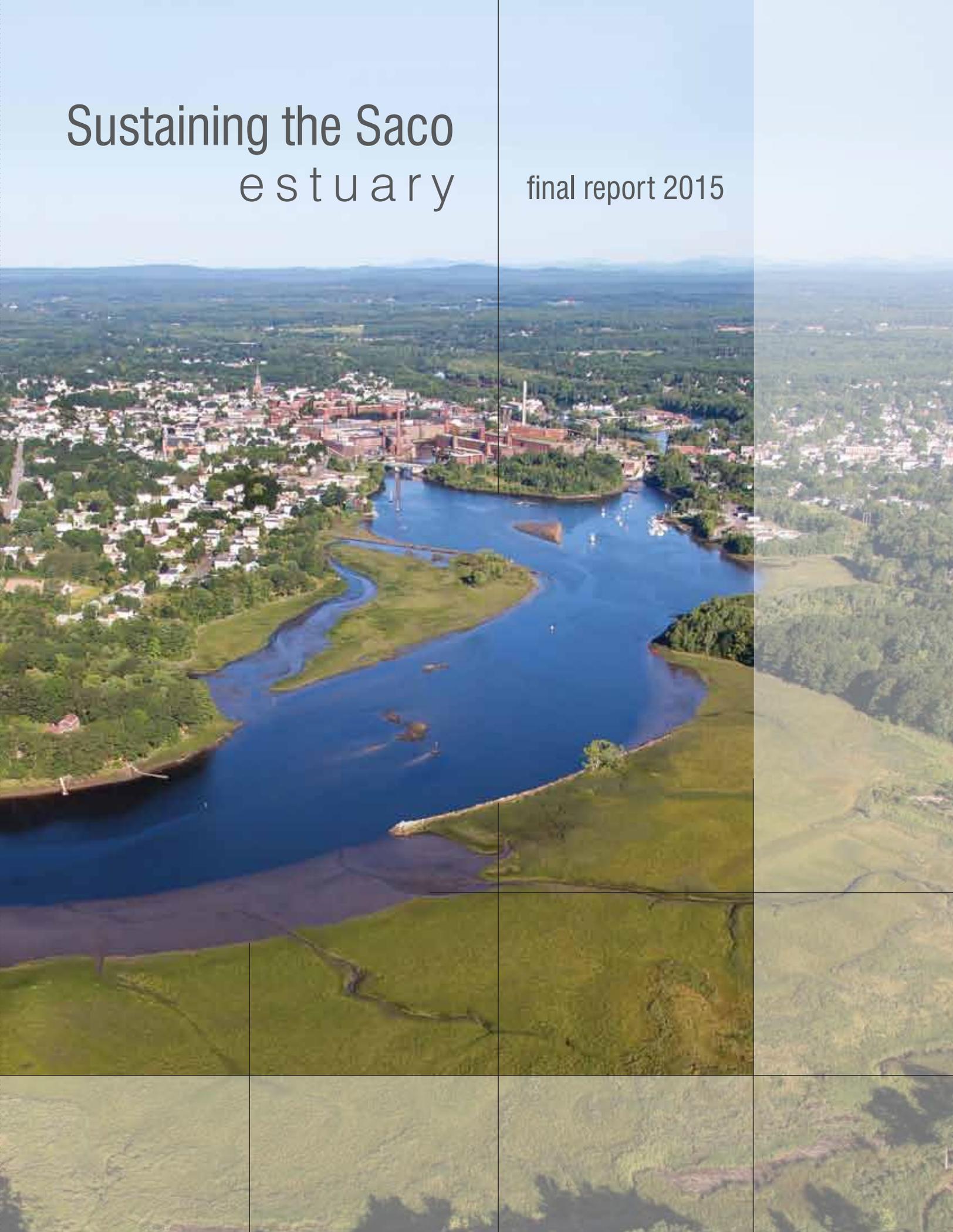


Sustaining the Saco e s t u a r y

final report 2015



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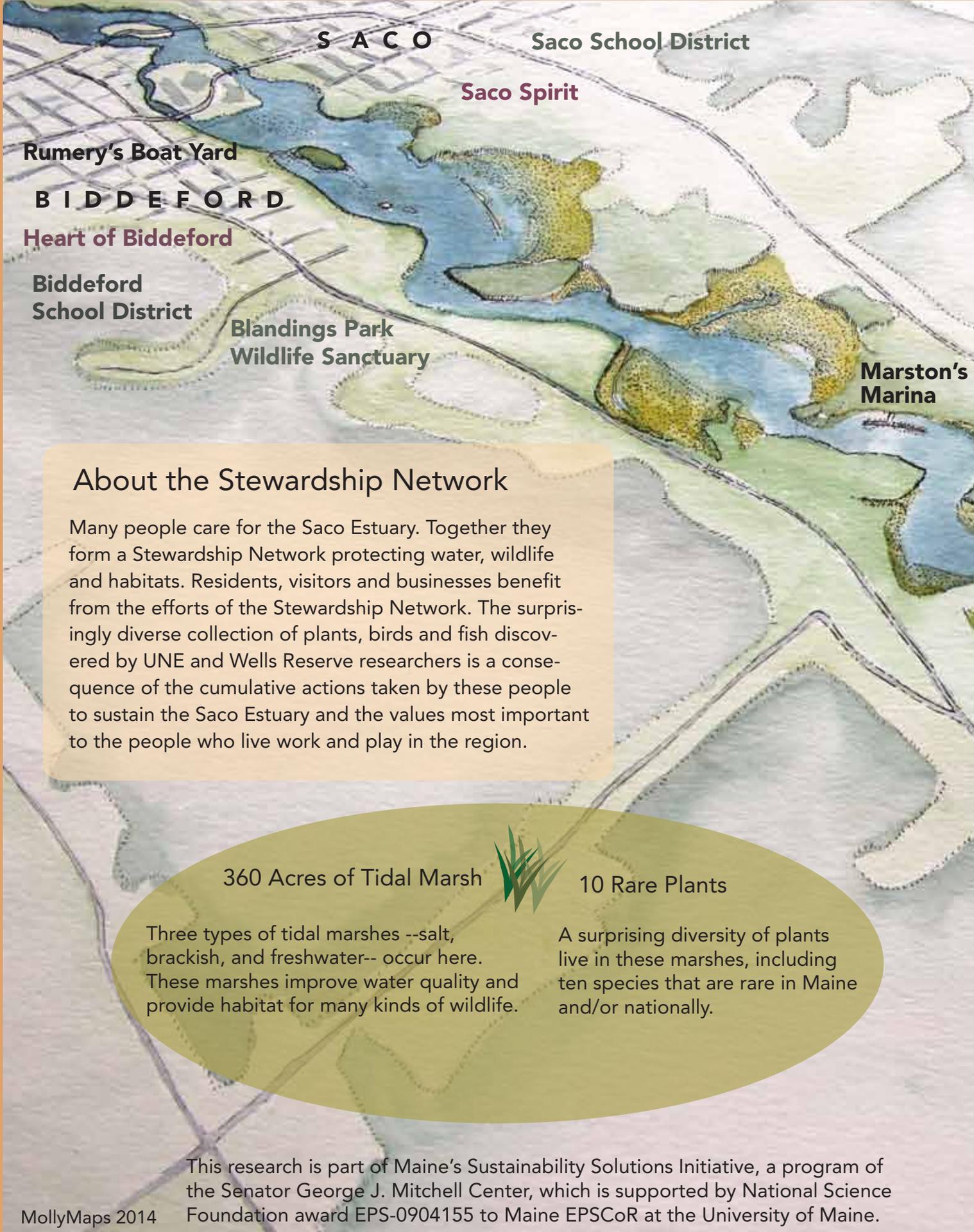
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About the Stewardship Network

Many people care for the Saco Estuary. Together they form a Stewardship Network protecting water, wildlife and habitats. Residents, visitors and businesses benefit from the efforts of the Stewardship Network. The surprisingly diverse collection of plants, birds and fish discovered by UNE and Wells Reserve researchers is a consequence of the cumulative actions taken by these people to sustain the Saco Estuary and the values most important to the people who live work and play in the region.

360 Acres of Tidal Marsh



10 Rare Plants

Three types of tidal marshes --salt, brackish, and freshwater-- occur here. These marshes improve water quality and provide habitat for many kinds of wildlife.

A surprising diversity of plants live in these marshes, including ten species that are rare in Maine and/or nationally.

This research is part of Maine's Sustainability Solutions Initiative, a program of the Senator George J. Mitchell Center, which is supported by National Science Foundation award EPS-0904155 to Maine EPSCoR at the University of Maine.

MollyMaps 2014

A Stewardship Network Sustains the Saco Estuary

60 Fish Species



The Saco River estuary has the highest number of fish species --including adult and larval fish caught in the river and bay -- recorded in any Maine estuary.

133 Bird Species



Nearly half of all bird species in Maine have been observed using the Saco River estuary. Many of the species are not commonly associated with estuaries.

Saco Bay Tackle

Camp Ellis

University of New England

FOOD WEB OF THE SACO ESTUARY'S TIDAL MARSHES

BY CARRIE BYRON

INTRODUCTION

For sustainable management of an ecosystem or resources within an ecosystem, it is not enough to study specific species of interest. It is much more informative for management and conservation decision-making to consider the connections among species in the ecosystem. Connections among most species in an ecosystem can be represented by a food web that provides visual representation of the flow of energy in a system described by predators and their prey. Primary producers (i.e., plants) capture energy from the sun, and then the energy is transferred to animals through herbivory and predation.

