Discussion

Decision triggers are a critical part of evidence-based conservation

Carly N. Cook a,⁎, Kelly de Bie b,c, David A. Keith d,e, Prue F.E. Addison b,f

a School of Biological Sciences, Monash University, Clayton, VIC 3800, Australia
b School of Biosciences, University of Melbourne, Parkville, VIC 3010, Australia
c Parks Victoria, 535 Bourke St, Melbourne, VIC 3000, Australia
d Australian Wetlands, Rivers and Landscapes Centre, University of New South Wales, Sydney, NSW 2052, Australia
e New South Wales Office of Environment and Heritage, Hurstville, NSW 2220, Australia
f Australian Institute of Marine Sciences, Townsville, QLD 4810, Australia

⁎ Corresponding author.
E-mail addresses: carly.cook@monash.edu (C.N. Cook), khu@unimelb.edu.au (K. de Bie), david.keith@unsw.edu.au (D.A. Keith), paddison@aims.gov.au (P.F.E. Addison).

1. Progress towards achieving evidence-based conservation

The international community has committed to halting the rate of biodiversity loss by 2020 through the effective management of natural systems (Aichi Targets 11 & 12; CBD, 2010). Achieving these goals requires that conservation organisations have systematic management processes in place to support effective management action. The value of evidence-based management to support effective conservation action has been given increasing emphasis in recent decades (Dicks et al., 2014). These changes have come from a desire for increased transparency of management outcomes and to facilitate responsive and effective management practices (Leverington et al., 2010; Ferraro and Pattanayak, 2006).

Evidence-based management involves using the best available evidence to support effective management decisions (Dicks et al., 2014). There are many approaches that promote evidence-based decision-making in conservation management (Table 1). Some of these broadly address the whole management process, from preparing for action, implementation and evaluation of management outcomes (e.g., Conservation Action Planning; Open Standards for Conservation Practice; Table 1). Other approaches focus on some steps within the broader management process, such as selecting the most appropriate management actions (e.g., evidence synthesis; project prioritisation protocol; Table 1), or improving management through the evaluation of outcomes (e.g., Vital Signs monitoring; Table 1) or governance processes (e.g., management effectiveness evaluation; Table 1).

Several approaches to evidence-based management focus on providing a structured process to select among a range of alternative management actions (Table 1). Management strategy evaluation and structured decision-making assist managers to predict the outcomes...
of different management alternatives before they are implemented, using available monitoring data, expert judgement and predictive models (Butterworth and Punt, 1999; Gregory et al., 2012; Table 1). Prioritisation approaches, such as project prioritisation protocol (Joseph et al., 2009; Table 1), are used where multiple actions are desirable but resources are limited; while evidence synthesis is focused on selecting the most effective action for a specific management context (Pullin and Stewart, 2006; Dicks et al., 2014; Table 1). When critical uncertainty exists in conservation management, adaptive management (AM), offers a rigorous and intensive process to develop, trial or experimentally test and select among multiple potentially effective management options (Walters and Hilborn, 1978; Table 1).

Management effectiveness evaluation (MEE) facilitates evidence-based management by providing a structured approach to assess the strength and weaknesses of the management process (from planning through to outcomes) to assist decision makers to learn from and improve management efforts (Hockings et al., 2006; Leverington et al., 2010). While there is increasing interest in evaluation, the implementation of MEE continues to be challenged by poor access to data (Cook et al., 2010), difficulty linking inputs (e.g., staff time and money) to actions and outcomes (Cook and Hockings, 2011), and difficulty “closing the loop” to integrate the results of evaluations into improved management practices (Jacobson et al., 2008; Addison et al., 2015a).

Vital Signs monitoring (Fancy et al., 2009; Table 1), Conservation Action Planning (TNC, 2007; Table 1) and the Open Standards for Conservation Practice (CMP, 2013; Table 1), focus on monitoring management outcomes as a means to improve conservation actions. While monitoring biodiversity to track changes in key ecological attributes over time is an important element of evidence-based management (Magurran et al., 2010), it is often poorly implemented. Poorly designed or implemented monitoring programs can lead to important ecosystem changes going undetected (Legg and Nagy, 2006). Even when changes are detected, the failure to link monitoring programs to management actions can mean decision makers fail to respond to observed declines (Lindenmayer et al., 2013). These criticisms highlight the need to consider a priori the management response to monitoring data and the importance of defining the point at which an ecological attribute crosses from acceptable to unacceptable (Lindenmayer et al., 2013).

