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Invasive Species and the Depth of Bioeconomic Integration

David Finnoff, Chad Settle, Jason F. Shogren, and John Tschirhart

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An established species is not considered invasive unless it triggers costs that outweigh any attendant benefits. Numbers of invasive species are increasing worldwide. In the United States alone, Pimentel et al. (2000) estimated that 50,000 non-native species have been introduced. Of these about 5,000 have become established and about 500 have become invasive.

Invasive species are a leading cause of biodiversity loss in ecosystems, and especially in lakes. Invasive species promote large ecosystem changes, and they interact with many other drivers of global environmental change. Although agriculture has been long plagued by invasives and a voluminous literature on cost effective pest control exists, only relatively recently has the problem of invasives in natural systems been examined in a bioeconomic context.

In the past, researchers have used an approach that assumes the economic system and the ecosystem affect each other in a one-sided way, which causes them to separate risk assessment from risk management. A change in the economic system is viewed as only changing the pressure on the ecosystem, or a change in the ecosystem is viewed as only changing the economic system. This approach does not address the idea of *co-evolution* – the two-way interactions and feedbacks between human and natural systems. Ecosystem changes alter human behavior and productivity in the economic system. People recognize the change in their productivity, and they adapt to this change, either by adapting the environment or by adapting to the environment. When people adapt, they alter the pressure they put on the ecosystem leading to further changes in the ecosystem. The co-evolutionary cycle continues.

Co-evolution can be addressed by integrating ecological and economic modeling into a single cohesive framework. The motivation behind integration is to get more precise estimates of invasive species damages on human and natural systems. Integration accounts for interdependencies, or *feedback loops*. Traditionally, economists have captured the notion of feedback loops using dynamic models. With a few exceptions, most standard bioeconomic models consider at most one or two feedback loops and operate at a relatively aggregate level. In many cases such models provide the needed insight into the underlying problem at hand. In other cases, however, more ecological or economic detail is needed to help avoid the unintended consequences of poorly advised policy. This challenge of balancing model tractability with more realism is not new in science, but it hits with full force when addressing the economics of invasive species management.

Herein we address two common questions that arise when doing integrated bioeconomic modeling for invasive species management: (1) what do we gain by integrating the web of life into economic analysis? and (2) if integration is worthwhile, how deep should we go?

What do we gain by integrating the web of life into economic analyses?

Our work over the last decade has addressed whether an explicit accounting of these feedback links yields different policy-relevant results than does non-linked analyses. Consider three examples of linked systems.

i. Yellowstone Lake

Settle and Shogren (2006) constructed an integrated bioeconomic model to examine how invasive lake trout affect native cutthroat trout in Yellowstone Lake. The two key items included in this model are the stocks of lake trout and cutthroat trout. Their results showed how integration of the economic and biological systems lead to different population results compared to treating the systems as separate. Three scenarios were considered, each with and without feedbacks between the economic and ecological systems. The best-case scenario eliminates lake trout immediately and without cost. The worst-case scenario leaves lake trout without any interference from the Park Service, and both lake and cutthroat trout are left to reach their steady-state equilibriums. The middle-ground scenario has the Park Service expending a fixed budget to reduce the risk to cutthroat trout by gill netting lake trout, assuming the Service's current level of expenditures is continuous and perpetual.

Using the population of cutthroat trout as a yardstick, we found that ignoring feedbacks biases risk estimates by overestimating cutthroat populations in the worst case and underestimating them in the best case. The difference arises from fishermen behavior. Without feedback, fishermen continue to fish as before. With feedback, fishermen adapt by fishing less and visiting other attractions more. Interestingly, the findings also revealed a troubling result from a species protection perspective in that only a small difference arises between the net benefits between the best- and worst-case scenarios, which suggests that gill netting for lake trout is inefficient. People preferred improvements in other park amenities (e.g., roads, wildlife viewing) relative to increased populations of cutthroat trout.