Beyond simply mapping predator-prey relationships, a food web characterizes the relative importance of each prey item in a predator's diet. Trophic level details can also be relayed via food web analysis that examines the direction of flow of energy. Bottom-up dynamics describe the flow of energy from primary producers to top order consumers and are dictated by production and food supply. Top-down dynamics describe the effects of consumption on prey populations. For example, predators may control the abundance of their prey (top-down), rather than the prey's food controlling their abundance (bottom-up). All of these relationships and energy flows can be quantified and described mathematically using a model.

Understanding these dynamics is important for the sustainable management of natural resources. People who live, work, and recreate in the Saco estuary value the health of the ecosystem, its ability to support clean water, healthy fish populations for recreational fishing, and natural resources for economic opportunities. People also value wildlife habitat and conservation of natural resources to protect biodiversity. Food web analysis helps to characterize the current state of the ecosystem so that resource managers and policy makers can better understand the dynamics in the system and potentially identify species groups and interactions on which to focus attention.

STUDY OBJECTIVES—FOOD WEB

Our objectives for the food web study were to answer these questions related to the tidal marshes of the Saco estuary:

1. How do species impact each other in the ecosystem?
2. How much do different species overlap with each other in their roles in the ecosystem?
3. How productive is the ecosystem?
4. How resilient is the ecosystem?

RESEARCH DESIGN AND METHODS

A food web for Saco River tidal marshes

The Saco estuary food web model was created specifically to describe the marsh ecosystem. Therefore, species that are restricted to the mid-channel, such as sturgeon, are not included in this model. Also, this model was intended to capture the average summer condition of the ecosystem. The static model presented here is not designed to describe extreme events or perturbations such as storm events. This food web model is limited in that it does not include rare species or species of low biomass. The primary purpose of using this modeling approach is to characterize the overall ecosystem and visualize key predator-prey interactions.

How is a food web model built?

Food web modeling is a simplified method designed to capture the complexity in species interactions. The modeler defines *species groups* based on observations and data collected that describe the organization of the ecosystem. The number of species groups in the model greatly adds to the level of complexity. The inclusion of too many species groups in the model can make the model too cumbersome to explain ecosystem dynamics.

To create a food web model, several parameters need to be measured, including an estimate of a *quantity*, a *rate*, and an *exchange* for every species in the food web. Biomass describes the quantity of species measured as a mass per unit area in the ecosystem. Vital rates describe physiological processes necessary to maintain life, such as metabolism, respiration, and consumption. Diet composition describes the exchange of energy through predation. Biomass (g/m^2 live weight) values for species in the Saco estuary's marsh ecosystem were collected by researchers, and their observations are presented in the relevant chapters of this report.

The parameterization of the model is based on two master equations (www.ecopath.org). The first equation describes how the production term for each species group can be divided (EQ 1). The second equation is based on the principle of conservation of matter within a group (EQ 2, Figure 1).

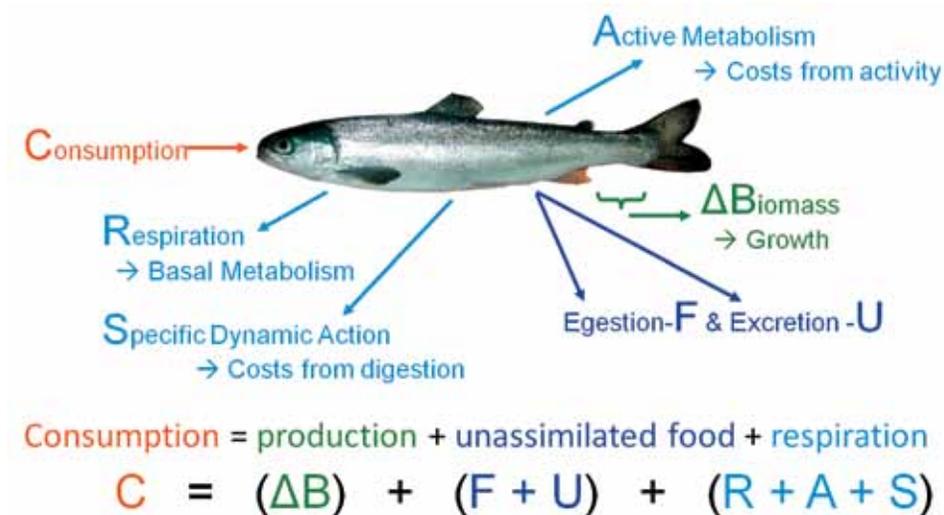


FIGURE 1 Energy balance. Modified from Kitchell.

EQ 1: Production = catches + predation mortality + biomass accumulation + net migration + other mortality.

EQ 2: Consumption = production + unassimilated food + respiration.

Vital rates (e.g., production, consumption, and respiration) for fish species were informed by the Fishbase database (www.fishbase.org). Vital rates for birds were informed using an allometric equation presented in peer-reviewed literature (Meire et al. 1994; Scheiffarth and Nehls 1997). Vital rates for many of the Saco estuary invertebrate species were inferred from vital rates presented in other estuarine food webs in peer-reviewed literature (Cusson and Bourget 2005). Diets of all species groups were also informed by online databases and published reports (i.e., Fishbase, Birds of North America, and Cornell Lab of Ornithology).