2. Decision triggers as part of evidence-based management

A relatively poorly developed component of evidence-based management is supporting decisions about when and how conservation managers should act if a system enters an undesirable state (e.g., Nie and Schultz, 2012; Lindenmayer et al., 2013). To this end, there has been increasing focus on the need for some form of decision trigger that links monitoring data to management action to support environmental management (e.g., Biggs and Rogers, 2003; Martin et al., 2009; Addison et al., 2015b; Table 2). Similarly to other authors (Table 2), we define a decision trigger as a point or zone in the status of an ecological attribute that when crossed triggers a management decision. The primary aim is to help managers determine the optimal time to intervene in any managed system through a systematic, a priori consideration of the desired status of the system and the management interventions that can positively influence that status. Discussion of decision triggers is often linked to concepts that seek to understand how ecological systems function, such as ecological thresholds (Grafton et al., 2006). However, our definition of decision triggers extends well beyond ecosystems that display detectable ecological thresholds.

Decision triggers promote proactive evidence-based management, where the best action to take depends on the current state of the system. Setting a decision trigger requires that an ecological attribute be identified, which can serve as an indicator for the state of the system or the threatening process that is the target for management. Managers must agree on the range of attribute values that distinguish desirable and undesirable states. The boundary between the zones of desirable and undesirable states becomes the trigger point for action, informed by monitoring the ecological attribute (Fig. 1a). A more nuanced view of the system may identify multiple states (e.g., desirable, acceptable, undesirable and unacceptable), with trigger points for different actions associated with each of the boundaries between these zones (Fig. 1b). The benefit of multiple states is that different corrective actions can be assigned to different trigger points, potentially offering early

<p>| Table 1 |
| Approaches to promoting evidence-based management in conservation management that are commonly discussed in the literature. |</p>
<table>
<thead>
<tr>
<th>Approach</th>
<th>Description</th>
<th>Focus*</th>
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<tbody>
<tr>
<td>Conservation Action Planning</td>
<td>A process to guide conservation teams to develop focused strategies and measures of success (Groves et al., 2002; TNC, 2007)</td>
<td>Preparing for action; on-going management; monitoring</td>
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<tr>
<td>Open Standards for Conservation Practice</td>
<td>Systematic approach to planning, implementing, and monitoring conservation initiatives (CMP, 2013; Schwartz et al., 2012)</td>
<td>Preparing for action; on-going management; monitoring; evaluation</td>
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<tr>
<td>Adaptive management</td>
<td>A decision-making process to develop, trial and select among multiple potentially effective management options (Walters and Hilborn, 1978)</td>
<td>Ongoing management; monitoring</td>
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<tr>
<td>Structured decision-making</td>
<td>An approach to identify and evaluate alternatives that focuses on engaging managers, policy makers, stakeholders and experts (Gregory et al., 2012)</td>
<td>On-going management; monitoring; evaluation</td>
</tr>
<tr>
<td>Project prioritisation protocol</td>
<td>A tool to identifying the most cost-effective options with the greatest probability of success (Joseph et al., 2009)</td>
<td>Preparing for action; on-going management</td>
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<tr>
<td>Systematic conservation planning</td>
<td>A structured approach to prioritising action across a landscape, particularly for selecting the optimal reserve design to maximise a particular conservation objective (Margules and Pressey, 2000)</td>
<td>Preparing for action</td>
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<tr>
<td>Evidence synthesis</td>
<td>Used to draw together the best available evidence on alternative management strategies to identify the most effective management actions for a given management context (e.g., Pullin and Stewart, 2006; Dicks et al., 2014)</td>
<td>On-going management</td>
</tr>
<tr>
<td>Management strategy evaluation</td>
<td>Modelling-based approach to assessing the consequences of different management strategies or options to assist in determining which approach will be the most appropriate to meet the operational objectives (Butterworth and Punt, 1999; Sainsbury et al., 2000). This approach is predominantly applied to the ecosystem-based fisheries management (Smith et al., 2007)</td>
<td>On-going management; monitoring</td>
</tr>
<tr>
<td>Vital Signs &amp; ecological integrity monitoring</td>
<td>Long term resource monitoring of parks (Fancy et al., 2009), focused on identifying and tracking key indicators of ecological integrity to infer the overall health of ecosystems (Timko and Innes, 2009).</td>
<td>Monitoring; evaluation</td>
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<tr>
<td>Management effectiveness evaluation</td>
<td>An assessment tool designed to assist conservation managers to understand, learn from and improve conservation management efforts (Hockings et al., 2006)</td>
<td>Evaluation</td>
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* Preparing for action refers to setting objectives for management in relation to key attributes and areas of interest. On-going management refers to determining the most appropriate actions to take. Monitoring refers to measuring the outcomes of on-going management relative to the objectives. Evaluation refers to assessing how effective the processes for planning and on-going management have been in achieving management outcomes.
**Table 2**