ii. Zebra mussels

Finnoff et al. (2005) studied an economic system, composed of a Midwest lake ecological system experiencing a zebra mussel invasion with a resource manager and a powerplant, to determine whether integrating the systems is worth the effort. Two feedbacks were considered—one between the biological system and power plants based on the stock of zebra mussels, and one between the power plants and the manager based on the manager's expectations over the plant behavior. For both loops, the decision maker's beliefs about invasions are central. In the absence of the link between the biological system and power plants, a plant behaves as if its actions cause no change in the biological system. The consequences depend on whether there is an invasion in the initial period, and whether the power plant acknowledges the presence of the invader. For example, with no initial invasion, the power plant neither controls nor adapts, and as the biological system changes, the power plant either uses too few or too many inputs relative to the optimal baseline. In turn, output correspondingly either under- or over-shoots its targeted level; either way this results in opportunity cost losses from production shortages or surplus, determined ex-post.

The second dimension is the feedback between the resource manager and power plant. Removing the feedback causes the manager to act as if the power plant does not respond to changes. For example, following a successful invasion, the manager ignores the private control actions of the power plant. This has direct welfare consequences as resources may not be allocated efficiently, but the magnitude of the consequence depends on the actual response of the power plant. The results suggest that feedbacks can matter for this case—but not in every dimension and in varying degrees. Both biological and economic consequences of not addressing feedbacks are sensitive to the initial environment, behavioral perceptions about the state of the environment, and the completeness of the manager's beliefs.

iii. Leafy spurge

Finnoff et al. (2006) developed an integrated model of a grazing land ecosystem and cattle ranching. The ecosystem consists of native grasses, leafy spurge (an invader noxious to cattle and wildlife), and cheatgrass (another invader). This model considers the stocks of each plant and cattle. Plants in these three species are assumed to behave as if they are maximizing their photosynthetic energy intake minus energy lost to respiration. To photosynthesize, they grow green biomass that provides them access to light; however, the plants are competitors for space. Over time one species eventually will win the competition by driving out the other two.

The results show that without humans, the native grasses are most likely to win. When humans enter and introduce cattle to the grazing ecosystem, the native grasses are placed at a competitive disadvantage, and leafy spurge generally becomes dominant depending on grazing intensity. The model illustrates the importance of accounting for grazing decisions when forecasting the further spread of leafy spurge.

If integration is worthwhile, how deep should it go?

Integrating ecological detail into economic models raises many issues on different levels. The fundamental issue is deciding how deep the integration should go within and between the economic and ecological systems. The tradition in economics

