water Conservation District. The proposed marsh restoration site lies adjacent to the Romburg Tiburon Center, the research center associated with the San Francisco NERR sites. The proposed restoration is a 180-acre area of diked historic wetlands (Figure 4). Restoration of the marsh would include removing existing dikes and levees as well as restoring historic flow to the area from nearby Gallinas and Miller creeks (Kamman et al. 2016). Our collaborators at the San Francisco NERR put us in contact with some of the partners associated with the McInnis Marsh restoration, and we were able to use this proposed restoration as a prospective case study to further test the adaptability of the generalized salt marsh ESCM to specific sites and contexts.

Figure 4. Proposed site of the McInnis Marsh restoration



Source: Kamman Hydrology 2016 (Google Earth Image)

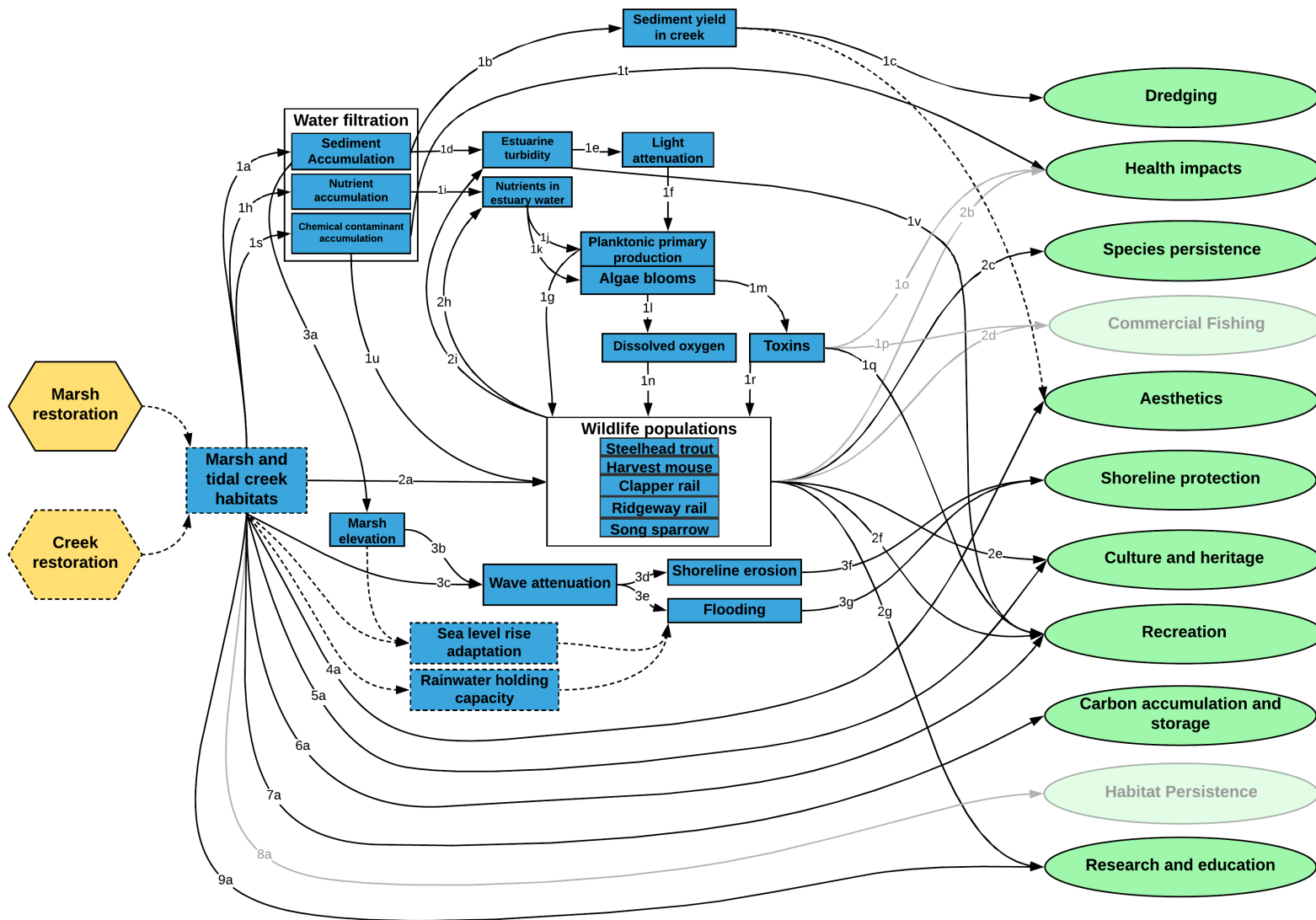
General ESCM Application

We gathered a group of relevant stakeholders from the San Francisco area to help adapt the generalized ESCM to the San Francisco Bay/McInnis Marsh context. These stakeholders included natural resource specialists from local government, members of local environmental organizations, local environmental consultants, academics, and employees of the San Francisco NERR. Stakeholders were familiar with or directly involved with the McInnis restoration project. After an introduction to the conceptual model project, the stakeholder group was asked for feedback on

- Significant missing or incorrect nodes, linkages, or both
- Specification of services for development of indicators
- Ecosystem services that are most important for the area.

