

economic productivity and stability. In developed countries, the impact will be slight. Hardly any market-oriented production in the United States, Japan, Western Europe, or Australia is dependent on the weather.

The main exceptions are agriculture, forestry, and fisheries. But in the United States, they account for less than 3 percent of our gross domestic product. The question is not whether we will lose production of food, Schelling said. “The issue is whether food production will become much more expensive, whether the water will be much more expensive to deliver, and whether techniques of cultivation may require new kinds of machinery and maybe more labor—and that’s leaving aside the fact that in the United States, we still generate agricultural surpluses.

“What we must recognize is that the real victims of climate change are going to be in the developing countries, where a third of the gross national product may be agricultural and maybe half the population practices subsistence agriculture,” Schelling said. Probably the best way for them to defend against the adverse effects of climate change is to develop as rapidly as they can, he said. The sooner Malaysia can become like Singapore, the sooner it can worry less about the impact of climate change on health, comfort, and productivity.

“This leads me to conclude that the right way to think about climate change is primarily a foreign aid program,” Schelling said. “The people who will benefit will be seven-eighths of the global population toward the end of the century. They are the people who need protection against climate change that they are not yet prepared for.” ■

## Managing Fish Portfolios

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Many fish stocks throughout the world are below biological target levels that ensure a sustainable population. Most of our knowledge about protecting and rebuilding overharvested fish stocks is based on efforts to protect a single species, such as the Chesapeake Bay blue crab. A common strategy is to place a limit on fishing for the species of concern. However, recent scientific advances in understanding how various species function and interact are leading to a new management paradigm that focuses on understanding the ecosystem in which the species of concern exists.

Marine scientists and policymakers are encouraging ecosystem-based fishery management, but there is limited guidance on how to put the concept into practice. In recent work on Chesapeake Bay fisheries, we have developed a method that accounts for species interdependencies, fluctuations over time, and sustainability constraints.

Our approach is loosely based on techniques employed in financial asset management. Investors used to focus on the risk (variance) and rewards (expected returns) of individual securities, similar to how fisheries are managed today. Portfolio theory shifted the perspective from choosing individual stocks to picking diversified portfolios, where taking into account the correlations across securities could re-

duce risks in order to yield the desired rate of return. Similarly, interdependencies between species, such as predator-prey or symbiotic interactions, mean that risks from harvesting each species can be correlated, making it possible to determine whether potential benefits could arise from jointly considering multiple fish stocks.

A portfolio approach to Chesapeake Bay fisheries management is a good fit for at least two reasons. First, Chesapeake Bay fishers are known locally as “watermen,” reflecting their ability to earn a living off the water from a variety of activities. They are already manage their individual portfolios by harvesting a variety of species—including oysters, blue crabs, and striped bass—and employing different methods, such as tongs for oysters, various types of nets for finfish, and crab pots and dredges for crabs.

Second, Bay policymakers from Maryland, Virginia, Delaware, Pennsylvania, and the National Oceanic and Atmospheric Administration’s Chesapeake Bay office have demonstrated interest in developing ecosystem-based fishery management plans. The latest update to the Chesapeake Bay Agreement includes a goal to develop such plans for target species, and the current Chesapeake Bay Fisheries Ecosystem Plan specifically calls for examining patterns of harvests as well as

incorporating uncertainty into fisheries management decisions.

Using readily available data on Chesapeake Bay fish catches and prices from 1962–2003, we derived an ecosystem frontier, a curve that plots the tradeoff between the variability of fishing revenues and the different levels of revenues (see figure below for an illustration of how this works). Minimizing this variability can be beneficial to fish processors, fishery-dependent communities, and individual fishermen, who may have boat and home mortgage payments but limited income outside of fishing. Furthermore, minimizing variability in fish populations, which is related to catch

volatility, is an important ecological objective because less stable systems can lead to lower biodiversity.

Our sample included the top 22 revenue-generating species: oysters, crabs, clams, snails, and finfish such as menhaden, striped bass, and blue fish. For low expected revenues, managers can diversify catches by completely curtailing total allowable catches for certain high-risk, low-return species. To reach a higher revenue target, however, managers must maximize the catch of more species. Each point on the frontier corresponds to a set of catch limits (see figure).