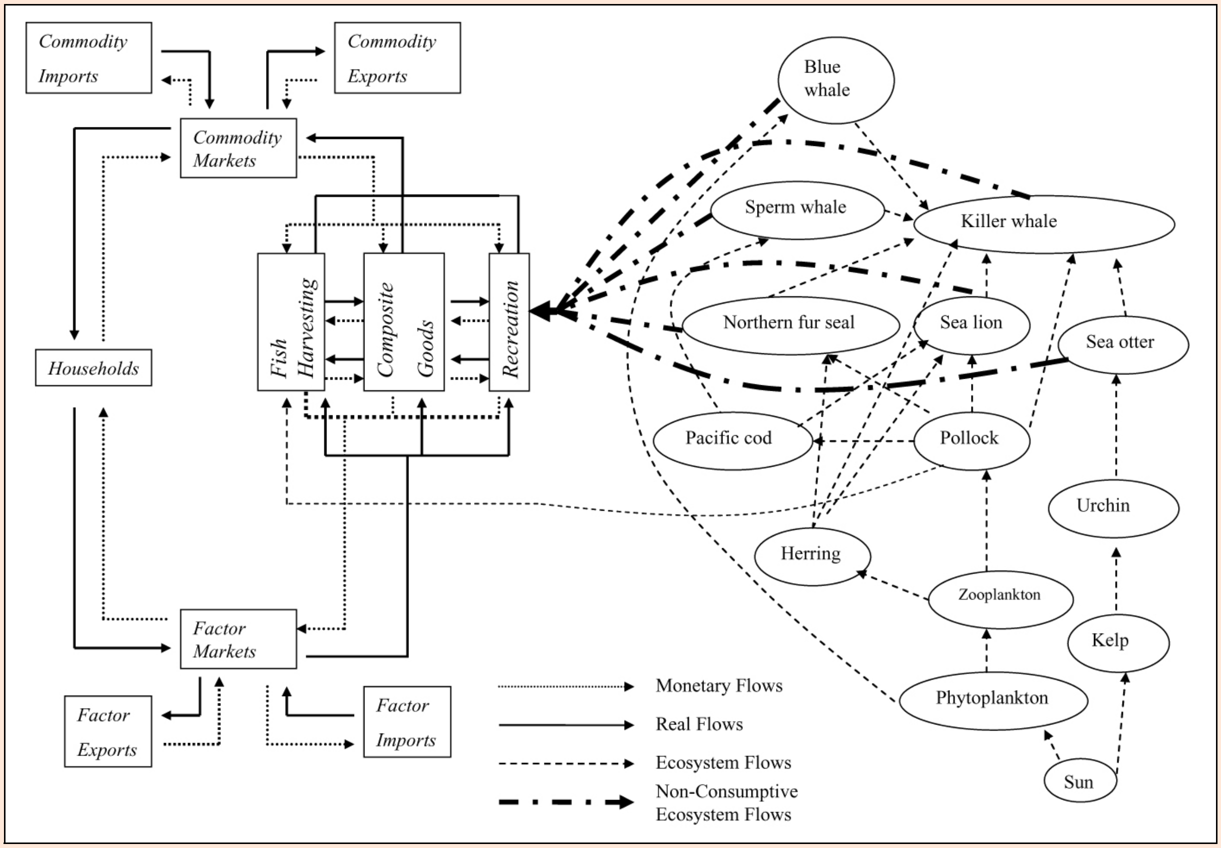

Figure 1. Bering Sea web of life.

is to represent ecological systems as a technical constraint, usually in the form of population growth for a single or aggregate species. The influence of all other species and other components of the ecological system are represented by a fixed carrying capacity. If the policies prescribed by these models do not impact other components of the ecological system, this representation may be appropriate. But if the policies do impact other components of the ecological system, the system can be "bumped" to different results with unintended consequences (Crocker & Tschirhart, 1992). Models not addressing these other components may miss important linkages between humans and nature and provide misguided policy prescriptions.

Deciding just how deep to dig within and between the economic and ecological systems depends on the number of contact points between the systems and the indirect effects within the systems. For cases with one or two points of contact, a *shallow*, or abridged form of integration might suffice. But in cases with multiple contacts or important indirect effects, a *deep* integration is necessary. But in doing so it is necessary to make other simplifying assumptions. Such deeply integrated models may not be more realistic if the feedback loop or other representations do not conform accurately to reality. Addressing the challenge of adding more realism and being forced to solve a problem computationally rather than analytically requires one to work with a solid theoretical framework that guides the depth of integration.

We illustrate the depth of integration challenge by using an example based on Finnoff and Tschirhart (2005) that examines the Alaskan economy and a marine ecosystem comprising Alaska's Aleutian Islands (AI) and the Eastern Bering Sea (EBS). Figure 1 shows the ecosystem and economic interactions and illustrates the thirteen key ecological descriptors and the feedback loops. The economy consists of Alaskan households and producing sectors linked to one another and the rest of the world through commodity and factor markets. All species in the food web are linked through predator-prey relationships and several species provide inputs to economic production. The prominent groundfish of the system, pollock, support a substantial fishery, and marine mammals including Steller sea lions (an endangered species), killer whales, blue whales, sperm whales, northern fur seals and sea otters. All of these species provide non-use inputs to the state's recreation sector. For a policy issue, we focus on the endangered Steller sea lion recovery via alternative pollock harvest quotas.