To make the generalized ESCM more applicable in the San Francisco context, stakeholders requested the addition of several nodes and links, including the link between sediment accumulation in Gallinas Creek and aesthetic value and new nodes for sea-level rise adaptation and rainwater holding capacity. Figure 5 displays those additional nodes and links with dashed outlines. We found that the generalized model worked as a good starting point and that with slight alterations and additions the model could be adapted to represent a conceptual diagram that San Francisco stakeholders felt characterized their system.

Figure 5. San Francisco/McInnis Marsh version of the salt marsh ESCM



Note: Solid outlines and arrows represent the generalized model, and dashed outlines and arrows represent additions made to the generalized model to adapt it to the San Francisco context. Linkages or services deemed unimportant in the San Francisco context are faded out.

Stakeholders provided feedback regarding specification of indicators through a set of questions shared with the expert stakeholder group. The ecosystem service/social outcome endpoints in the generalized salt marsh model are ecosystem service categories, and when the general model is specified for a local context, those categories must be broken down into specific services that are relevant in a particular system. The stakeholder group was given background about each service category in the general model and asked a series of questions to elicit local specificity (Table 1).

Table 1. Service categories specified in the San Francisco case study

Ecosystem service/social outcome category	Details and questions
Health impacts (water quality)	Health impacts could include illness from exposure to contaminated water by swimming or drinking. <i>Is this exposure important or relevant in San Francisco? Which contaminants should we focus on? Which contaminants introduce the greatest health risks? Are San Francisco populations more vulnerable to certain contaminant risks because of other prevalent health conditions?</i>
Health impacts (dietary)	Health impacts could include dietary changes based on changing fish/shellfish populations and availability. <i>Are these changes relevant for certain populations in the San Francisco Bay? Which groups of people rely on fish/shellfish from the San Francisco Bay? What portion of their protein or micronutrient needs are met by local fish/shellfish? Do San Francisco residents depending on wild local fish/shellfish have access to dietary alternatives with similar nutritional qualities?</i>
Existence	Existence value represents the value that people place on the existence of elements of the ecosystem. These elements can include the marsh or specific species that use the marsh as habitat. Often endangered, threatened, or charismatic species have high existence value. <i>Which species should we be considering? Are there groups of people who value the marsh for its existence? Which population's existence values do we care about capturing (local San Francisco Bay residents, U.S. residents, global residents)? Which species are valued by those focal populations? Which marsh characteristics are most valued?</i>
Commercial fishing	Commercial fishing represents the amount (or value) of fish/shellfish extracted from San Francisco Bay. <i>Which commercially harvested species (if any) are most important? Which commercially harvested species are economically important to Bay Area fishers? Which commercially harvested species are culturally important to Bay Area fishers? Which commercial stocks are most likely to be affected by possible interventions?</i>
Aesthetics	Aesthetic value represents the value that people place on the beauty or scenery provided by the marsh, stream, or both. <i>What scenic elements of these marshes do people value most? Do different groups of people value different scenic elements? Do property values reflect marsh or stream aesthetics in the area?</i>
Culture and heritage	Cultural value represents any value provided by the marsh, stream, or both that is an element of culture. This element could include an historic site, a species with specific cultural meaning, or a site with religious/spiritual importance. <i>Are there any cultural sites or species of note in the Gallinas Creek watershed that would be relevant? Are important cultural sites or species different for different populations?</i>

continued

Ecosystem service/social outcome category	Details and questions
Recreation	We have included birding, boating, hiking, biking, swimming, and fishing as important recreational activities in this area. Are there recreational activities that should be added or removed from this list? <i>Are there certain activities that are of particular importance to certain populations?</i>
Shoreline protection	Shoreline protection can include maintenance of the coastline, protection of coastal properties and infrastructure, and protection of coastal habitats. Are there other local shoreline protection concerns of which we should be aware? <i>How often does flooding normally occur and what type of flooding normally occurs in Marin County? Are there major erosion problems in the area? What important coastline features (natural or manmade) are most at risk to flooding?</i>

Note: Context about each service was given (black text in the “Details” column), and the stakeholder group was then asked a question about that service (blue text in the “Details” column) to elicit specificity about that service locally. Additional questions for prompting service specificity are shown in italics—though these questions were not used during the McInnis Marsh stakeholder workshop, they may be useful for consideration when planning a stakeholder elicitation.

