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ANALYSIS

Reassessing the costs of biological invasion: *Mnemiopsis leidyi* in the Black sea

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Abstract

Invasions of ecosystems by exotic species have been the focus of a growing body of research in applied biology and ecology, but relatively little attention has been paid to their economic consequences. Even where economic estimates have been made these often make ad hoc assumptions about the biological relationships of interest and lack grounding in economic theory. This paper develops an integrated ecological-economic approach to assess the economic consequences of invasion for a commercially harvested endemic species whose population dynamics are altered by the invader. As a case study, the Black Sea anchovy fishery represents an interesting example of such a situation. In the early 1980s, the comb jelly *Mnemiopsis leidyi* invaded the Black Sea, eventually becoming established and experiencing a population explosion with dire consequences for the commercial anchovy fishery. In modeling the population dynamics of the Black Sea anchovy (*Engraulis encrasicolus*), the influence of *Mnemiopsis* is incorporated as a structural change in the anchovy stock-recruitment relationship. Then the economic loss associated with this structural change is assessed, using a discrete, dynamic bioeconomic model. It is shown that *Mnemiopsis* had a dramatic effect on the potential sustainable harvest from an optimally managed anchovy fishery but these losses were at least an order of magnitude lower than estimates cited elsewhere.

Keywords: Anchovy; Bioeconomic model; Economic valuation; Exotic species

1. Introduction

Interest in the unwanted economic consequences of species introductions has been increasing, in part because of a recent estimate of the costs of such invasions imposed on the economy of the US (Pimentel et al., 2000). Yet there exists little formal economic analysis of the costs imposed by species invasions.[1] A number of issues arise in attempting to add to the limited knowledge on this issue. How should a

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[1] For exceptions, see the collection of papers in the *American Journal of Agricultural Economics*, (Number 5, 2002) and Perrings et al. (2000).

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species invasion be characterized in terms of its ecological and economic dimensions? Can historical invasions be subjected to proper empirical analysis grounded in theory, or will the problem remain one of primarily theoretical interest supplemented with occasional ad hoc calculations of economic impacts? Are existing methodologies adequate for quantifying the social costs imposed by invasions or are more specialized techniques required? This paper addresses such questions using as an example a well known marine invasion that has had a large impact: the introduction of the comb jelly *Mnemiopsis leidyi* into the Black Sea. This invasion makes a good case study since initial estimates of its economic impact on the fisheries of the Black Sea have been published in the scientific literature (Travis, 1993). These estimates make a useful reference point for the more formal analysis developed in this paper.

Invasions represent a problem with both economic and ecological dimensions. The economic cost associated with a historical biological invasion has several components. In addition to direct impacts on human welfare (i.e. they are arguments in the utility function), invasions are likely to affect human welfare indirectly via disruptions in the population dynamics of valuable indigenous species. Valuation of these latter effects can be accomplished using the production function or related approaches (Knowler, 2002). Additionally, any costs of control should be included to provide a full accounting of the social costs of invasion.

The characteristics of the invasion of the Black Sea analyzed in this paper motivate the particular modeling approach adopted here. For example, the direct impact on utility and the costs of controlling the invader once it became established were not included in the model, since these have not been significant factors in the case study application. Instead, a bioeconomic modeling approach was used to capture the indirect influence of the invader (*M. leidyi*) on a commercially harvested species, the Black Sea anchovy (*Engraulis encrasicolus*). A bioeconomic model can employ the tools of welfare measurement when there is a change in an environmental input into a production activity (Freeman, 1993). However, applying this approach requires that the underlying biological and ecological relationships be specified explicitly.

In biological and ecological terms, an invasion constitutes an ecosystem surprise or shock, potentially leading to nonlinear, discontinuous and other complex dynamic behavior (Holling, 1986). Applied modeling of such events faces challenges, not least because of the limitations of conventional modeling techniques that rely on continuous variables for most biological (and economic) applications. Moreover, the sudden appearance of a foreign species in an ecosystem cannot be characterized readily by existing predator–prey or similar models, as these presuppose some degree of continuity in the ambient environment, allowing the researcher to concentrate on the interrelationship between predator and prey without worrying about other relationships. In contrast, the entry of an exotic species may set off numerous responses among a wide range of species, disrupting preexisting ecosystem functioning and creating feedbacks that cannot be captured by the relatively narrowly focused predator–prey model.

For the present, empirical researchers may need to be satisfied with characterizing prior and post states and examining the long run implications of an invasion in economic terms. This observation implies an analysis of steady states (assuming these exist), with the economic costs of invasion measured as the difference in economic welfare under the pre- and post-invasion states (Barbier, 2001). When taking this approach, the shift from one state to another can be conceived as a structural change in the biological relationships characterizing the initial state of the ecosystem. For example, the introduction of an exotic comb jelly may alter the population dynamics of a species that it preys upon and/or competes with and this could be captured as a structural change in the parameters of the stock-recruitment relationship of the prey. Structural change models are widely used in economics (see Maddala and Kim, 1998), but this paper applies such a model to the biological relationship between an invading species and a commercially important fish species.

An important attribute of the model is its assumption of optimal management of the Black Sea anchovy fishery, which contrasts with the historic condition of de facto open access.[2] Moreover, since anchovy is an

[2] It might be argued that the situation comes closer to what Homans and Wilen (1997) refer to as regulated open access, since the Turkish authorities imposed some restrictions in the form of minimum catch size but it is not known how well these were enforced.