COMMENTARY

Value of ecosystem-based management

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Taking the pulse of an ecosystem is not quite as straightforward as taking the pulse of a person, especially when that ecosystem is the Chesapeake Bay. At 195 miles long and 3,237 square miles in area, the size and complexity of the bay's coupled social and ecological systems has challenged efforts to assess its health. Building on more than 30 y of research, Lefcheck et al. (1) offer an innovative way to take the pulse of this much loved and debilitated coastal estuary. By developing a model of the bay ecosystem that brings data from long-term, large-scale monitoring together with knowledge of the mechanisms underlying those patterns, Lefcheck et al. make a compelling case that ecosystem restoration initiatives of the last 30+ y are paying off.

The results of Lefcheck et al. (1) show the nutrient reduction enabled by a series of watershed scale agreements over the last three decades are consistent with the observed increase in the bay-wide area of underwater grasses, also known as submersed aquatic vegetation (SAV). SAV is one of the primary sentinels of bay health, and the extent of eelgrass (*Zostera marina*) and the 15 other species commonly found in different parts of the bay is one of the primary means by which scientists evaluate the effectiveness of nutrient reduction measures and other restoration strategies (2). Based on their results, Lefcheck et al. (1) propose that much of the SAV recovery observed through aerial and on-the-ground surveys over the last 30 y is a direct result of the monumental effort to reduce nutrient inputs and lower nutrient concentrations throughout the bay.

Some may be loathe to draw conclusions this bold from a modeling study. However, the scope of the scientific and management challenges in the Chesapeake, as in many other coastal regions worldwide, demands creativity. The approach presented by Lefcheck et al. (1)—not only the model that is central to their analyses, but also the experiments and observations of ecosystem patterns and change that enabled the work—is emblematic of how, in this era of unprecedented environmental change, we must be innovative in how we collect, interpret, and communicate data, so that our knowledge can be used to enable more effective and efficient marine stewardship.

It is important to note that the structural equation model used is a very different and more empirical approach than the watershed and estuarine models used to set regulatory targets through the Chesapeake Watershed Agreement (3). Pollutant inputs are estimated by the watershed model, but responses in the estuary are based on observational data.

Lefcheck et al. (1) sought to trace the within-ecosystem and ecosystem–human system connections that are most salient to explaining changes in the extent of underwater grasses throughout the bay. These grasses are both beneficiaries and enablers of ecosystem recovery (2). They require minimum levels of water quality to survive in the bay, and exactly what that level is varies depending on the species in question, where it is in its life cycle, and the environment within which it lives. Once these species have taken root, they become ecosystem engineers, literally changing the environment within which they are living (in the sense of ref. 4). The blades of the plants alter local hydrodynamics, slowing water and encouraging trapping of sediment and other materials that contribute to turbid water. With the increased water clarity that the mere presence of these underwater grasses facilitates, more sunlight reaches the bottom of the shallow bay, which in turns encourages further SAV growth.

Once Lefcheck et al. (1) developed this new type of structural equation model that reflected what is known about the ecology of SAV, including the engineering behavior mentioned above (the first innovation), they were then able to examine how changes in nutrient loading into different parts of the bay would influence the extent of SAV in those same places. Lefcheck et al. found a strong correlation between the modeled extent of SAV throughout the bay and nutrient loading and changes in these patterns through time.

These nutrient sources are diverse and have changed dramatically through time. Both point sources of pollution (e.g., wastewater treatment plants) and nonpoint sources (e.g., agricultural and urban fertilizers, manure, and other nutrients, including those that enter the bay through airborne sources) contribute to nutrient levels in the bay. Even though the watershed's human