Stakeholder feedback regarding the most important ecosystem services for McInnis Marsh was assessed during the online workshop and with a follow-up email survey. The survey specified different aspects of each service category and asked stakeholders to rate whether that service aspect was of high or low importance as well as whether they felt that service was unique for their context (see Table 2 and Appendix B). The survey revealed that two service categories (habitat persistence and commercial fishing) from the general model were unimportant at this location, and they were faded from the San Francisco version of the model (Figure 5).

Table 2. Excerpt from the stakeholder online survey

Service category	Specific services	Ranking		
Shoreline protection		High	Low	Unique
	Coastal erosion protection			
	Reduced loss of property			
	Reduced property damage			
	Reduced Infrastructure damage			
	Reduced habitat loss			
Existence value		High	Low	Unique
	California clapper rail			
	California black rail			
	Salt marsh harvest mouse			
	Longfin smelt			
	Steelhead trout			

Note: Stakeholders were asked to rate the importance of different aspects of each service category. The survey shows the aspect breakdown of the shoreline protection and existence value service categories. The full survey included rankings for all service categories represented in the ESCM diagram (see Appendix B). High = important to quantify; Low = don’t need to quantify (not very relevant in this case/ location); Unique = services unique to this watershed that are important to emphasize.

Quantitative Case

Adapting the Model for Quantification

Quantitative models can be used to bound the range of costs and benefits for alternative interventions and can be useful decision-support tools. We were therefore also interested in testing whether ESCMs could form a basis for scalable and transferable quantitative ecosystem service models. We built an experimental Bayesian network model based on the ESCM adapted to the McInnis Marsh context to create an example predictive model for the marsh restoration project. The ecosystem service ranking survey (Table 2 and Appendix B) completed by the stakeholder group helped to identify focal ecosystem services, whereas the specification questions (Table 1) guided the selection of metrics for quantification.

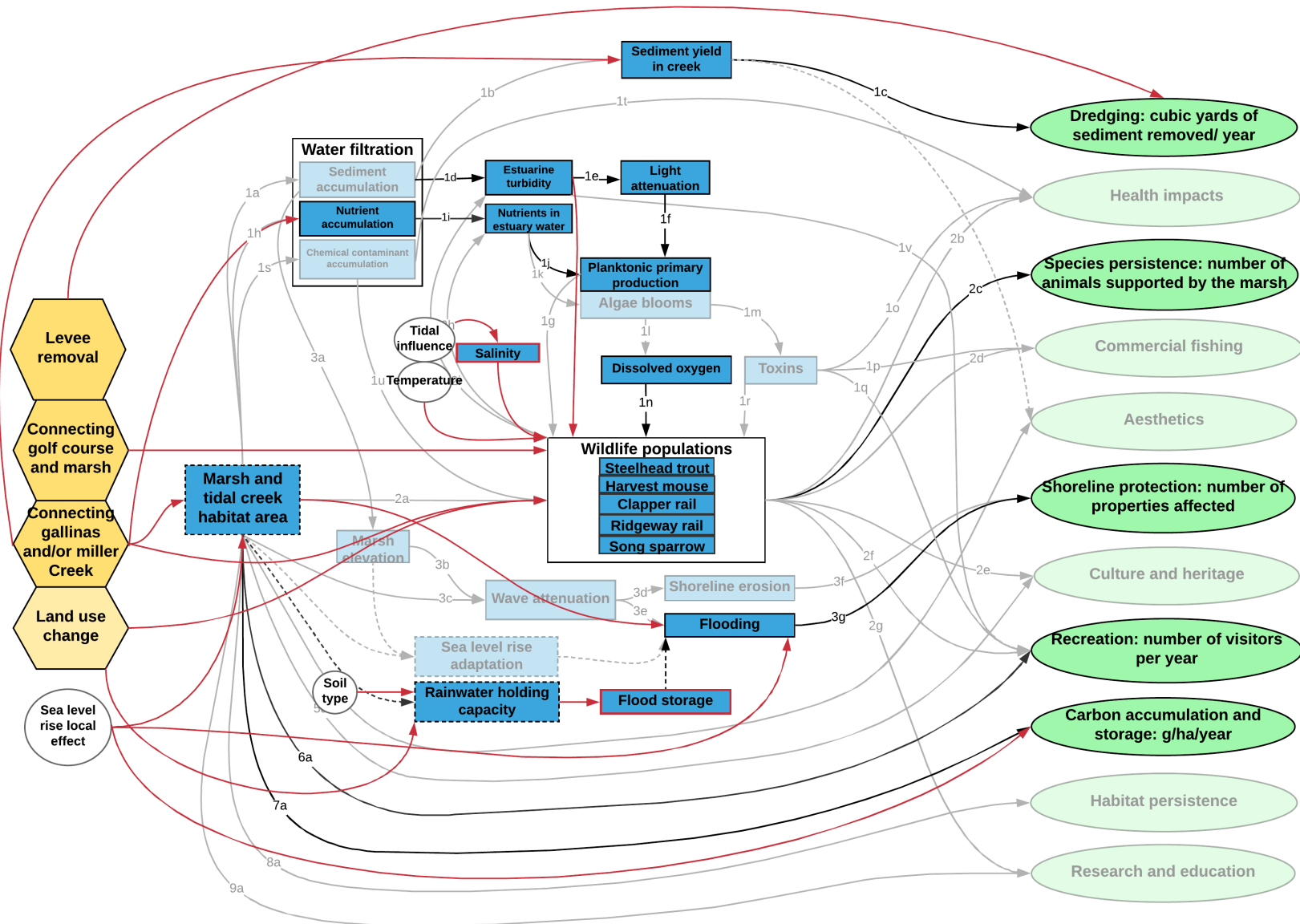
We developed a Bayesian network model using the framework of the San Francisco ESCM. For this test, only a partial model was built with a few of the highly ranked and data-rich services modeled (linkages/services included in this initial model are in the non-faded elements in Figure 6). The general structure of the Bayesian network model remained true to the ESCM; however, alterations were made (Figure 6). This model is still under development; therefore, the model image shown here may not reflect the final Bayesian model developed to represent ecosystem services at McInnis Marsh. A publication presenting the final model is forthcoming (Shi et al. forthcoming).

