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Research article

Making the best use of experts' estimates to prioritise monitoring and management actions: A freshwater case study

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ABSTRACT

Under limited time and resources, ecological managers are under increasing pressure to demonstrate tangible impact of monitoring activities. Value of Information (VOI) has been advocated as an ideal tool to evaluate whether more data is required to improve expected management outcomes. Yet, despite several recent works explaining its value, VOI remains seldom used in practice. Here we provide an example of a successful ecological application of VOI. We apply VOI to a novel multi-objective freshwater management problem and show how to make the best use of expert data through a robust sensitivity analysis. Unlike previous VOI approaches, our analysis provides statistical confidence to our recommendations. We apply our approach to the recovery of Moira grass (*Pseudoraphis spinescens*) plains, a threatened vegetation community at the Ramsar-listed Barmah Forest on the Murray River, Australia. Working closely with managers, we discovered that although many threats may impede Moira grass recovery, reducing grazing pressure and applying ideal depth and duration of flooding were most likely to lead to recovery. We found that learning from monitoring can significantly increase the existing extent of Moira grass, although these gains are modest compared to immediate management action. Our study shows how VOI can be used to demonstrate efficient use of limited environmental water to maximise ecological impact and increase transparency when making monitoring or management decisions. More broadly, the study methods will be of interest to any environmental manager who needs to prioritise monitoring and evaluation activities subject to a limited research budget. At a time where researchers and managers are asked to be more accountable for their decision-making, VOI provides a very accessible tool that can speed up the decision of whether to wait and collect more data or act immediately despite uncertainty.

1. Introduction

Ecological managers are under increased pressure to demonstrate that their limited resources have been invested in the best possible way. This requires managers to demonstrate tangible impact of their decisions on their study systems, but demonstrating impact is difficult because the effects of management are usually uncertain. When the best management action is uncertain, managers face the difficult decision to either invest in immediate management action and risk taking a suboptimal action, or delay action and invest in monitoring to identify the best management action for future decisions (Chadès et al., 2008; McDonald-Madden et al., 2010; Martin et al., 2017). Among the many approaches proposed to help ecological managers make informed decisions, Value of information analysis (VOI) (Howard, 1966; Canessa et al., 2015) stands out as a simple approach that can prioritise promising management actions in a short amount of time. Despite several attempts to democratise the use of VOI (Canessa et al., 2015; Williams and Johnson, 2015), VOI has only been applied to a handful of case studies in ecology (Keisler et al., 2014), notably Runge et al. (2011), Moore and Runge (2012), Johnson et al. (2014a), Johnson et al. (2014b), Maxwell et al. (2015), Tulloch et al. (2017). Here, we provide the first example of a successful application of VOI

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to the ecological management of a freshwater system (Keisler et al., 2014).

Overexploitation, flow modification, destruction or degradation of habitat and invasion by exotic species threaten freshwater biodiversity worldwide (Dudgeon et al., 2006). For many species and ecosystems, human intervention to address these threats is required to preserve biodiversity. Actions to manage threats to freshwater biodiversity are diverse, however the effectiveness of many actions is uncertain. For example, environmental flow releases are used to manage numerous threats, but there is considerable uncertainty about the ecological responses to a given input of water (Humphries et al., 1999; Poff and Zimmerman, 2010; Koehn et al., 2014).

Management actions with uncertain outcomes are problematic for managers (Polasky et al., 2011; Mills et al., 2014). For example, an action with high predicted impact but also high uncertainty may result in very low impact when implemented (or vice versa). A simple way to incorporate this uncertainty is by considering the expected benefit of actions, i.e., the predicted impact weighted by the likelihood that the impact will be achieved. Although calculating the expected benefit suggests actions under existing uncertainty, it does not quantify the value of reducing uncertainty.

Monitoring can improve certainty in outcomes, but the cost of investment in data collection and analysis should be weighed against the potential benefit of learning the best management action (McDonald-Madden et al., 2010). Monitoring is a good investment where the expected benefits of removing the uncertainty outweighs the cost of monitoring. Where resources for environmental management are limited, data collection should be prioritised so that resources are used to learn about key uncertainties and improve future management (Canessa et al., 2015).