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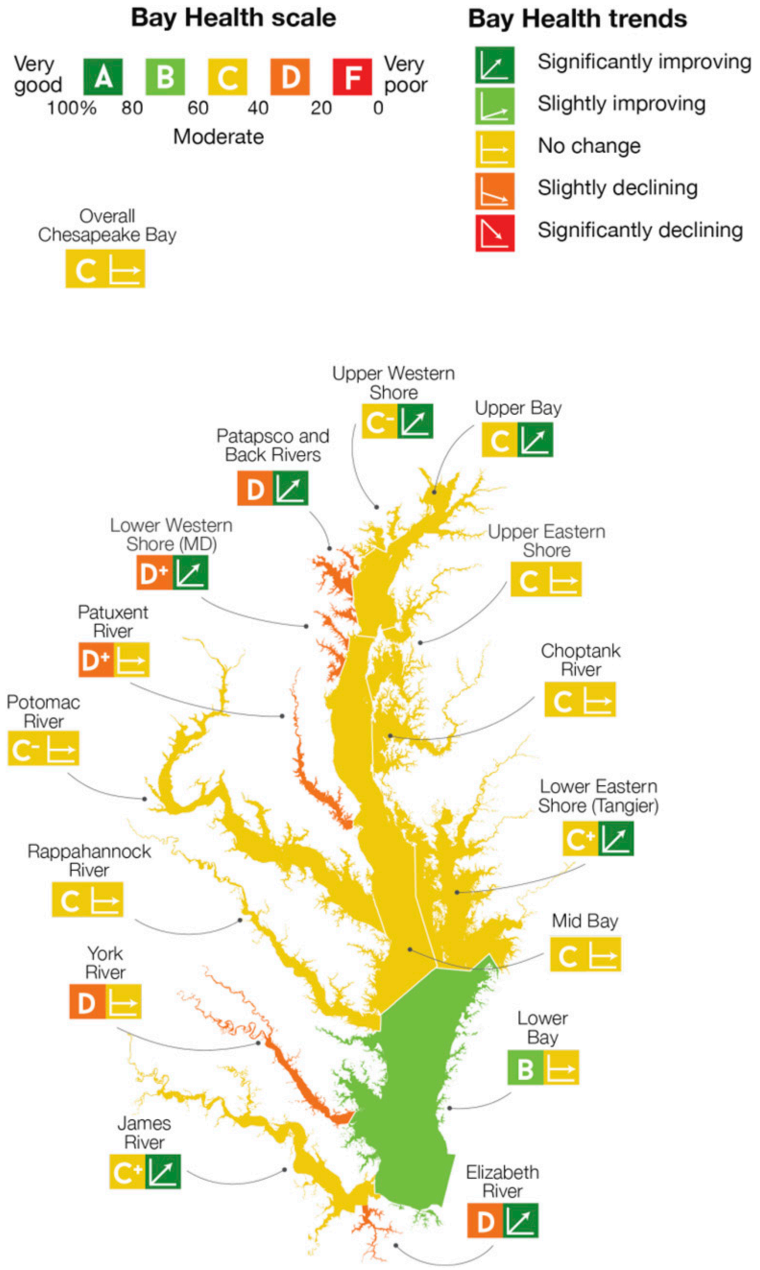

Fig. 1. Spatial heterogeneity in bay health is significant, as illustrated by this visualization from the 2016 Chesapeake Bay Report Card. Reprinted with permission from the University of Maryland Center for Environmental Science. See https://chesapeakebay.ecoreportcard.org for the full report.

population has more than doubled since 1950, total nitrogen discharge from wastewater points sources have been cut in half between 1984 and 2014, and phosphorus discharge also has been reduced by almost three-fourths (5). And in terms of nonpoint sources, particularly airborne emissions, nitrate levels in streams draining forested watersheds within the bay have been reduced by a median of 41% from 1986 to 2012, thanks to targets required by the US Clean Water Act (6).

The goals of the Chesapeake Bay Watershed Agreement (3) illustrate the ecosystem-based approach that has enabled improvements like those cited in the last paragraph. By ecosystem-based, I am referring to management approaches—specifically in coastal and marine domains—that consider the connections between different elements of the ecosystem, including people, and also recognize the full range of benefits that marine systems provide (7). These benefits, or ecosystem services, include healthy and local food, clean water, areas for recreation and habitation, and protection from coastal storms and pollution (8).

Marine ecosystem-based management (EBM) is not a singular approach, but rather a framework for managing people's interactions with the environment. In the marine context, the emphasis on maintaining or restoring ecosystem functioning distinguishes EBM from other integrated management frameworks. Additional elements of EBM include generating knowledge and managing at the ecosystem scale as well as actively engaging with local communities and other stakeholders (7, 9). As multiple jurisdictions are often involved, EBM also often involves numerous collaborators and governance arrangements supported by diverse institutions.

Chesapeake Bay has long been held up as an example of ecosystem-based management, in part because of the geographic and institutional extent of the effort. The Chesapeake Bay Program, the partnership that coordinates efforts to improve and sustain the health of the Bay, involves 16 federal agencies, six states, and the District of Columbia. The Chesapeake is also a notable example because of its longevity: the citizens, scientists, resource managers, and political leaders within the watershed have pursued many elements of EBM for more than 30 y (10).