To adequately model the restoration of McInnis Marsh, the original interventions (salt marsh restoration and creek restoration) had to be specified further to unique restoration options (seen in the yellow hexagons in Figure 7). Each individual intervention can be turned “on” or “off” in the Bayesian model so that the effects of different restoration alternatives can be compared. When the Bayesian model was developed, certain linkages had to be added or altered to reflect local data, mathematical relationships between variables, or specificity based on the unique restoration interventions. New/altered linkages are shown in red (Figure 6). Variables important in a predictive model, such as sea-level rise, that are not directly affected by marsh or creek restoration (and therefore were not included in the original ESCM), are added to the quantitative model diagram in white circles (Figure 6).

Outputs of the partial Bayesian network model include estimates for each modeled service (dredging, species persistence, carbon storage, and shoreline protection). These estimates represent probability distributions of a certain ecosystem service outcome, which are available for different combinations of restoration interventions.

A separate evidence library was created for the quantitative model. It details the data and evidence available for quantifying the relationships in the McInnis Marsh context. Excerpts of that evidence library can be found in Appendix C to provide an example of the site-specific evidence necessary for modeling.

Figure 6. Visual representation of the Bayesian network model developed from the McInnis Marsh version of the salt marsh ESCM



Note: Linkages that were added or altered from the McInnis Marsh conceptual model are shown in red. Model endpoints include the indicator that was modeled.

CONCLUSION

We think ecosystem services conceptual models can be an effective implementation tool for incorporating ecosystem services into decision making. As we explored here, general conceptual models can be adapted and applied to site-specific uses, providing a jumping-off point that reduces duplication of effort and helps standardize how ecosystem services are considered. Though further exploration is needed, the test cases indicate that the development of a set of reference ESCMs for common management interventions and management contexts is possible and that the models in the library could be valuable tools for increasing efficiency and consistency for the consideration of ecosystem services in decision making.

APPENDIX A: ECOSYSTEM SERVICE INDICATORS

When ESCMs are developed for a specific site, it is important to identify endpoint indicators relevant to the local context. Choosing relevant indicators is key for developing socio-economic monitoring programs, but the feasibility of gathering data is also a primary consideration. Notably, some metrics are monetary values, whereas others are not. The context of the project will determine whether monetary metrics are needed or whether non-monetary metrics are sufficient. Table A.1 displays a collection of ecosystem service-related metrics gathered from conversations with NOAA and from an Abt report on socio-economic indicators (Abt Associates 2015). These metrics do not represent the only metrics available for the services related to coastal systems, but they can be a starting point when developing metrics for a specified ESCM.

Table A.1. Ecosystem service-related metrics

Service/social benefit	Potential indicator(s)* (\$ symbol = monetary measure)
Water treatment costs	Avoided costs of navigational waterways dredging (32) (\$) Avoided costs of wastewater treatment (\$)
Health impacts	Reduction in number of households exposed to waterborne disease with the project in place (27) Reduction in number of households exposed to toxic pollutant with the project in place (27) Increase in number of households with improved access to seafood (27)
Existence	Willingness to pay for a certain species or habitat type (\$) Books, art, or literature related to a specific charismatic species or habitat
Commercial fishing	Area of aquaculture leased bottom in the project's vicinity (32) Number of commercial fishing/shellfishing permit holders affected by project (32) Increases in commercial fishing/shellfishing revenues (32) (\$) Avoided number of days of shellfish bed closures (acres/ days) (32) Increases in commercial species harvest (32) NOAA commercial fishery dependence measures**
Aesthetics	Changes in property values associated with increased aesthetics (\$) Number of photos tagged at the project site
Culture and heritage	Number of cultural or heritage properties benefitting from the project (30) Reduction in number of cultural or heritage properties exposed to flood events with the project in place (29)
Carbon storage	Carbon sequestration rate by habitat Social cost of carbon (\$) Market value of carbon credits (blue carbon) (\$)