How does this compare to a single-species approach? Analyzing both an

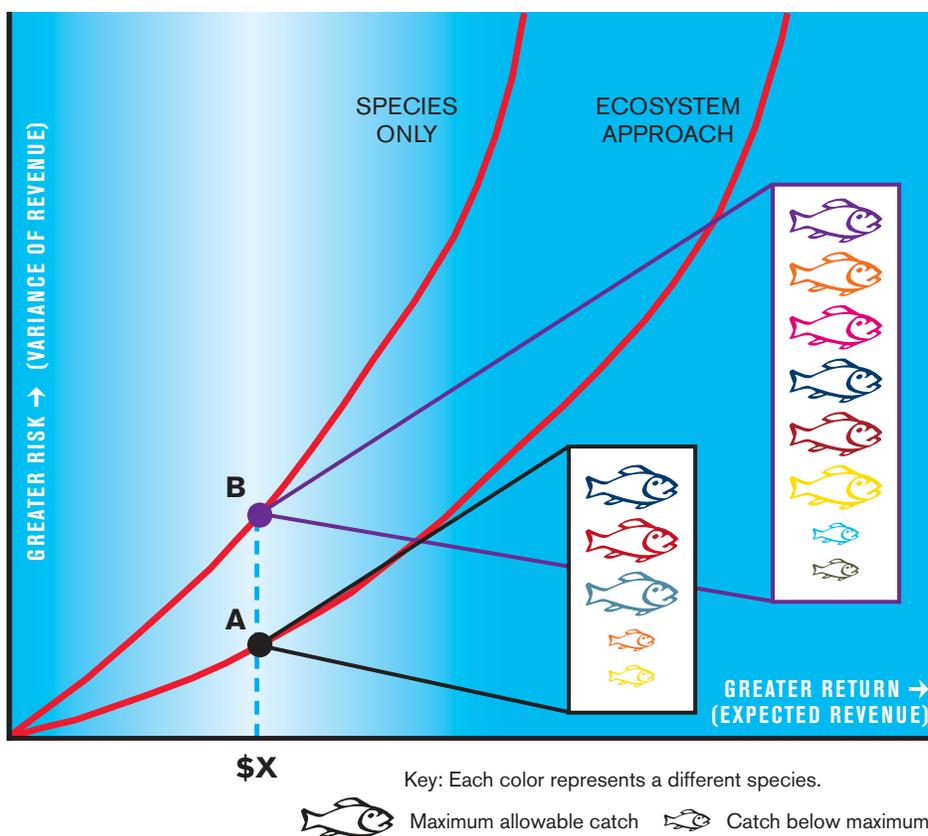
ecosystem frontier and a species frontier (which does not take into account the species interactions and is akin to how fisheries are for the most part managed today), we find that there are gains to be had. For example, for the same revenue target, the ecosystem approach can have considerably less variance (compare point A to point B). The inset to the figure also shows how different the recommendations for catch limits can be between the two approaches, where the single species approach more often relies on larger catches and includes a greater number of species than the ecosystem approach.

We also compared the actual revenues for each species in the Bay, (working from a subset of the larger sample) to the implied allocations from the ecosystem frontier and found that managers could have reduced the variability in returns. Preliminary analysis also confirms the structural change to the Chesapeake Bay ecosystem, in terms of species interactions, that resulted from the devastating oyster disease in the early 1980s, which dramatically reduced the oyster population.

A variety of other modeling methods are being developed for ecosystem-based fisheries management. Our portfolio approach complements this emerging suite of tools by incorporating, in a practical way, knowledge of the interactions of species within an ecosystem. ■

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## RISK-RETURN TRADE-OFFS



For an expected level of revenue of \$X million, the ecosystem approach recommends point A and the species-only approach point B, which has greater variability than A. Each point on this representative frontier corresponds to a set of catch levels for the species in the ecosystem. We find, in general, that the species-only approach results in greater catches of some individual species and includes more species than the ecosystem approach.