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Research article

Managing for climate change on protected areas: An adaptive management decision making framework

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ABSTRACT

Current protected area management is becoming more challenging with advancing climate change and current park management techniques may not be adequate to adapt for effective management into the future. The framework presented here provides an adaptive management decision making process to assist protected area managers with adapting on-park management to climate change. The framework sets out a 4 step process. One, a good understanding of the park's context within climate change. Secondly, a thorough understanding of the park management systems including governance, planning and management systems. Thirdly, a series of management options set out as an accept/prevent change style structure, including a systematic assessment of those options. The adaptive approaches are defined as acceptance of anthropogenic climate change impact and attempt to adapt to a new climatic environment or prevention of change and attempt to maintain current systems under new climatic variations. Last, implementation and monitoring of long term trends in response to ecological responses to management interventions and assessing management effectiveness. The framework addresses many issues currently with park management in dealing with climate change including the considerable amount of research focussing on 'off-reserve' strategies, and threats and stress focused *in situ* park management.

1. Introduction

Protected areas are one of the most effective mechanisms for achieving conservation and afford a high level of defence against biodiversity loss and environmental degradation (Geldmann et al., 2015). They require constant management and monitoring to be effective (Leverington et al., 2010; Watson et al., 2014; Coad et al., 2015; Pressey et al., 2015). Effective management of protected areas requires sound practices and an appropriate level of management and resources which may frequently be limited (Shoo et al., 2014). Climate change will make protected area management even more challenging. Climate change is key threatening process to biodiversity and natural systems (Krockenberger et al., 2003; Gonzalez, 2010; Sommer et al., 2010) and it will exacerbate a number of already existing threats (Auld and Keith, 2009). Anthropogenic climate change is having an increasing impact on biodiversity because the rate of temperature change is greater than in the past and many of the ecosystems are already under stress from other human impacts (Krockenberger et al., 2003; Perry, 2015).

Past and current park management techniques may not be adequate for protected areas to adapt to a changing climate because parks were originally developed and managed with the notion of static boundaries and with the aim of maintaining current values (Zaccarelli et al., 2008). They have been established under assumptions that species and vegetation are relatively static (Hagerman et al., 2010a) and are generally managed *in situ* (Pressey, 1994). Landscapes are dynamic and will become more so under future climate variability so therefore must be managed for change rather than static conditions (Lindenmayer et al., 2008; Wiens and Hobbs, 2015). The global protected area estate is at risk because few reserve management objectives have been developed with climate change in mind (Hannah et al., 2002).

2. A framework for managing protected

We developed an adaptive management decision making framework to assist protected area managers with adapting on-

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park management to climate change. The framework (Fig. 1) consists of three sections; context, protected area management, and management options. The context sets the foundation for clarifying the protected area system's attributes and how they inter-relate. Protected area management addresses the aspects involved with carrying out park management. Management options include assessing possible park management strategies and determining a course of action to adapt on-park management to climate change.

2.1. Context

Climate change and protected area management form a complex system (Lemieux and Scott, 2005), and in conservation science it is important to describe the context of the system in a way that is simple, clear and provides a common understanding for all protected area managers and stakeholders (Salafsky et al., 2002). The context of the decision making framework includes investigating climate change projections and park values/threats as part of the biophysical, social and economic park structure. This is an important component of assessing climate change impacts on the protected area and to assess its vulnerability.

Vulnerability assessments are a useful tool to develop a manager's understanding of which species or systems will be affected by projected changes and why they may be vulnerable (Glick et al., 2011). Understanding vulnerability (sensitivity, exposure and adaptive capacity) of natural systems and other protected area values informs the development of effective management strategies and is a critical step of climate change adaptation and planning (Rowland et al., 2011). Vulnerability assessments are being applied worldwide and in the context of protected area management to reduce uncertainty and better inform management decisions. Tools include approaches for assessing vulnerability of species, habitats, places (i.e. protected areas through to entire countries), ecosystem processes and services, water catchments, and social values (Johnson, 2014). Assessments are being undertaken based on ecological modelling, quantitative and empirical data; but also involve many levels of expert elicitation (Steffen et al., 2009; Glick et al., 2011; Lee et al., 2015; Reside et al., 2016).

