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Optimal control of an invasive species with imperfect information about the level of infestation

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ABSTRACT

The presence of invasive species is often not realized until well after the species becomes established. Discovering the location and extent of infestation before the invasive species causes widespread damage typically requires intensive monitoring efforts. In this paper, we analyze the problem of controlling an invasive species when there is imperfect information about the degree of infestation. We model the problem as a partially observable Markov decision process in which the decision-maker receives an imperfect signal about the level of infestation. The decision-maker then chooses a management action to minimize expected costs based on beliefs about the level of infestation. We apply this model to a simple application with three possible levels of infestation where the decision-maker can choose to take no action, only monitor, only treat, or do both monitoring and treatment jointly. We solve for optimal management as a function of beliefs about the level of infestation. For a case with positive monitoring and treatment costs, we find that the optimal policy involves choosing no action when there is a sufficiently large probability of no infestation, monitoring alone with intermediate probability values and treatment alone when the probability of moderate or high infestation is large. We also show how optimal management and expected costs change as the cost or quality of information from monitoring changes. With costless and perfect monitoring, expected costs are 20–30% lower across the range of belief states relative to the expected costs without monitoring.

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1. Introduction

The movement of people and goods around the globe has increased the movement of species into novel environments often far removed from their place of origin. Some newly introduced species become invasive species that establish and spread because they lack effective competitors, pathogens, or predators to keep the population in check, and cause ecological or economic harm. Harm can occur because an invasive species reduces populations of native species, damages crops or forage (e.g., cheatgrass, *Bromus tectorum*), damages infrastructure (e.g., zebra mussels, *Dreissena polymorpha*, and their impacts on water intake pipes) or causes other forms of damage. Measures of the economic cost of invasive species are imprecise but these costs may be quite large. Some estimates of damage are in the billions of dollars annually (e.g., Lovell et al., 2006; OTA, 1993; Pimentel et al., 2000, 2005). The US government spends over $1 billion dollars annually on invasive species control efforts (US National Invasive Species Council, 2006). Allocating control efforts so that costs associated with invasive species are minimized is an important issue.

In this paper, we analyze the problem of controlling an invasive species when there is imperfect information about the degree of infestation. The presence of invasive species is often not realized until well after the species becomes established (Costello and Solow, 2003). Infestations often start with small populations that may go unnoticed for some time. Detection may not occur until the population has grown larger when it is easier to detect the species through search efforts or because there are observable damages that can be linked to the presence of the species. Even when the presence of a species is detected, the actual extent of the infestation may still be unknown. Optimally controlling an invasive species whose presence or degree of infestation is not known involves choosing a level of monitoring effort to learn about the degree of infestation as well as choosing a level of treatment to reduce or eliminate the invasive species in the environment. Because damage grows as the population of the invasive species grows, there is value to monitoring to be able to spot an invasion early. Because treatment is costly, there is value to monitoring to gain information about the scale of the problem to know when and where to apply treatment. However, because monitoring itself is costly, monitoring should only be done when monitoring costs are low relative to the probability of infestation and expected damages from infestation, and there is effective (but costly) treatment.

We model the problem of controlling an invasive species with imperfect information about the level of infestation as a partially observable Markov decision process (Cassandra, 1994). The process is partially observable because the decision-maker receives a signal about the degree of infestation but this information is imperfect. The signal (information) may be from reported observations of the species, but these reports may contain both false positive and false negative signals. There might also be observed damage to vegetation associated with the presence of an invasive species. However, damages may go unobserved for some time and some observed damage may be due to other causes. Higher infestation levels make it more likely that the decision-maker will get a correct signal of infestation but the signal is still not likely to be perfect, especially with respect to the degree of infestation. The decision problem of controlling an invasive species in this context is a Markov process because the degree of infestation in the next period is a function of the degree of infestation and management actions taken in the current period. The objective of the decision-maker is to try to minimize the sum of discounted costs associated with management (monitoring and treatment), and damages caused by infestation of the invasive species in the environment. Based on the beliefs about the probability distribution about the level of infestation, the decision-maker chooses whether to do nothing (no action), only monitor, only treat, or do both monitoring and treatment jointly. Monitoring improves the information about the degree of infestation while treatment reduces the level of infestation.

The introduction of imperfect information about the degree of infestation increases the complexity of solving for optimal management, as compared to the case with complete information where optimal policy only involves comparisons of benefits and costs of treatment. With incomplete information, the set of decisions includes monitoring and treatment. But optimal monitoring and treatment decisions require an assessment about the likely degree of infestation. Probability distributions of the degree of infestation should incorporate information on management action and probability distributions of the degree of infestation in the prior period, plus any new information