The variety of terms and specific definitions for analogous approaches to decision triggers, and the related concepts that inform when to intervene in natural systems.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Assessment points</td>
<td>The values (often multiple points) of an attribute (i.e., a monitored variable) that represent ecosystem condition (a continuum from good to poor condition), which can inform (but not force) the need for management action to avoid undesirable ecosystem changes (Bennetts et al., 2007).</td>
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<td>Classification thresholds</td>
<td>The values of an attribute that define where preventive management should occur (e.g., managing changes that make ecosystems vulnerable to deterministic change) or restorative management should occur (e.g., managing degraded ecosystems; Bestelmeyer, 2000).</td>
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<tr>
<td>Decision thresholds</td>
<td>The value of an attribute that once exceeded triggers a management action. Decision thresholds can incorporate information about the ecosystem being managed (e.g., ecological thresholds* where they exist) and value--based information that represents regulatory requirements (e.g., utility thresholds*; Martin et al., 2009).</td>
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<tr>
<td>Decision-making triggers</td>
<td>The value of an attribute that once exceeded triggers a management action, reflecting predefined commitments to an adaptive management plan. Decision-making triggers can build on ecological knowledge (e.g., ecological thresholds*) and policy requirements, such as regulatory standards* or utility thresholds* (Nie and Schultz, 2012).</td>
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<tr>
<td>Harvest quotas</td>
<td>The value of an attribute that represents an acceptable level of harvesting of a species of management focus (e.g., an overabundant species; En Chee and Wintle, 2010).</td>
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<tr>
<td>Management thresholds</td>
<td>The value (point or zone) of an attribute that once crossed represents when management intervention is required to address undesirable ecosystem changes. Management thresholds can build on ecological knowledge (e.g., defined ecosystem condition) and regulatory standards* or utility thresholds* (e.g., Addison et al., 2015b).</td>
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<tr>
<td>Reference points</td>
<td>The values of an attribute that represent the intended and unfavourable states of a managed system (e.g., target and limit reference points used in fisheries management), and the point where management intervention is required (e.g., trigger reference point; Link, 2005).</td>
</tr>
<tr>
<td>Regulatory standards</td>
<td>The value (often a single point) that represents the acceptable level of an attribute (e.g., air and water quality), outside of which requires management intervention (ANZECC, 2000).</td>
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<tr>
<td>Statistical thresholds</td>
<td>The value of an attribute that represents where management is required, which is derived from optimizing the relative Type I error rate (the cost of management intervention when it was not required) and Type II error rate (the cost of an undesirable environmental change that goes undetected and unmanaged) associated with statistical inference (Field et al., 2004).</td>
</tr>
<tr>
<td>Thresholds of potential concern</td>
<td>The values (often an upper and lower limit) that define the acceptable natural variability* and/or condition* of an attribute, which once crossed triggers management action (Biggs and Rogers, 2003).</td>
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<tr>
<td>Related concepts that commonly inform decision triggers</td>
<td>The desired state or condition of an attribute that a management organisation aspires to achieve and maintain over time (Lookingbill et al., 2014).</td>
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<tr>
<td>Ecological condition or status</td>
<td>The value (point or range) that represents rapid or irreversible change in an attribute that is reflected as a change in ecosystem state/organisation/process (Goffman et al., 2006).</td>
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<tr>
<td>Ecological thresholds</td>
<td>The desired state or condition of an attribute that is based on scientific information about ecosystem condition and/or value-based information, such as regulatory or policy requirements (Moldan et al., 2012).</td>
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<tr>
<td>Environmental targets</td>
<td>The acceptable range of natural variation of an attribute, which helps define what ecosystem conditions may require management intervention (Landres et al., 1999).</td>
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<td>Range of natural variation</td>
<td>Represent undesirable ecosystem state and can be determined by value judgements by policy-makers and managers and/or regulatory requirements (Martin et al., 2009).</td>
</tr>
<tr>
<td>Utility thresholds</td>
<td>Represent undesirable ecosystem state and can be determined by value judgements by policy-makers and managers and/or regulatory requirements (Martin et al., 2009).</td>
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Fig. 1. The relationship between number of target zones and decision triggers based on: a) a simple two zones approach — desirable and undesirable; or b) a multi zones approach — desirable, acceptable, undesirable, unacceptable. The broken lines represent the trigger points, which if breached trigger management actions. 