RESULTS AND DISCUSSION

A food web model for the Saco River's tidal marshes

Food Web Structure

We used 29 species groups in the Saco estuary food web model (Table 1; Figure 2). These species groups are organized by trophic level, with primary producers at the bottom and top consumers at the top of the web. The apex predators of the ecosystem are the colonial water birds, which feed on small fish. American eels are also a top predator in the estuary, feeding on a widely varied diet. Eels were one of the larger fish species found using marsh surface sampling, so eels contribute to a relatively high biomass despite being fewer in number than many other fish species. Like eels, sunfish have a varied diet and have a relatively high trophic status. White suckers occupy a lower trophic level because they feed on benthic invertebrates and lower trophic order species groups. The sunfish also had relatively high biomass

TABLE 1 Species functional groups. Saco estuary marsh species with similar ecosystem function (i.e., similar predators and prey) are grouped together in this table.

Functional Group	Species in Functional Group	Description
1 Rails	<i>Corvus brachyrhynchos</i> , <i>Rallus longirostris</i> , <i>Gallinago gallinago</i> , <i>Rallus limicola</i>	Primarily insect-eaters
2 Swallows	<i>Riparia riparia</i> , <i>Hirundo rustica</i> , <i>Chaetura pelagica</i> , <i>Stelgidopteryx serripennis</i> , <i>Tachycineta bicolor</i>	Primarily insect-eaters
3 Sparrows	<i>Ammodramus nelsoni</i> , <i>Agelaius phoeniceus</i> , <i>Melospiza melodia</i>	Primarily insect-eaters
4 Shorebirds	<i>Pluvialis squatarola</i> , <i>Tringa melanoleuca</i> , <i>Charadrius</i> <i>vociferous</i> , <i>Calidris minutilla</i> , <i>Tringa flavipes</i> , <i>Calidris</i> <i>maritime</i> , <i>Charadrius semipalmatus</i> , <i>Calidris</i> <i>pusilla</i> , <i>Actitis macularius</i> , <i>Calidris fuscicollis</i> , <i>Tringa</i> <i>semipalmata</i>	Primarily insect-eaters
5 Colonial Waterbirds	<i>Megaceryle alcyon</i> , <i>Nycticorax nycticorax</i> , <i>Plegadis</i> <i>falcinellus</i> , <i>Ardea herodias</i> , <i>Ardea alba</i> , <i>Egretta thula</i>	Primarily fish-eaters
6 Gulls and Terns	<i>Sterna hirundo</i> , <i>Larus marinus</i> , <i>Larus smithsonianus</i> , <i>Sternula antillarum</i> , <i>Larus delawarensis</i>	Primarily feed on molluscs and crustaceans
7 Ducks and Geese	<i>Anas rubripes</i> , <i>Branta canadensis</i> , <i>Anser cygnoides</i> , <i>Anas platyrhynchos</i> , <i>Anas clypeata</i> , <i>Aix sponsa</i>	Primarily plant-eaters
8 Bluefish	<i>Pomatomus saltatrix</i>	Transient species, primarily benthic feeder, mostly juveniles caught
9 Atlantic Silverside	<i>Menidia menidia</i>	Transient species, primarily plankton feeder
10 Sticklebacks	<i>Apeltes quadracus</i> , <i>Gasterosteus aculeatus</i>	Transient species, primarily plankton feeder
11 White Perch	<i>Morone americana</i>	Estuary-dwelling species, primarily plankton feeder
12 Atlantic Herring	<i>Clupea harengus</i>	Transient species, primarily plankton feeder

Functional Group	Species in Functional Group	Description
13 Minnows	<i>Couesius plumbeus</i> , <i>Notemigonus crysoleucas</i> , <i>Notropis hudsonius</i>	Freshwater species
14 Yellow Perch	<i>Perca flavescens</i>	Freshwater species, primarily benthic feeder
15 Atlantic Tomcod	<i>Microgadus tomcod</i>	Estuary-dwelling species, primarily plankton feeder
16 Killifish	<i>Fundulus diaphanous</i> , <i>F. heteroclitus</i> , <i>F. magalis</i>	Estuary-dwelling species, primarily benthic feeder
17 River Herring	<i>Alosa pseudoharengus</i> , <i>A. aestivalis</i>	Diadromous species, primarily plankton feeder
18 Sunfish	<i>Lepomis macrochirus</i> , <i>L. gibbosus</i> , <i>Micropterus salmoides</i>	Freshwater species
19 American Eel	<i>Anguilla rostrata</i>	Diadromous species, primarily benthic feeder
20 White Sucker	<i>Catostomus commersonii</i>	Freshwater species, primarily benthic feeder
21 Sand Shrimp	<i>Crangon</i> sp.	Marine crustacean
22 Green Crab	<i>Carcinus maenas</i>	Marine crustacean
23 Annelids	<i>Annelida</i> sp.	Mud-dwelling segmented worms
24 Molluscs	<i>Mollusca</i> sp.	Marine invertebrates possessing a mantle
25 Arthropods	<i>Arthropoda</i> sp.	Crustaceans, insects and other animals with exoskeletons
26 Ichthyoplankton	various	Fish eggs and juvenile planktonic stages
27 Marsh Plants	<i>Spartina</i> sp., others	Grasses, sedges, succulents
28 Phytoplankton	various	Photosynthetic algae
29 Detritus	various	Decaying organic matter