continued

Service/social benefit	Potential indicator(s)* (\$ symbol = monetary measure)
Shoreline protection	Number of households potentially affected by flood events by a project (27) Reduction in number of households exposed to flood events or nuisance flooding with the project in place (27) Reduction in number of properties exposed to flood events with the project in place (29) Reduction in percent of total residential and commercial value of property expected to be damaged in floods with the project in place (29) Property value of residential and commercial properties exposed to flood events with and without the project (29) (\$) Reduction in flood insurance premiums or change in the Community Rating System (CRS) rating of the National Flood Insurance Program as a result of the project (29) (\$) Tax base increase attributed to residential and commercial properties exposed to a flood event with project in place (29) (\$) Reduction in expected damages to properties from floods with the project in place (29) (\$) Reduction in miles of transportation infrastructure exposed to a flood event—leading to decreased accessibility—with the project in place (29) Reduction in number of users potentially affected due to exposed transportation infrastructure (29) Avoided repair/replacement cost to transportation infrastructure (29) (\$) Avoided days of closure of transportation infrastructure (29) Avoided losses from closures or delays of transportation infrastructure (29) (\$) Changes in commuting time due to flooding impacts on roads/bridges Reduction in number of critical service and utility facilities exposed to a flood event with the project in place (29) Reduction in number of users or customers potentially affected due to disruption of critical services or utilities (29) Avoided days of closure or disruption of critical services or utilities (29) Avoided losses from closures or delays of critical services (29) (\$) Increase in property value of residential and commercial properties due to project (30) (\$) Number of residential, commercial, cultural, or heritage properties benefitting from reduced beach erosion, increased beach width, or restored dunes (30) Increase in property value of residential and commercial properties from reduced beach erosion, increased beach width, or restored dunes (30) (\$) Avoided costs of beach renourishment (32) (\$)
Research and education	Increase in number of repeat volunteers at events (34) Increase in number of households participating in public planning sessions or project-run events (34) Increase in number of households making changes to their own property due to visible benefits from project (34) Increase in number of communities and other institutions accessing project products or tools (35) Provision of technical assistance/training to communities or stakeholders as part of the project (35) Increase in number of tailored or gap-filling plans, datasets, maps, or models for specific communities due to the project (35) Creation of science or other tools that can be used by other organizations and leveraged for research goals (35) Use of science or tools by other organizations or stakeholders (35) Number of educational, outreach, and volunteer events held by the project (36) Number of sites with enhanced educational programs (36) Number of researchers, volunteers, and students engaged at the site or with the project (36) Number of community groups involved in the project (36) Increase in number of schools with access to natural resources (36)

*Indicators from DOI report contain a page number from the report.

** For more detail, see Jepson and Colburn (2013).

Sources

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APPENDIX B: RANKING ECOSYSTEM SERVICES

An electronic survey was sent to the McInnis Marsh stakeholder group to gauge the relative importance of different ecosystem services in the San Francisco context. Because the Bayesian model described in this publication was an experiment, we did not have the resources to develop a model that incorporated every service. Therefore, the most important services were identified and included in this version of the quantitative model; the hope is that further testing will expand the model to include more of the services. The survey structure can be seen in Table B.1.