For most cases of marine EBM, we simply don't have this long a track record. Instead, we are dealing with cases of aspirational EBM, where communities have begun to articulate elements of EBM for their particular geography, particularly in terms of innovative institutional arrangements (like the Chesapeake Bay Program). But, in most cases of marine EBM in practice, there has not yet necessarily been much "in the water" change: that is, the types of improvements in social and ecological conditions that we would predict to see once ecosystem-based approaches have taken root (11, 12).

In the Chesapeake, however, scientists and other stakeholders have been working at ecosystem-based management for a long time. They came together in the 1970s in response to widespread recognition of the failing health of the bay. SAV like eelgrass and other underwater grasses were disappearing. Water was murky, fisheries were failing, and many imagined that there had to be a better way to live on the bay. From this recognition of the challenges facing the people and ecosystems of the bay, the Chesapeake Bay Program was born. In 1983, thanks to catalytic support from the United States Environmental Protection Agency and many, many other federal, state, and local government partners, the Chesapeake Bay Program was able to bring people together from across the 64,000-square mile watershed, from the farmlands of Pennsylvania to the bayside communities of Maryland and Virginia, to work toward a common aim: a healthy bay.

Determining how to measure health is a nontrivial endeavor. Indeed, many scientists are squeamish about the term, preferring to talk about changes in species richness, primary productivity, and other metrics by which we evaluate shifts in ecosystem structure and functioning. However, evaluating ecosystem health requires more than aggregating data on a place's species composition and productivity, just as assessing a patient's health requires more than taking her blood pressure and temperature.

Understanding emergent phenomena, like migratory shad and shorebirds, and how these biological dynamics intersect with human dynamics—through fisheries, tourism, and where people choose to live and work—demands knowledge of the connections within and among the social and ecological systems of which the Chesapeake Bay is composed. It also requires recognition that not every mile of shoreline or acre of estuary operates in the same way. The spatial heterogeneity of the bay's social–ecological interactions and the influences this variation has on the functioning and ultimately, the health of the bay is really important.

Lefcheck et al. (1) highlight the importance of spatial heterogeneity in their assessment of bay health. They note that, while nonpoint sources of nutrient pollution have a more significant impact on the recovery of SAV in the bay, there are places where point sources, such as wastewater treatment plants, may be inhibiting SAV recovery. Lefcheck et al. are able to draw this conclusion thanks to the scale of their data; the aerial surveys of SAV collected by the Virginia Institute of Marine Science and partners over the last 30+ y offer a dataset of enviable grain and extent for one of the most referenced, and arguably one of the most important, indicators of bay health. Thanks to that dataset, the spatially variable impact of biodiversity (i.e., species richness) on SAV recovery became evident, enabling Lefcheck et al. to explain why the impact of SAV diversity matters more in fresher parts of the bay than in salty spots.

Spatial heterogeneity also is a strong feature of other indicators of bay health (Fig. 1). Evaluating drivers of this spatial heterogeneity requires knowledge of mechanism and here is the second innovation of Lefcheck et al.'s (1) approach: their model enables assessment of the impacts of ecosystem-based approaches (particularly those related to nutrient management) at multiple geographic scales and with consideration of multiple mechanisms.

Restoring the health of the Chesapeake Bay is an ongoing effort, but as the report of Lefcheck et al. (1) makes clear, great progress has been made in the last 30 y. Ecosystem-based approaches have been central to this progress, and thus the model offered by the Chesapeake matters not only to the region's 18 million residents, but to all of us who care about coastal ecosystems and the human communities that are part of them.

Sustaining the observing system that enabled Lefcheck et al.'s (1) analyses—a vital part of our nation's ecosystem infrastructure—requires both fiscal and human resources. Both are currently threatened. The President's fiscal year 2019 budget included a 90% reduction in US Environmental Protection Agency funding for the Chesapeake Bay Program and, last fall, the House of Representatives approved an appropriations amendment that would prohibit the US Environmental Protection Agency from enforcing the pollution diet (also known as the Chesapeake Bay Total Maximum Daily Load) that is central to restoration of the Bay. Moreover, the recovery to date—and that to come—requires collaboration among scientists who are competent in diverse disciplines and share a commitment to working across knowledge domains to achieve a common purpose (13). Let us hope that both the human and financial commitments on the part of politicians, scientists, and citizens not only continue, but spread beyond the Chesapeake Bay. The stakes are too high and the benefits too great to do any less.

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