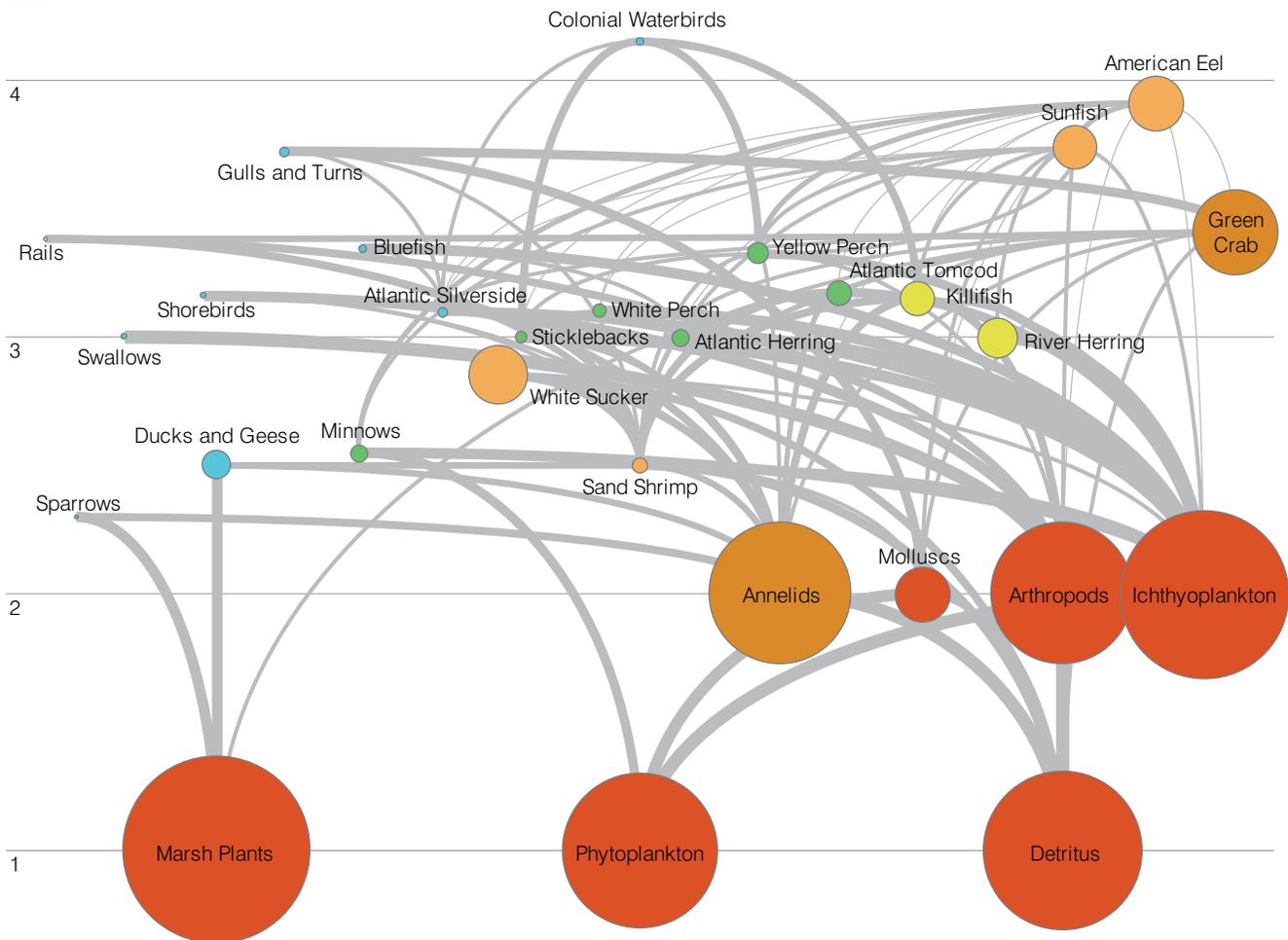


FIGURE 2 Food web diagram for the Saco estuary's tidal marshes. The food web diagram provides several layers of detail of the trophic structure and energy flow within the Saco estuary marsh food web. Circles represent functional groups of species and the size and color of the circle indicate relative biomass. Line thickness describes relative amount of energy flow between species groups. The horizontal number lines represent trophic levels.

due to its large individual size despite relatively lower abundances in the marshes. It is important to note that a large biomass of small invertebrate species and plankton is needed to support the diverse fish community and bird community. Resource managers interested in maintaining species biodiversity and a stable ecosystem in the Saco estuary should monitor the prey base of plankton and benthic invertebrates because these organisms are essential to the food web.