Table B.1. Survey structure

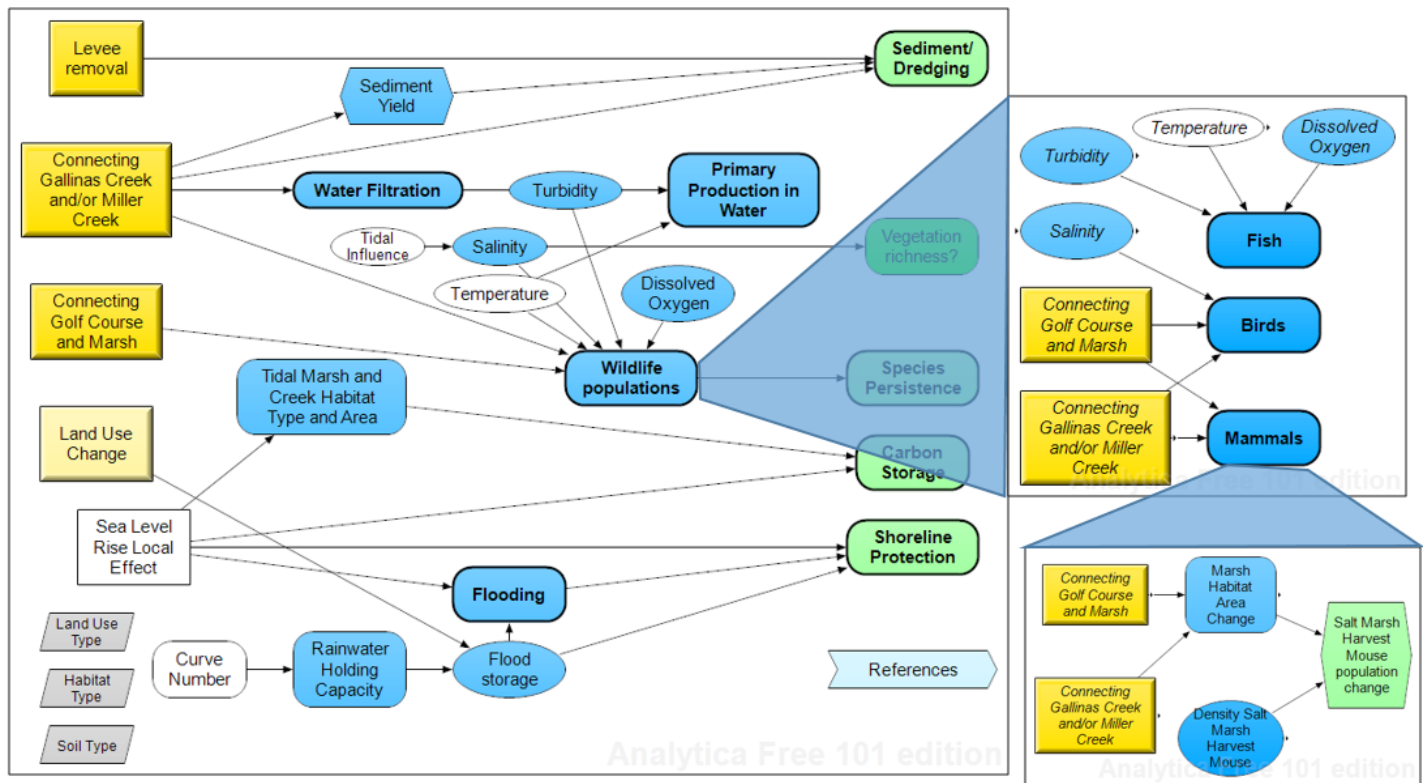
Service category	Specific services	Ranking		
Dredging		High	Low	Unique
	Cost savings from dredging			
Health (water quality)		High	Low	Unique
	Health impacts from reduced water quality exposure through swimming			
	Health impacts from reduced water quality exposure through drinking			
Health (diet)		High	Low	Unique
	Health impacts from reduced availability of certain fish/shellfish species			
Existence value		High	Low	Unique
	California Clapper Rail			
	California Black Rail			
	Salt marsh harvest mouse			
	Longfin smelt			
	Steelhead trout			
	Salmon			
	Otters			
	Migrating waterfowl			
	Migrating shorebirds			
	Migrating songbirds			
	Tidal marsh song sparrow (indicator species)			
	Biodiversity (overall)			
Education and research		High	Low	Unique
	Research performed			
	Educational experiences provided			
Aesthetics		High	Low	Unique
	Marsh landscape			
	Aesthetic value of marsh restoration vs. gray infrastructure			

continued

Service category	Specific services	Ranking		
Culture and heritage	Marsh ecosystem value to Coastal Miwok Tribe	High	Low	Unique
Recreation	Birding Kayaking Hiking Biking Dog walking Duck hunting Airport (recreational flying)	High	Low	Unique
Carbon	Carbon sequestered by the marsh	High	Low	Unique
Shoreline protection	Coastal erosion protection Reduced loss of property Reduced property damage Reduced Infrastructure damage Reduced habitat loss	High	Low	Unique

Note: High = important to quantify; Low = don't need to quantify (not very relevant in this case/ location); Unique = services unique to this watershed that are important to emphasize.

(b) With examples of sub-models



Note: Additional sub-models for other nodes in the diagram exist beyond the ones shown in this figure.

Evidence Library

An evidence library, somewhat similar to the one for the general model, was built for the Bayesian Network Model (see Mason et al. 2018 for the general model evidence library). The entire library is not provided, but excerpts are shown below to provide insight into the type of evidence needed for a localized, quantitative ecosystem services model.

This evidence library differs in some regards from the one presented in Mason et al. (2018) for the general model. The evidence library excerpt here often combines evidence for multiple links into one entry. This strategy reflects the interconnectedness of much of the data used to populate the model and the desire to facilitate discussion of all data “feeding into” a certain node in one entry. Because the evidence assessment could not be performed in the same manner as the one performed for the generalized model, due to the need to combine multiple links in one evidence entry, a statement describing the applicability and utility of the evidence is provided, but no grade is given. However, because we hope to test the transferability of this model, an evaluation of the transferability of the evidence is indicated in the strength of evidence statement.