The first level of analysis is to understand the behavior of the actors in Figure 1. Economists study the behavior of individual consumers and producers. Consumer behavior has people within the household sector box making choices over combinations of goods and services. In Figure 1 this is a focus. Producer behavior is likewise captured by individual firms within the fish harvesting sector box choosing both their optimal mix of inputs and their optimal output level. Alternative quota levels are interpreted as changes in the prices faced by the households or producers. Similarly, ecologists study the behavior of individual animals; they would consider an individual pollock's optimal foraging behavior, and how foraging changes impact pollock populations as depicted within the pollock box. The alternative quotas would be interpreted as changes in the pollock populations.

The next level of analysis is to integrate all economic and ecological agents directly affected by pollock quotas through a bioeconomic harvesting model. In the economic system, individual consumer demands for pollock are aggregated to derive market demand, required for producers' decisions. Producer supplies are in part determined by the availability of pollock, which is derived from the aggregation of individual pollock behavior and population dynamics. Therefore, this level requires integration *across* the household, fish harvester, and pollock components. Linking these three components allows the derivation of market demand and pollock supply, which allows an assessment of how alternative quota policies impact the whole system.

But this level of integration is insufficient if we are interested in how the repercussions of the policies impact all of Alaska. In this case, deepening the analysis a further step *within* the economic system is necessary to include the other producing sectors of the Alaskan economy (recreation and composite goods in Figure 1), all other household demands, and trade flows into and out of the region. A complication arises, however, because the recreation industry depends on the marine mammals. Still further depth of integration is needed *to* increase depth *within* the ecosystem to account for the predator-prey relationship shown in Figure 1.

Finally, another level of integration is needed with nonmarket valuation. Nonmarket valuation involves assessing the total values (e.g., existence values) associated with scenarios of reduced human and environmental damages posed by some invasive species so we can better understand the net benefits of policy. The idea is that valuation work needs integration models to develop credible valuation scenarios. In turn, integration models need the parameters as defined by valuation work to capture the full range of benefits associated with the web of life. For instance, in the Yellowstone Lake case, Settle and Shogren (2006) integrated a valuation experiment within their bioeconomic model. They developed the *Yellowstone Interactive Survey* to ask people to value alternative scenarios designed to inform their integrated model. They determined the value for seeing/catching each species and used these estimates to parameterize the value to see/catch each species in measuring the visitor's welfare from Yellowstone National Park. The disquieting result that people preferred fixing the roads to protecting the native cutthroat trout emerged directly from this integration. Both valuation and bioeconomic modeling can likely be more relevant for policy if the scenarios people are asked to value are valid and if the scenarios created were informed by values stated by actual people. There are gains from joint production of values and feedback loops between economic and ecological systems.

Concluding Comments

Over the years, traditional bioeconomic modeling has improved environmental and natural resource decision making. Today researchers are exploring the next level of integration by expanding the number of feedback loops within and between systems and by making a better link to nonmarket valuation work. This message applies in general to natural resource economics and in particular to invasive species economics. The open question is how to determine the appropriate level of integration for the problem at hand? Is a traditional damage function approach sufficient? Does a one or two state variable optimal control model provide enough guidance, or do we require an even deeper integration between and within disciplines that may only be solved computationally? Addressing these questions requires one to judge a method based on results, not by preconceived methodological principles. Our decisions on the depth of integration in invasive species economics should evolve from our experience about what works and what does not work.

For More Information

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David Finnoff (finnoff@uwyo.edu) is Assistant Professor, Department of Economics and Finance, University of Wyoming, Laramie, WY. Chad Settle (chad-settle@utulsa.edu) is Associate Professor, Department of Economics, University of Tulsa, Tulsa, OK. Jason Shogren (jramses@uwyo.edu) is the Stroock Distinguished Professor and John Tschirhart (jtsch@uwyo.edu) is Professor, both at the University of Wyoming, Laramie, WY. The authors thank the Economic Research Service (USDA), National Science Foundation, and the Environmental Protection Agency for funding support.