How species in the food web impact each other

A food web model allows us to understand how each species group impacts other species groups. We can capture these impacts in a mixed trophic impact analysis (Figure 3). This analysis describes the relative impact each predator species has on

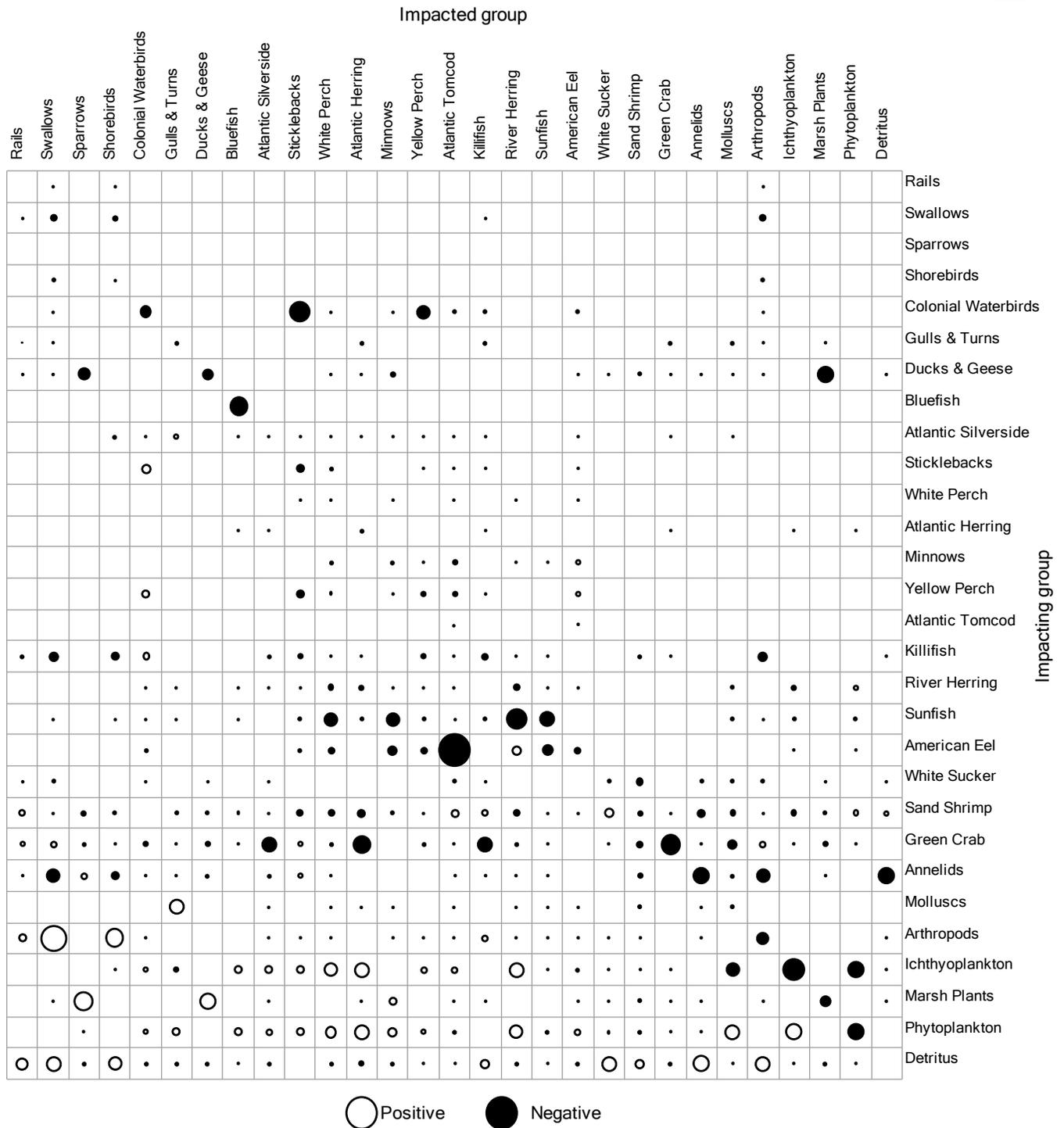


FIGURE 3 Mixed trophic impact analysis. The relative impact each predator species has on each prey species. The figure is designed as a matrix that allows relationship analysis between all species of all trophic levels. Shown along the right are the predators (i.e., impacting species), while prey are shown across the top (i.e., impacted species).

each prey species. The predators (i.e., impacting species) are shown on the right, while the prey (i.e., impacted species) are shown across the top. Impacts may also be caused by competition for prey.

The largest negative impacts in the Saco estuary marsh food web are the American eel on tomcod, sunfish on river herring, and colonial waterbirds on sticklebacks. Almost all species groups have a negative impact on themselves due to intraspecies competition for the same prey.