Link: Connecting Gallinas Creek and/or Miller Creek → Sediment Yield

Assumed Relationship

We have the average annual sediment load data for Gallinas Creek. If we add breaches to Gallinas Creek and Miller Creek or if we add breaches to Miller Creek, there will be more sediment loading from Miller Creek, which will increase the sediment yield.

Description of Relationship

If we are only connecting to Gallinas Creek, the annual sediment loading rate is about 1,166 tons/mi²/yr. If we add an additional connection to Miller Creek, we can add a component to the sediment yield to account for the sediment loading rate from Miller Creek.

Summary of Evidence

There are four scenarios for the creek connections: no action, breach to Gallinas Creek, breaches to Gallinas Creek and Miller Creek, and breaches to Miller Creek. Gallinas Creek has an average annual sediment load of 1,166 tons/mi²/yr (San Francisco Estuary Institute-Aquatic Science Center 2017). The sediment loading rate from Miller Creek is estimated to be 3,500 to 9,000 tons/year (Kamman et al. 2016). The free-flowing watershed area upstream of the head of tide is 1.17 mi² for Gallinas Creek for 1994 to 2009 (San Francisco Estuary Institute-Aquatic Science Center 2017). So we can calculate the annual loading rate for Miller Creek to be a uniform distribution from 2,991 to 7,692 tons/mi²/yr.

Strength of Evidence

This piece of evidence is site specific. Other sites may have different creek connection options that will result in changes of the sediment yield.

Sources

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Link(s): Connecting Gallinas Creek, Miller Creek, or Both AND Connecting Golf Course and Marsh AND Salinity → Wildlife Populations

Assumed Relationship

Connecting Gallinas Creek, Miller Creek, or both and high levee removal will add to wildlife habitat size. Because we know wildlife species of interest and their local densities, we can estimate the change in wildlife populations on the basis of additional habitat area. Wildlife species of interest include the California Ridgeway's Rail, California Black Rail, Tidal Marsh Song Sparrow, and Salt Marsh Harvest Mouse.

Description of Relationship

If we connect Gallinas Creek, Miller Creek, or both, the habitat area for California Ridgeway's Rail, California Black Rail, Tidal Marsh Song Sparrow, and Salt Marsh Harvest mouse will increase by 48.56 ha. The restoration action of high levee removal will reconnect 14.16 ha of high marsh to the bayland. (Kamman Hydrology & Engineering, Inc. 2016) To calculate the wildlife population of interest, we can multiply the habitat area by the known density distribution of a species to estimate the number of individuals supported by that habitat. California Ridgeway's Rail density peaks at 25 psu.

Summary of Evidence

Current habitat size in Marin County for the California Ridgeway's Rail is 320.42 hectares (Veloz et al. 2014). Rail density ranges from 0 to 0.55 birds per hectare of habitat. The bird habitats in our study area near the Gallinas Creek and McInnis Marsh range from 0 to 0.26 birds per hectare of habitat (Veloz et al. 2014). Ridgeway's rail density is positively correlated with marsh size (less than 50 ha, steep drop in density, little difference beyond 100 ha) and channel density (rail density peaks when channel density is between 50 m and 150 m per hectare). There is a 25% or so increase in birds per hectare with the desirable channelization which is 5–10% for low marsh, 30–60% for mid marsh, and 5–10% for high marsh. Rail density is also positively correlated with salinity (rail density peaks at highest spring salinity levels at about 25 psu), percent invasive *Spartina*, and compactness of marsh shape (round marsh with low perimeter-area ratio better). A formula for population abundance is current population + 0.05 (new salinity - current salinity) (Liu et al. 2012).

Current habitat size for California Black Rail in Marin County is 404.83 hectares (Veloz et al. 2014). The Rail density ranges from 0 to 3.36 birds per hectare of habitat. The bird habitats in our study area near the Gallinas Creek and McInnis Marsh range from 0 to 0.14 birds per hectare of habitat (Veloz et al. 2014). Black Rail density is negatively correlated with salt grass cover, positively correlated with tidal marsh proportion within 1,000 m and total vegetation cover (Sprutz et al. 2006). Because we don't have the specific coefficients associated with our site, we estimate the combined effect of surrounding land use instead.

Current habitat size for Tidal Marsh Song Sparrow in Marin County is 306.63 hectares (Veloz et al. 2014). Sparrow density ranges from 0 to 25.78 birds per hectare of habitat. The bird habitats in our study area near the Gallinas Creek and McInnis Marsh range from 7.38 to 19.61 birds per hectare of habitat (Veloz et al. 2014). Song Sparrow density is associated with Coyote brush cover, Gumplant cover, and pond/pan cover and is negatively correlated with Rushes cover (Spautz et al. 2006).