Intervention options that may be cheaper or less invasive, correcting the system before undesirable changes occur. For example, a trigger point between desirable and acceptable states may initiate more intense *in situ* conservation actions, while crossing the boundary between undesirable and unacceptable may trigger the more extreme action of taking individuals from the wild for a captive breeding program. Multiple trigger points also accommodate uncertainty as to the exact value that would best initiate action.

Decision triggers can be informed by ecological thresholds when they exist (Martin et al., 2009), assisting managers to prevent catastrophic shifts in ecosystems (e.g., Carpenter et al., 1999). However, decision triggers can also be designed to manage and counter degradation processes that are more gradual and continuous (Lookingbill et al., 2014; Table 2) or *a priori* environmental targets (Moldan et al., 2012; Table 2), whereby the desired condition of the system is defined and triggers set to keep the system within a preferred ecological state. Decision triggers can be informed by value-based information, such as utility thresholds (e.g., maintaining wildlife populations at a sufficient size to provide visitors with a high probability of encounters; Martin et al., 2009), or regulatory standards (e.g., water quality standards, representing an unacceptable risk to human health, that if breached trigger corrective action; ANZECC, 2000). Although often discussed in relation to species (e.g., the status of a threatened population), decision triggers can also relate to threats (e.g., the density of an invasive...
et al., 2013). Well-documented examples of decision triggers being developed and successfully implemented within a conservation management context are rare (e.g., Biggs et al., 2011). Fisheries management provides opportunities to demonstrate the effectiveness of analogous approaches. For example, McClanahan et al. (2011) demonstrate an approach to developing decision triggers for coral reefs. Their data showed that fishable biomass was a reliable indicator of ecological attributes, such as macroalgal cover and species richness, allowing decision triggers (“threshold”) to be set for fishing limits or fishery closure. They also demonstrated that total fishery closure was more likely to keep or return fisheries to within acceptable bounds than mechanisms to limit catch.

3. The benefits of decision triggers for evidence-based management

3.1. Why conservation scientists are embracing decision triggers

The importance of assisting decision makers to link evidence to action has seen growing support within the literature for the value of decision triggers (e.g., Guntenspergen and Gross, 2014). Many approaches to evidence-based management (Table 1) implicitly link evidence to action by focusing on selecting effective actions. Decision triggers not only make this link explicit but also make it quantitative, removing the ambiguity about when a decision has to be made. As such, decision triggers can be complementary to other evidence-based approaches. For example, triggers could be used in association with adaptive management to help managers decide when to shift resources from one strategy to another after a period of implementing both strategies and evaluating their outcomes through monitoring.

When developing decision triggers, it can be useful to draw on elements of many of the other approaches that support evidence-based management. Evidence synthesis (Table 1) is an essential precursor to setting decision triggers, summarising the current knowledge of the ecological system. Along with relevant social and political information, this knowledge can be used to set explicit management objectives and desired states. Another essential foundation for setting decision triggers is to link the management objectives to a key ecological attribute of the system that can be monitored and used to assign a quantitative value to a trigger point. A range of qualitative and quantitative modelling techniques are available to assist with these steps (reviewed in Addison et al., 2013).

Explicit, a priori consideration of the possible management alternatives that may influence the state of the system, and the likely outcomes of implementing these actions is a critical consideration when developing decision triggers. This step is essential when assigning multiple trigger points, which may represent moderate and more extreme management interventions (Fig. 1), because interventions should be selected that have a high probability of moving the system towards the desired state.

The development and implementation of decision triggers should not be seen as a static process in which trigger points, and the possible management actions associated to them, are set and become fixed or immovable. Evidence-based management is an iterative process (e.g., adaptive management; Walters and Hilborn, 1978, and structured decision-making; Gregory et al., 2012), and decision triggers should be evaluated and adjusted over time as new information becomes available (Nichols et al., 2007). This is critical because not only will our understanding of the system change over time, but the responses of the system itself are also likely to be modified in response to environmental change (e.g., climate change; Walther, 2010).

3.2. Benefits of decision triggers for management organisations

While there has been some debate about whether decision makers support the use of decision triggers (McAlpine et al., 2002; Bennett et al., 2007), an increasing number of jurisdictions are attempting to integrate some form of decision trigger into their management practices. Several countries are developing or already using decision triggers to some extent within their conservation management practices (e.g., South Africa (Biggs and Rogers, 2003); United States (Martin et al., 2011); Australia (Addison et al., 2015b); Canada (Timko and Innes, 2009) and New Zealand (Cook et al. unpublished data)).