The largest positive impacts in the estuary's marshes are from arthropods on swallows. Most of the primary producers and first order consumers have a positive impact on most other species because they are the base of the food web supplying energy to higher trophic levels. This flow of energy is indicative of bottom-up processes.

Most of the energy generated by marsh plants and phytoplankton flows up to first and second order consumers. A small portion of it gets used for ecosystem respiration, and much of the rest of it gets recycled as detritus. Detritus, composed primarily of dead and decomposing plants, is an important part of the marsh food web as well. Protecting sediment quality and adequate land area may promote healthy and robust primary production of native rooted plants. Taking action to improve the clarity of water will promote deeper light penetration, thereby stimulating primary production of phytoplankton in the water column.

Niche overlap

Many species depend on the same resources, or prey, as other species. These competing uses are what yield a web-like structure instead of a single chain-like structure when describing the food web. Overlap in resources is described by niche overlap (Figure 4). An ecological niche describes how species utilize resources. The two species with the greatest niche overlap are white perch and river herring, meaning that they share the same prey and the same predators. Other species that have a high degree of niche overlap are: sticklebacks and yellow perch, Atlantic silverside and Atlantic herring, white perch and yellow perch, and sand shrimp and annelids. Conversely, minnows have the lowest degree of niche overlap with killifish, river herring, and white perch.

The concept of niche overlap is a way for managers to assess the organization of species in the food web. High niche overlap can be an indicator of redundancy in energy flow pathways that is necessary for ecosystem stability. On the other hand, species that exhibit low niche overlap may be serving a critical role in maintaining pathways for energy to flow from lower order trophic groups to higher order trophic groups. If these critical species were lost, energy to higher trophic levels also may be lost, thereby decreasing species biodiversity, abundances, and biomasses. The food web model depicted a total of 34 pathways from prey to predators (Figure 1). Maintaining niche overlap will also maintain these energy pathways.