2.1.1. Climate change projections

Forecasting probable changes in climate is an important factor in assessing climate change related impacts because predictions help develop the context and understanding of the challenges for the protected area site (Perry, 2015). Although there is a degree of uncertainty associated with climate change modelling (Foley, 2010), predictions give a general indication of how climatic elements are shifting. Predictions, together with an understanding of a park's values and threats will give protected area managers an idea of how a park may respond to climate change.

2.1.2. Park values and threats

Park managers require an understanding of park values in order to undertake appropriate decision making and setting management objectives for a protected area. They are the features that give the park meaning and the reason/s why the park is protected (Lockwood, 2006). Many parks are set aside for nature conservation and biodiversity protection; however more recently parks are being managed for a much wider range of values (Watson et al., 2014). There are now expectations from society that protected areas will provide more than conservation, such as sustainable resource use, carbon sequestration, ecosystem services and support for local communities (Corson et al., 2014; Watson et al., 2014; Larsen et al., 2015).

Critical for management effectiveness, park values should be assessed against a full suite of threats (Salafsky et al., 2008; Wade et al., 2011) with a wide variety of these threats relevant to climate change impacts. A good understanding of the park's threats include direct threats (e.g. invasive species, fire), indirect threats (e.g. surrounding land use) as well as underlying causes (e.g. community attitudes, values and perceptions) (Worboys et al., 2006). Some threats are more significant than others, particularly when combined with climate change such as fire and invasive species, and may require more attention.

2.1.3. System understanding

It is important to have a thorough understanding of the biophysical, social and economic elements that the system is composed of and how they interact with each other. This provides a foundation for analysing the issues and impacts and a better understanding of how a protected area is likely to respond to climate change. This will improve a decision maker's ability in establishing objectives and management strategies by identifying and possibly reducing uncertainty, improving park threats and social assessments, exploring a wider range of options and increasing social acceptability (Biggs et al., 2011; Bryan et al., 2011; Geyer et al., 2015; Perry, 2015). There are a number of existing processes that can support understanding of complex conservation situations such as systematic assessment, environmental impact assessments, conceptual and mental models, and scenarios (Knight et al., 2006; Worboys et al., 2006; Margoluis et al., 2009; Biggs et al., 2011; van Vliet et al., 2012). Whichever procedure is used, the process should identify the key natural, social and economic drivers of the system and establish the linkages between these variables for a full understanding of the relationships. Understanding natural and social processes and capacities decrease uncertainty in the decision making process (Fischman et al., 2014). One of the most common and effective methods is conceptual modelling (Margoluis et al., 2009).

Conceptual modelling is a useful tool in conservation planning. It helps explain complex natural systems that include diverse values, drivers and linkages (Margoluis et al., 2009). Conceptual modelling can draw attention to the interactions between drivers and endpoints, and anticipate the major sensitivities of a system (Johnson and Weaver, 2009). Conceptual modelling also provides an effective communication tool useful for stakeholder consultation (Delgado et al., 2009). Its ability to do this, as well as be updated over time and provide feedback into management makes it very compatible for adaptive management (Dale et al., 2010; Howes et al., 2010).

In developing a conceptual model to gain an understanding of an ecological system, there are many factors that need to be taken into account. A good understanding of the park, as well as the surrounding landscape is essential which will lay down the groundwork for assessing climate change impacts (Perry, 2015). What are the park's features (i.e. physical elements such as size, shape and boundary), its current climatic influences, natural and cultural values, associated threats, and current condition of the park and park values? Without a good understanding of the biophysical environment, it is difficult to predict a park's vulnerability to climate change impacts.

Effective conservation also requires an understanding of the region's socio-ecological structure. An assessment without it can be one of the limiting factors to effective planning and management (Knight et al., 2006). Diverse social values can be a limiting factor in climate change adaptation (Adger et al., 2009). Values influence societies in terms of the different levels of significance they place on a diverse range of issues, including climate change (O'Brien and Wolf, 2010). Values influence why and how decisions are made, choices of different strategies, and allocation of limited resources. Even when there is agreement on objectives of adaptation, there