Here we use VOI (Yokota and Thompson, 2004) to quantify the expected gains from resolving uncertainty using different monitoring and management approaches and to prioritise actions. We posit that the best uncertainty to target is the uncertainty which, if resolved, would lead to the greatest increase in expected management outcomes. We demonstrate how VOI can be used to inform decisions on how to best restore a declining aquatic grassland community.

2. Methods

2.1. Case study

We use VOI to quantify the expected value of reducing uncertainty about the factors limiting Moira grass (*Pseudoraphis spinescens*) plains recovery at Barmah Forest in Victoria, Australia (Fig. 1).

Barmah (and the adjacent Millewa forest) supports the largest and most southerly area of Moira grass plains in Victoria (Colloff et al., 2014). Moira grass plains are an instrumental part of Barmah's Ramsar ecological character description (Hale and Butcher, 2011), yet reduction in their area means the ecosystem type is now threatened with extinction. The rate of decline suggests that Moira grass may no longer dominate any area of open plains by 2026, which threatens the forest's Ramsar listing (Colloff et al., 2014). Grazing and changes to the flood regime through river regulation are implicated as key drivers of the reduction of Moira grass plains (Colloff et al., 2014; Vivian et al., 2015).

Environmental water managers at Barmah manage for Moira grass, attempting to provide winter/spring inundation and a summer drying phase to promote growth. Although a basic model of the water regime for floodplain grassy wetlands is known, it is based on a few key studies and uncertainty remains about how environmental watering impacts Moira grass growth. Water managers can monitor to determine the impact of managing Moira grass, however they must do this with a limited budget: spending resources investigating a specific hypothesis means diverting resources from investigating other uncertainties. It is necessary to prioritise monitoring to reduce the uncertainties that will have the largest impact on management outcomes.

2.2. Value of information analysis

Choosing which management actions maximise the chance of achieving management goals is difficult because both the factors limiting recovery and the effectiveness of management actions are uncertain. Uncertainty about the factors limiting recovery can be represented as alternative hypotheses about the system, each with a probability of being true and different outcomes under proposed management actions (Runge et al., 2011).

VOI analysis provides an analytic framework to quantify the value of acquiring additional evidence to inform a decision problem. In this study, we use VOI to inform whether additional research is required to resolve uncertainty, and what combination of monitoring and management would yield the greatest likely benefits.

VOI assumes that there are hypotheses h about the factors limiting the achievable benefit, each with probability p_h that it is the limiting hypothesis, and management actions that can be implemented to improve outcomes. If hypothesis h limits performance, the value of taking action a is denoted as $V(a,h)$.

To determine whether research is required to resolve uncertainty, we compute the expected value of perfect information (EVPI). EVPI is the difference between the expected management outcomes when a decision is made based upon prior information and when new information is gained (Yokota and Thompson, 2004). The EVPI is the expected benefit of eliminating uncertainty:

$$EVPI = EV_{certainty} - EV_{uncertainty} \tag{1}$$

The first term on the right hand side of equation (1) is the expected value of certainty $EV_{certainty}$:

$$EV_{certainty} = \mathrm{E}_h\left[\max_a V(a,h)\right] = \sum_h p_h \times \max_a V(a,h) \tag{2}$$

$EV_{certainty}$ represents the expected value assuming we know which hypothesis limits management performance. If we knew the true hypothesis before choosing an action, the best action would be that which returns the highest value for that hypothesis, i.e., $\max_a V(a,h)$. However, since the true hypothesis limiting uncertainty is unknown, we weight the outcome of the best action under each hypothesis by the probability that it is the limiting hypothesis.

The second term on the right hand side of equation (1) is the expected value of uncertainty, $EV_{uncertainty}$:

$$EV_{uncertainty} = \max_a[\mathrm{E}_h(V(a,h))] = \max_a \sum_h p_h \times V(a,h) \tag{3}$$

This is the value gained from implementing the action that returns the maximum expected value, assuming we do not know which hypothesis is true prior to making a decision.

The EVPI assesses the value of removing uncertainty, but does not recommend which uncertainty to reduce first. When prioritising strategies, managers may implement actions without monitoring (act under existing uncertainty). Alternatively, managers may test a hypothesis, then implement management after learning from the monitoring (we assume that monitoring either confirms or refutes the hypothesis; here managers act under partial uncertainty).