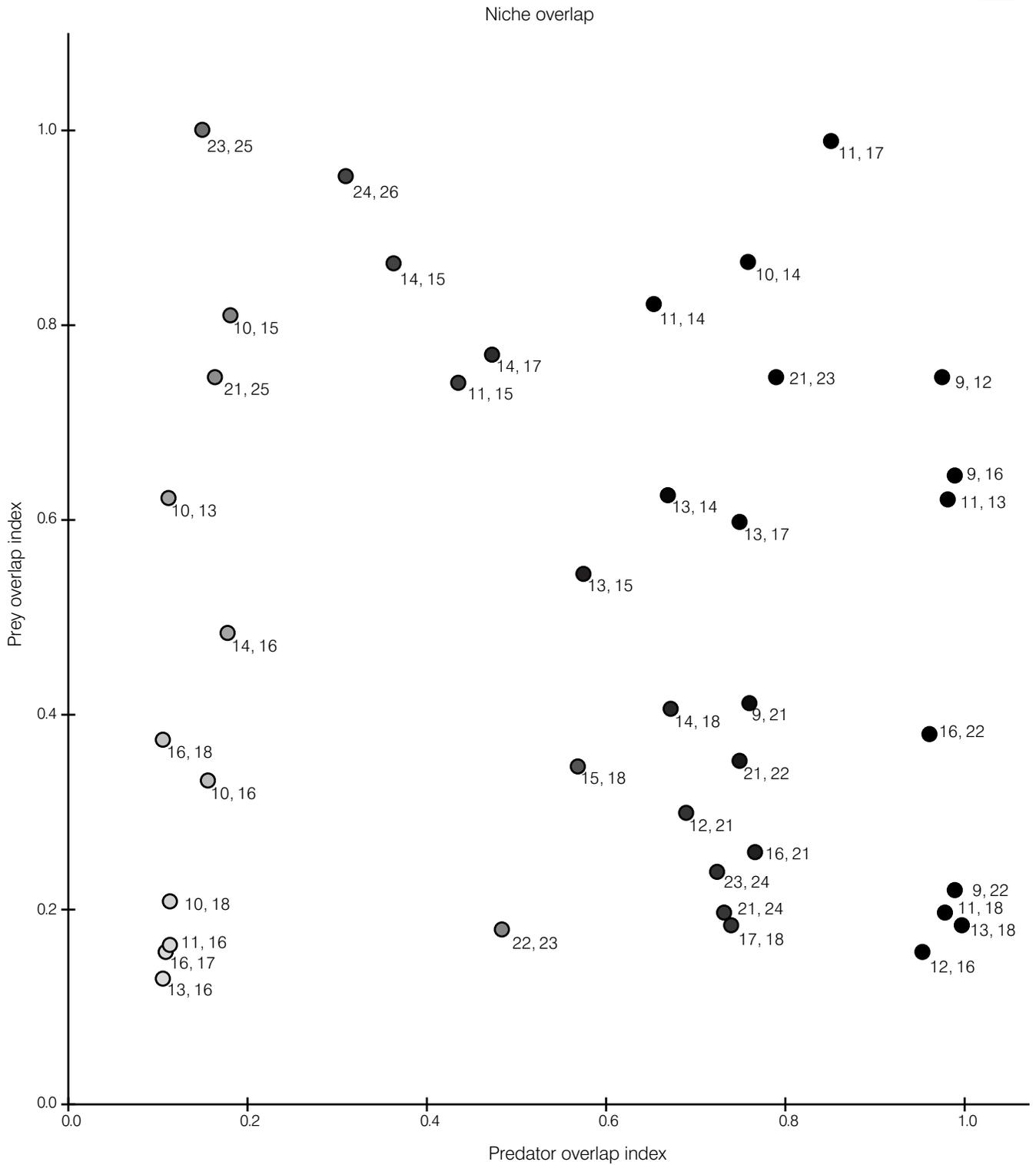


FIGURE 4 Niche overlap between predator and prey. A value of 0 (white dots) suggests that the two species do not share the same resources, and a value of 1 (black dots) indicates complete overlap. Dots in the upper left corner have a high overlap of prey, and dots in the upper right corner have a high overlap of both predators and prey. The numbers next to each dot correspond to particular species groups as presented in Table 1.

Energy: productivity and transfer efficiency

Overall, the Saco estuary is quite productive, with a much higher primary production (PP) rate than respiration (R) rate. High PP/R suggests that the estuary is a highly productive and immature system, which is typical of most marsh systems. High primary production provides much fuel for the system, but it needs to be balanced by the respiration rate of consumers.

The efficiency at which energy is transferred between trophic levels also has implications for the amount of energy that is available to the top consumers. Transfer efficiencies in the estuary's marshes decreased with increasing trophic level as expected and are generally within the typical range of 5-20%.

The health of the Saco estuary's tidal marshes

Ecosystem health—in this case, health of the Saco estuary tidal marshes—can be measured to determine how well the system is functioning. From this information we can assess whether the marsh can maintain its structure and function over time and whether it has the capacity to recover from external stress, such as that from an extreme storm event (Costanza and Mageau 1999). We plotted metrics for these qualities (i.e., degree of organization and resilience capacity) to get a picture of the health of the marsh (see Figure 5). The Saco estuary marsh food web is highly organized and has relatively lower resilience, which is common for young and highly productive systems such as marshes. Much of the energy in young marshes goes to



FIGURE 5 Health of the Saco estuary's marshes. Ecosystem organization and resilience are indicators of health. The Saco estuary's marshes are highly organized, meaning there are a large number and diverse interactions between species. Resilience refers to the ability of the ecosystem to maintain its structure in the presence of stress.

creating additional biomass and developing more complex ecosystem structure. In contrast, the energy in mature marshes goes primarily to maintaining diverse structure, which makes them more resilient (e.g., more likely to withstand storm events without sustaining significant damage to the functioning of the marsh).

CONCLUSIONS

We made the following conclusions from our food web modeling of the Saco estuary:

- Food web modeling is a useful approach to conceptualizing complex dynamics in an ecosystem and can provide valuable information to resource managers looking to develop conservation plans for the Saco estuary.
- There was a lack of data on important prey species (i.e., annelids, arthropods, and molluscs) in the Saco estuary to inform the model for these groups. These prey groups are some of the most critical species groups in the food web for channeling energy from primary producers to higher order consumers. A diverse and robust prey base is essential for the stability of natural resources in an ecosystem.
- From a conservation perspective, it would be advisable to protect the habitat of these prey groups (i.e., sediment) as a precaution until we know more about the role of these species in the Saco estuary.
- A sensitivity analysis revealed six species that were highly sensitive to changes in parameter values in the model: colonial waterbirds (e.g., herons and egrets), sunfish, American eel, white perch, yellow perch, and bluefish. All of these sensitive species are higher order predators. Additional data on the diets of these species could help improve the Saco estuary marsh model.
- Once a food web model is developed, it can be used for asking “what if” type questions. For example, what if the abundance of the invasive green crab (*Carcinus maenas*) in the Saco estuary increases? We manipulated the biomass of green crabs in the food web model to see how an increase in biomass may impact other species groups and the transfer of energy among those groups. At some extreme biomass, competition for resources with other species will cause changes to the structure and function of the Saco estuary marsh ecosystem. Our analyses suggested that the Saco estuary marsh food web could withstand a ten-fold increase in green crab biomass without any change to other species or to the structure or function of the ecosystem. Increases in green crab biomass beyond this carrying capacity limit of the ecosystem will have negative impacts, primarily on annelids and marsh grasses.
- With the aid of a skilled food web ecologist, these types of questions on species impacts or carrying capacity could be addressed for any species of concern in the Saco estuary marsh food web. Such information not only helps to characterize the ecosystem but can also be used to aid resource managers and policy makers in prioritizing research efforts and policy decisions.
- Developing data-intensive food-web models helps to highlight areas where more research is needed.

ACKNOWLEDGEMENTS

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