Environmental Modelling & Software 71 (2015) 159–173

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

An iterative method for discovering feasible management interventions and targets conjointly using uncertainty visualizations

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ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form
20 May 2015
Accepted 21 May 2015
Available online 5 July 2015

Keywords:
Uncertainty
Environmental flows
Visualization
Wetlands
Decision making
Environmental management
Systems

ABSTRACT

This paper presents a generic method, referred to as Iterative Discovery, to guide deliberation with analysis where the aim is to plan refinements to management interventions with difficult-to-define objectives, often due to system uncertainties and diverse stakeholder positions. The method can be initiated by evaluating a scenario describing the current-best intervention. This provides the starting point for three evaluation cycles, focusing on model assumptions, alternative interventions and management targets. The outcome of this method is a list of management targets that can and cannot be achieved, the potential interventions that correspond to these targets, and the assumptions and uncertainties associated with these interventions. It was applied to a case study for environmental flow management in the Macquarie Marshes, Australia. We identified feasible management targets based on ecological outcomes in flood suitability across different locations, climate conditions and species, and the suitable environmental flow volumes that correspond to these targets.

1. Introduction

Making management and policy decisions is a complex and difficult task when the problem of interest encapsulates pervasive complexity, dynamism and uncertainty, as occurs for example with contested, multi-dimensional environmental issues (Hamilton et al., 2015; Hughes and Louw, 2010). When the contextual biophysical, social and political systems are constantly changing and interacting, the requisite scientific knowledge tends to be continually evolving. These challenges hinder the development of management strategies and raise the need for adopting suitable learning models in management in order to respond effectively in uncertain and dynamic decision environments (National Research Council, 2009).

Traditionally, decision processes often involve several sequential stages: identifying a problem and objective, developing possible courses of intervention, and selecting a course of intervention (Janssen, 1992). Program evaluation (Mark et al., 2000) is a learning model well suited to this process because it assumes explicit and predefined objectives, and a good understanding of the connections between interventions and objectives and between objectives and outcome indicators. By comparing the pre- and post-intervention outcomes, the effectiveness of the intervention can be evaluated. However, program evaluation can be practically challenging in situations where there are different and often conflicting objectives required by multiple stakeholders, or when uncertainties are high and the decision environments (biophysical and societal conditions and scientific knowledge) are constantly changing (National Research Council, 2009). These uncertainties call for more flexible and iterative learning models such as adaptive management (Walters and Holling, 1990), or deliberation with analysis (Stern and Fineberg, 1996).

Adaptive management embraces uncertainties in the connections between interventions and objectives and proposes learning by doing (Williams, 2011). This learning model treats interventions as experiments: it focuses on monitoring and learning as systems change, and continuously responding and adapting to new situations. Adaptive management has been used in many environmental management practices (Downs and Kondolf, 2002; Grafton and Kompas, 2005; Pahl-Wostl, 2007; Stankey et al., 2005; Williams, 2011). However, it can be ineffective when the impacts of interventions are delayed or hard to measure (e.g. climate change

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http://dx.doi.org/10.1016/j.envsoft.2015.05.017

adaptation), opportunities for interventions are sparse (e.g. releasing environmental flows), or explicit experimentations are costly or not practical (McLain and Lee, 1996; Walters, 1997). As with program evaluation, it usually assumes a unitary decision maker (National Research Council, 2009).

Deliberation with analysis emphasizes an iterative, analytic-deliberative process where the deliberative process and analytic process integrate and interact in every step of decision making, from problem framing to selecting options (Stern and Fineberg, 1996). The deliberative process involves multiple stakeholders deliberating on multiple objectives and interventions. The analytic process involves integrating and analyzing information and scientific knowledge to support that deliberation. The combined process is collaborative and adaptive, well suited to the complex task of environmental decision making, especially when dealing with uncertain and dynamic biophysical and societal systems and continuously evolving scientific knowledge and technology (National Research Council, 2009).

Deliberation with analysis appears to be the most appropriate learning model for a broad range of environmental decision making problems. One category of such problems may be referred to as "planning refinements with difficult-to-define objectives". To our knowledge, this problem type has not previously been explicitly defined despite seemingly being quite common. By our definition, such problems have the following characteristics:

- a current management intervention is already in place, which is known to have limitations, none of which are considered pressing;
- there are significant uncertainties in the systems and models;
- management targets are too complex to satisfactorily explore with optimization tools;
- management targets need to be set that are dependent on what can be achieved, because trade-offs mean that the ideal outcome is not achievable.