A previous study in Suisun Marsh, California, found 18.9 +/- 2.5 mice/hectare in tidal wetlands (Sustaita et al. 2011). Salt Marsh Harvest Mice prefer habitat with pickleweed cover with foliage height between 6 cm and 30 cm (Bias et al. 2006). However, we don't have the vegetation survey data to predict the change in the mice population based on vegetation cover. We are only looking at the effects of change in marsh habitat area in this model.

Strength of Evidence

This piece of evidence is site specific. However, the approach can be applied to other sites. Other sites may derive their own wildlife population densities from local wildlife surveys.

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Link: Sea-Level Rise Local Effect → Tidal Marsh and Creek Habitat Type and Area

Assumed Relationship

If there is a high sea-level rise local effect, more high or mid marsh will turn into low marsh or mudflats.

Description of Relationship

We have seven scenarios of sea level rise in this model: 0 ft, 1 ft, 2 ft, 3 ft, 4 ft, 5 ft, and 6ft. We have six marsh habitat types: subtidal, mudflat, low marsh, mid marsh, high marsh, and upland. Higher sea-level rise will lead to more inundation of marsh area.

Summary of Evidence

Our base scenario would be 62,440 ha subtidal, 16,320 ha mudflat, 2,918 ha low marsh, 8,584 ha mid marsh, 1,317 high marsh, and 37,220 upland if we derive the area at the 0 ft sea-level rise map (DOC, NOAA, NOS, OCM 2017) (Table C. 1). The area in each habitat type changes as we increase the inundation from sea-level rise (Veloz et al. 2014). With more inundation, there will be more lower marsh types and less higher marsh types (Veloz et al. 2012).

Table C.1. Hectares of each habitat type under different sea-level rise scenarios

	0	1	2	3	4	5	6
Subtidal		62540.00	62740.00	62740.00	62740.00	62750.00	62750.00
Mudflat		16550.00	16480.00	16520.00	16560.00	16630.00	16680.00
Low Marsh		2868.88	2853.37	2851.80	2848.32	2841.00	2840.65
Mid Marsh		8320.39	8277.17	8274.03	8272.03	8262.26	8261.74
High Marsh		1301.14	1277.17	1273.60	1271.42	1267.67	1266.80
Upland		37210.00	37170.00	37140.00	37110.00	37050.00	37000.00

Note: The top row indicates different sea-level rise scenarios, measured by feet of sea-level rise. The left column indicates hectares of each habitat type that would exist under each scenario.

Strength of Evidence

The evidence we use in this model is site specific. The sea-level rise information is available for all states on the NOAA website. Other sites can use the sea-level rise data set to assess their current marsh type and area.

Sources

DOC (Department of Commerce), NOAA (National Oceanic and Atmospheric Administration), NOS (National Ocean Service), and OCM (Office for Coastal Management). 2017. NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Aggregate Record. Retrieved from <https://coast.noaa.gov/slrdata/>.

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Link: Sea-Level Rise Local Effect → Shoreline Protection

Assumed Relationship

As sea-level rise increases, more property will be affected.

Description of Relationship

Different levels of sea-level rise correspond to different amounts of area flooded. We can calculate the number of each type of property within the flooded area according to the tax parcel map and the sea-level rise map to assess the total value of property affected.

Summary of Evidence

We model four types of dwellings: single-family home, improved single-family home, multi-residential, and commercial/industrial/rural. We use the average sale value for each type from the 2016 real estate sales data from Marin County. The values we use are: single-family home (\$975,000), improved single-family home (\$1,271,059), multi-residential (\$1,254,155), and commercial/industrial/rural (\$4,547,153). We assess the average flood damage value of each property type on the basis of a percent damage index that is dependent on flood water depth (Dutta et al. 2003). The damage index varies from 5% to 60% for residential properties and from 18% to 60% for non-residential structures with flood water up to 6 meters (Dutta et al. 2003). Using the sea-level rise map and the tax parcel map, we calculate the number of each property type affected and multiply the number of properties by the average damage value of that property type. We add up the property values in each type to estimate the total property damage value under each sea-level rise scenario.

Strength of Evidence

This piece of evidence is site specific. However, this technique could be applied to other projects if the real estate sales data are available.

Sources

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National Ecosystem Services Partnership

The National Ecosystem Services Partnership (NESP) engages both public and private individuals and organizations to enhance collaboration within the ecosystem services community and to strengthen coordination of policy and market implementation and research at the national level. The partnership is an initiative of Duke University's Nicholas Institute for Environmental Policy Solutions and was developed with support from the U.S. Environmental Protection Agency and with donations of expertise and time from many public and private institutions. The partnership is led by Lydia Olander, director of the Ecosystem Services Program at the Nicholas Institute, and draws on the expertise of federal agency staff, academics, NGO leaders, and ecosystem services management practitioners.

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