

Fisheries in a Complex Ecosystem

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Abstract : An important subset of natural resource management addresses preserving and/or harvesting biological resources. Examples are policies that derive from the Endangered Species Act including habitat conservation plans, the U.S. Forest Service's logging practices, and fishery management councils' decisions regarding catches. To understand the effectiveness of management policies requires an understanding of the interactions between the natural world and the human economy, because economies and ecosystems are inextricably linked. Common economic variables such as incomes and prices affect and are affected by common ecosystem variables such as resiliency and species populations. In spite of the linkages between the two systems, models of economies and ecosystems usually disregard one another.

The fisheries literature may be where biology and economics have been integrated most closely. Economists have made liberal use of the biology inherent in the familiar Schaefer curve model to describe optimal harvesting of fish and other species under a variety of economic conditions including alternative market structures and property right assignments, and using different regulatory instruments including taxes, permits and quotas. In addition, the biology has been extended to allow for harvesting species that are in predator-prey relationships (egs. Quirk and Smith, 1970; Clark, 1976; Wacker, 1999). The latter extension is important because in reality a harvested species is likely to be in one or more predator-prey relationships with other species who are, in turn, likely to be in still other predator-prey relationships. The ecosystem to which the harvested species belongs is a complex web of numerous interacting species, many of which may affect and be affected by harvesting decisions. However, capturing all the interactions in bioeconomic models is difficult (Munro and Scott, 1985).

This paper offers a different approach to the fisheries model and the harvesting decision that allows for any number of interacting species. The approach employs a general equilibrium model of an ecosystem that resembles a general equilibrium model of an economy, yet captures salient biological features (Tschirhart, 2000). The ecosystem is modeled by viewing each species as economists view industries. Industries are comprised of firms and species are comprised of organisms. As firms buy and sell intermediate goods between each other, organisms demand and supply biomass between each other. As firms substitute across factors of production to maximize profit, predator organisms substitute across biomass from alternative prey species to maximize net energy intake. As firms respond to factor prices as signals, predators respond to the costs or prices of

capturing prey which are in units of energy. When organisms prey on other organisms to acquire energy and biomass, they also lose energy and biomass to predation and through respiration and reproduction. Physiological functions govern each species transformations of captured (input) energy into predation and respiration (output) energy, similar to the way firms' production functions transform inputs into outputs. All energy in the ecosystem originates from the sun and is passed from primary producers to secondary producer to predators.

Each organism's maximization problem yields the organism's demand for and supply of biomass to other organisms as functions of the energy prices. The demands and supplies for each biomass are aggregated over all organisms in each species which yields biomass markets wherein biomass prices are determined. A short-run equilibrium is established when all organisms are maximizing and demand equals supply in every biomass market. If a species exhibits positive (negative) net energy in equilibrium, its population increases (decreases) and a new equilibrium follows. The demand and supply forces in the biomass markets drive each species toward zero net energy and a long-run equilibrium. Population adjustments are not based on typical Lotka-Volterra differential equations in which one entire population adjusts to another entire population, thereby masking organism behavior; instead, individual organism behavior is central to population adjustments.

To illustrate the model's general equilibrium properties, to see how the model captures biological functions, and to understand how it can be used to address problems in a fishery, a simulation of a food web containing commercial fish species is employed. The food web is taken from a study in *Science* (1998) and consists of killer whales, sea otters, pinnepeds, fish, sea urchins

and kelp in the seas off Alaska. The study investigates why the whales were preying less on declining pinniped populations and more on otters, resulting in explosions in the urchin populations which are prey for otters, and collapses in the kelp populations, which are prey for urchins. These changes in turn are depleting the fish which need kelp, and depleting the pinnepeds which prey on fish. The authors conjecture that excessive harvesting of fish by humans led to this chain reaction in the ecosystem. The final result to the economy is to have lower fish stocks for harvesting, and it is these types of economic/ecosystem interactions that a general equilibrium model of an ecosystem uncovers. The advantage of the general equilibrium ecosystem model is that it shows not only how the fish population changes owing to both direct human harvesting and to indirect food web interactions, but also how the pinniped, whale, otter, urchin and kelp populations are changed. These latter changes will have direct impacts on other economic markets, because humans make non consumptive use, and possibly consumptive use, of whales, otters and pinnepeds.

The paper examines these interactions by combining the ecosystem model with a computable general equilibrium model of the economy. Consumers can purchase fish or a composite good, and both of these final goods are produced using capital and labor. Considering both open access and optimal harvesting, we can trace how a policy that does not account for the complex interactions in the ecosystem can lead to declining stocks of fish and of the other species in the food web.

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