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# Optimal renewable resource management in the presence of endogenous risk of invasion

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**Abstract**

In this paper we examine the optimal management of a renewable resource that is at risk from alien species invasion. The objective of this paper is to derive implications for optimal management of a resource when options exist for both preventing the arrival of an invasive species and mitigating the impact of that arrival. Uncertainty about the timing and nature of an invasion can have important implications for the choice of management strategy, and a key feature of this analysis is an explicit treatment of that uncertainty.
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## 1. Introduction

Invasive species are emerging as a major environmental policy concern (Pimentel et al., 1999, 2000). The introduction of non-native plants, animals, viruses and other organisms into ecosystems has been recognized to be the largest source of ecosystem change and biodiversity loss in the world after habitat destruction (Glowka et al., 1994). There are numerous examples of the destructive impact of invasive species. The introduction of brown trout in New Zealand in 1862 has led to a complete elimination of the native Galaxiid fish today (Flecker and Townsed, 1994). Introduction of the Nile Perch to Lake Victoria caused the extinction of about 100 native fish species (McNeely, 2000). Introduction of the African Tilapia into Lake Nicaragua caused the collapse of one of the world's unique freshwater ecosystems (McNeely, 2000). A well-known example of unintentional introduction is the case of zebra mussels (*Dreissena Polymorpha*) imported into the Great Lakes in ballast water; this non-native species has caused significant reduction in phytoplankton biomass and biofouling of man made structures (McIsaac, 1996). The value of fish catch alone in Lake Erie has gone down from $600 million in 1986 to $200 million in 1990 due to Zebra mussel invasion (McNeely, 2000). Invasive weeds have also been estimated to cost US farmers about $4 billion a year (Devine, 1998). Overall damages from invasives species are estimated to be much higher at about 138 billion dollars a year (Pimentel et al., 2005).

The risk of harmful invasions is increasing with the growth in international trade and tourism, and with climate change. Changes in climatic conditions can create favorable conditions for non-native species to establish themselves in new locations (Karevia et al., 1993; Stachowicz et al., 2002). Similarly, economic activities and biological invasions have been found to be positively correlated (Jenkins, 1996). With increasing international trade in agriculture, forestry, livestock, etc., alien species have been transmitted all over the globe. In Britain, for example, there have been more frequent incidents of the disease 'spring variaemia' since the relaxation of the import regime by the European Union in 1993 (The Economist, 2003). The cost of attempts to prevent such invasions in the

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United States has been very high. The General Accounting Office reports that the US government spends $600 million annually on combating invasive species (Hosansky, 2001). "Every year, the 2000 inspectors in the Agricultural Department's Animal and Plant Health Inspection Services (APHIS) face the Herculean task of checking some 50,000 ships, 1 million aircraft and tens of millions of travelers arriving from overseas with countless tons of cargo and packages" (Hosansky, 2001).

While a number of studies exist on the ecological aspects of species invasion, work related to the economic aspects of these invasions has only recently begun to emerge. Recent studies include those by Shogren (2000), Knowler and Barbier (2000), Eiswerth and Van Kooten (2002), Settle and Shogren (2002) and Eiswerth and Johnson (2002). The focus of this literature has been on the methods used to control the invaders without specific attention paid to the role of management of native species themselves for their survival and continuing economic productivity. Intuitively, the risk of losing a resource to invasion would, all other things being equal, reduce societal incentives to conserve the native species. This logic suggests that reduced conservation efforts and higher harvests would be the optimal response to the risk of invasion. However, if the resilience of the system is dependent on the stock of the native species itself, then the incentives for stock management may be reversed.

In cases where post-invasion survival and productivity of resources are stock dependent, the analysis of the invasive species management problem becomes much more complex. Notable in this regard is the study by Knowler and Barbier (2000) who analyze the economic losses from invasion in a dynamic predator–prey setting. They characterize the damages from invasion based upon the difference between the pre-invasion and post-invasion size of the native species stock. However, their model does not consider the possibilities of manipulating that difference through management of the pre-invasion stock or other prevention efforts.

In this paper we examine the optimal management of a renewable resource that is at risk from alien species invasion. The objective of this paper is to derive implications for optimal management of a resource when options exist for both preventing the arrival of an invasive species and mitigating the impact of that arrival. Uncertainty about the timing and nature of an invasion can have important implications for the choice of management strategy; a key feature of this analysis is an explicit treatment of that uncertainty. In our analysis, the uncertainty associated with an invasion is controllable through the preventive control measures and is thus endogenized.

The next section develops a model of a bio-economic system at risk of invasion. In the context of the model, we examine optimal rules for levels of native resource stock as well as prevention and mitigation effort. The analysis concludes with a numerical simulation illustrating the sensitivity of the optimal steady-state approach path to variation of important policy parameters.

## 2. The model

The literature on invasive species often divides the process of invasion into three phases; introduction of the species, establishment of the species and conversion into pests (Perrings, 2003). Invasive species can be managed through preventive, mitigative, and adaptive measures. Preventive measures address the first step in the process and include activities to eradicate or control potential invaders in their 'home locations' as well as measures to limit their movement into new territories. Examples of such efforts are requirements that ships eliminate ballast water before entering protected waters, and manual inspection of import goods such as timber that may carry harmful pests. We denote preventive efforts as $\varepsilon_p$.

Preventive activities will generally only help reduce the probability that an alien species will become introduced into a system. Mitigative measures address the second and third steps in the process, and are taken to limit damages after a species has been introduced into a new environment. Specifically, mitigative measures include steps taken to increase the resiliency of the resource in the wake of invasion by creating conditions that would limit the non-native species population, so that, although established, the extent of its impact on the native system is diminished. We denote mitigative efforts as $\varepsilon_m$.

Adaptive measures include more direct, post-invasion controls involving physical, chemical, or biological elimination of invasive species. They also include indirect methods of control such as change in consumption and production behavior in order to minimize the spread and damages from the established species. Although it would be possible to incorporate such strategies through the specification of the resource's post-invasion value function, we do not explicitly incorporate this management option into our model.

Our terminology differs slightly from that found in the previous literature. Perrings (2003) defines mitigation as "actions that reduce the *likelihood* of invasions by reducing the invasiveness of species or the invasibility of ecosystems", and adaptation as "actions that reduce *the impact of introduction, establishment or spread* without changing the likelihood that it will occur." Our use of the term "mitigation" is broader than Perrings' in that it refers to all pre-invasion actions that reduce the extent to which invading species can establish themselves. Mitigative efforts may still allow for invasions, but they endeavor to keep those invasions contained. Our use of the term "adaptation", on the other hand, is more narrow than Perrings' in that it refers solely to actions taken once the invading species has arrived and established itself in order to reduce the impact of that establishment and prevent spread. This allows us to separate efforts, and the costs of

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