Resource and Energy Economics 37 (2014) 226–241

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

Monitoring as a partially observable decision problem

Paul L. Fackler[a,*], Robert G. Haight[b]

[a] Department of Agricultural and Resource Economics, North Carolina State University, Box 8109, Raleigh, NC 27695, USA
[b] U.S. Forest Service Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108, USA

ARTICLE INFO

Article history:
Received 5 April 2012
Received in revised form 20 December 2013
Accepted 27 December 2013
Available online 9 January 2014

JEL classification:
C61
C63
Q20
Q50

Keywords:
Environmental monitoring
Dynamic programming
Partial observability
Value of information
POMDP

ABSTRACT

Monitoring is an important and costly activity in resource management problems such as containing invasive species, protecting endangered species, preventing soil erosion, and regulating contracts for environmental services. Recent studies have viewed optimal monitoring as a Partially Observable Markov Decision Process (POMDP), which provides a framework for sequential decision making under stochastic resource dynamics and uncertainty about the resource state. We present an overview of the POMDP framework and its applications to resource monitoring. We discuss the concept of the information content provided by monitoring systems and illustrate how information content affects optimal monitoring strategies. Finally, we demonstrate how the timing of monitoring in relation to resource treatment and transition can have substantial effects on optimal monitoring strategies.

1. Introduction

Resource managers undertake monitoring activities to estimate the state of the resource and learn about its dynamics. Because monitoring activities are costly, it is appropriate to integrate them into a larger resource management plan (Nichols and Williams, 2006; McDonald-Madden et al.,

* Corresponding author. Tel.: +1 1919 515 4535; fax: +1 1919 515 1824.
E-mail addresses: paul_fackler@ncsu.edu (P.L. Fackler), rhaight@fs.fed.us (R.G. Haight).

0928-7655/$ – see front matter
http://dx.doi.org/10.1016/j.reseneeco.2013.12.005

2010). For example, resource monitoring can be coupled with treatment in an adaptive management framework to gather information and reduce uncertainty about resource dynamics (Walters and Hilborn, 1976; Probert et al., 2011; Williams, 2011). Monitoring can also be used to reduce uncertainty about the state of the resource and improve the quality of treatments. This paper focuses on the problem of determining optimal monitoring strategies when the state of the resource is uncertain.

Researchers have used the Partially Observable Markov Decision Process (POMDP) framework to address resource management problems in which the resource state is uncertain. We review the POMDP framework and its applications to resource monitoring. For example, Haight and Polasky (2010) use the POMDP framework to determine a management strategy for controlling an invasive species with imperfect information about level of infestation. Other applications include monitoring strategies for erosion control (Tomberlin and Ish, 2007), environmental compliance (White, 2005), the presence of an invasive species (Regan et al., 2006), and the presence of an endangered species (Chadès et al., 2008).

A distinguishing feature of the POMDP framework is its recognition that, although managers undertake monitoring activities to discover the true state of the resource, those monitoring activities may not provide correct information. For example, a monitoring system may not detect the presence of an invasive species when in fact there is a moderate infestation (Haight and Polasky, 2010). The POMDP framework includes an observation model that predicts the probabilities of observing different resource states as a function of the actual resource state and the type of monitoring activity that is undertaken. The optimal resource treatment and monitoring activities over time depend on their associated observation models and costs.

The applications of the POMDP framework to resource monitoring have paid scant attention to the information content and timing of monitoring activities. We discuss the concept and measure of information content and show how the relative information content provided by alternative monitoring activities affects the optimal monitoring strategy. In addition, we address the issue of timing the monitoring activity in relation to the treatment decision and resource transition. We present a novel formulation in which monitoring is performed prior to treatment decisions, which in turn are conditional on the monitoring results.

2. Applications of POMDPs to environmental issues

The literature applying POMDPs to environmental issues is relatively small but growing. Lane (1989) appears to be the first paper to use the POMDP framework in a resource management problem which involves fishing decisions when the fish stock is not directly observed. The problem is to determine where to fish during the season given current beliefs about the level of the aggregate fish stock. Rather than viewing monitoring as a separate and costly activity, monitoring is assumed to occur in conjunction with the fishing activity. The model includes an observation function for each fishing location that specifies the probabilities of catch levels given the aggregate level of fish stock. The outcome of the fishing activity is used to update beliefs about the aggregate fish stock and decide where next to fish. Partial observability in fisheries management has also been addressed by making the decision directly dependent on the monitoring outcome rather than on belief states (Clark and Kirkwood, 1986; Moxnes, 2003; Sethi et al., 2005).

Studies that focus on monitoring as a separate and costly activity fall into three main application areas that address various land management issues and the management of endangered and invasive species. In land use applications, a site is classified into two or more categories but the current state of the site is not known. Monitoring can be undertaken to reduce uncertainty about the state of the site and treatment activities can also be initiated to alter the state of the site. White (2005) addresses the problem of choosing a monitoring system to support decisions concerning conservation activities on land sites when the current state of a site is not known with certainty. The site is classified according to which of two alternative vegetative covers dominates. Four different monitoring systems are considered, differing by their information content and cost. Tomberlin and Ish (2007) consider the problem of when to monitor or repair a logging road to reduce erosion when the degree of erosion is not known with certainty. Crowe and White (2007) consider the optimal use of potentially degraded