Many existing computational techniques can be used to support deliberation with analysis. Optimization of objectives is used extensively in environmental management to identify suitable interventions for further discussion (Maier et al., 2014, 2003). The applicability of optimization approaches has been extended in several ways. Firstly, deep uncertainty can be accounted for within optimization using scenarios that capture alternative future conditions (Beh et al., 2015; Kang and Lansey, 2014), including well known approaches such as Robust Decision Making (Lempert and Groves, 2010; Matrosov et al., 2013) and Info-Gap Decision Theory (Ben-Haim, 2006; Korteling et al., 2013). Secondly, optimization techniques can handle many objectives by identifying trade-offs expressed using Pareto-optimal solutions, as in the Many-objective Robust Decision Making (MORDM) framework (Kasprzyk et al., 2013). Thirdly, where a fixed problem formulation is unsuitable, the problem formulation can also be iteratively evaluated and updated, for example in the adaptive approach to multi-objective optimization formulations developed by Piscopo et al. (2015). However, any method based on optimization intrinsically requires a clear set of pre-determined optimization objectives in quantitative terms, which may be difficult to define in some problem situations (Maier et al., 2014).

As a result of this limitation, planning refinements with difficult-to-define objectives have instead been tackled using scenario-based approaches outside of an optimization framework. Some of these approaches are very specific. Assumption-based planning (Dewar, 2002) is intended to improve the robustness of existing complete and realistic plans. It involves identifying signposts, shaping and hedging actions to address vulnerabilities associated with important assumptions. Dynamic Adaptive Policy Pathways (Haasnoot et al., 2013) similarly improve robustness to deep uncertainty by analyzing the sequencing of future actions. More generally, Exploratory Modeling and Analysis (Bankes, 1993; Pruyt, 2010) and Computer Assisted Reasoning (Bankes et al., 2001; Lempert, 2003) involve using computational techniques to produce scenarios and either filter out those that appear interesting, or produce insights to help refine plans and objectives. Despite the availability of these techniques and frameworks, no overarching framework exists that summarizes how to organize analyses of model outputs to support the implementation of deliberation with analysis.

This paper describes a generic method, referred to as Iterative Discovery, to guide deliberation with analysis where the aim is to plan refinements to existing management with difficult-to-define objectives. The method is based on a current-best intervention, and is designed to help identify feasible environmental management targets and alternative interventions, and associated assumptions and uncertainties (Section 2). We use environmental flow management for the Macquarie Marshes in Australia as a case study, and employ visualization to help illustrate the model outputs (Section 3 with results in Section 4). Discussion in Section 5 summarizes the contribution of Iterative Discovery, its key features and limitations and potential extensions of the method and the illustrative case study.

2. The Iterative Discovery method

Iterative Discovery proposed here is intended to help identify achievable and specific management targets and alternative interventions by iteratively evaluating interventions using model and uncertainty visualization tools. The method assumes an intervention is already in place, which is considered to be the best available despite its limitations. We refer to this as the "current-best intervention". A scenario (defined below) incorporating the current-best intervention is then evaluated. This provides the starting point for three cycles, focusing on updating model assumptions, alternative interventions and management targets. The method aims to provide guidance on what to look for in model results within iterations of visualizations, and to strengthen knowledge partnerships between analysts, decision makers and stakeholders.

In this paper, we refer to the following nomenclature:

- '*Target*' refers to specific and quantifiable environmental management objectives with clear indicators (e.g. a target can be to 'reduce sediment loads by 10 tonnes per year' with 'reduction in sediment loads' as the indicator), as opposed to broader management objectives which are often descriptive (e.g. 'increase water quality') and tend to stem from high-level agreements and policies. Although a review of approaches to target setting is not within the scope of this paper, readers are directed to Samhouri et al. (2012) for further information.
- '*Intervention*' refers to management or policy options which can alter environmental outcomes. Examples of interventions are diverse depending on the environmental problem addressed, such as restricting forest clearing, adjusting environmental water entitlements, erosion control measures, and social interventions including education. Interventions can be transient or long term measures.
- A '*scenario*' encompasses a combination of model inputs associated with specific interventions and socioeconomic or biophysical drivers of the studied system. For example, a baseline scenario for land management is represented by a set of model inputs that represent the current land management practices and current climate conditions.