There are many advantages for conservation management organisations in adopting decision triggers as part of their evidence-based management practices. A major benefit of decision triggers for management organisations is that they provide decision makers with clarity around when to intervene in a system they manage. This is increasingly important to conservation management organisations as more cases of monitoring species to extinction are documented (e.g., Martin et al., 2012a). By facilitating proactive management, decision triggers have the potential to generate better management outcomes.

Management organisations can also benefit from decision triggers when proactive management leads to cost savings by eliminating the need for more expensive management options, such as captive breeding programs (Field et al., 2004). Decision triggers can also help management organisations to prevent resources being wasted on monitoring where there is no intention to take action (Lindenmayer et al., 2013).

Another benefit to management organisations in adopting decision triggers is that triggers enable transparent decision making. Conservation organisations are under increasing pressure to be accountable to the public (Leverington et al., 2010) and financial donors (Ferraro and Pattanayak, 2006). Clear links between monitoring and management assist organisations to assess and report on the outcomes of management decisions (e.g., management effectiveness evaluation; Table 1), especially in relation to whether management actions have efficiently improved conservation outcomes. Decision triggers also support organisations to demonstrate that management decisions are based on the best available evidence. This is particularly important for management issues subject to high levels of socio-political scrutiny, such as harvesting native wildlife or restricting popular visitor activities that can negatively impact biodiversity (e.g., the golden eagle, Aquila chrysaetos, in Denali National Park, USA; Martin et al., 2011).

4. Challenges and opportunities

We have outlined the many benefits of decision triggers for evidence-based management and for assisting management organisations to achieve transparency and clarity around their management decisions. Moving forward, the key challenge is to support organisations to develop decision triggers that can be integrated into existing management approaches.

A range of methods are required that can guide the different stages of developing and implementing decision triggers across a broad range of management issues and decision-making contexts. There has been some recent progress in developing methods to set trigger points when long-term monitoring data are available, such as receiver operating characteristic (ROC) curves (Connors and Cooper, 2014), control charts (Morrison, 2008) and participatory modelling (Addison et al., 2015b). These methods require robust baseline data to set trigger points in relation to natural background variation. They also require on-going monitoring with sufficient statistical power to detect when a system has crossed a trigger point (Field et al., 2007). While long-term biological monitoring data are becoming more available to inform conservation efforts internationally (Lindenmayer and Likens, 2010) monitoring needs to be fit for purpose to ensure it provides the information required for management, and requires collaboration between scientists and managers in the design, implementation and interpretation of monitoring data (Addison et al., 2015a).

There are few methods available that can assist organisations to develop decision triggers where the datasets are not available for data intensive methods. However, setting decision triggers based on utility
thresholds (i.e., value-based judgements; Martin et al., 2009) or using expert elicitation methods (see Martin et al., 2012b) may be useful for developing decision triggers in these situations, with the potential to refine these trigger points if new information becomes available. There are no methods we know of that can compensate for an inadequate ecological understanding of the system. Gaps in the understanding of relevant ecological processes, ecosystem drivers, and general biology are pervasive, despite a strong desire from on-ground managers for more scientific information (Cook et al., 2012). Decision triggers will only be as good as the current understanding of the system. Therefore, the development and implementation of decision triggers should be an iterative process that explicitly incorporates learning, whereby triggers and associated management actions are evaluated and adjusted over time as new information becomes available and knowledge of the system is refined.

5. Moving forward

The desire for management processes that support evidence-based management by guiding the integration of the best available science into management is part of a broader trend around the world (Worboys et al., 2015). Decision triggers have the potential to be a powerful component of evidence-based management, linking evidence to action and giving decision makers the confidence to act to avert negative outcomes. Importantly, decision triggers can support transparent management decisions and safeguard against undesirable conservation outcomes by defining when and how to act to maintain the system within the desired state.

Despite increasing acceptance of the value of decision triggers (Guntenspergen and Gross, 2014; Table 2), there is a need for greater understanding of the suite of methods that can assist in setting decision triggers and guidance on how to integrate triggers into the existing management approaches within organisations. Repeated calls for more targeted monitoring and research to help progress the field of conservation (e.g., Nichols and Williams, 2006; Cvitanovic et al., 2013) are of little use to conservation managers without the ability to incorporate this information into management decisions (Legg and Nagy, 2006). Whether lack of knowledge about managed systems is perceived or real, it highlights the need for bilateral knowledge transfer, such that management needs define the need for scientific research and targeted biophysical and social science informs management (Cook et al., 2013). Methods that evaluate and articulate existing knowledge about a system provide an opportunity to identify critical gaps, and enable the view of the system to be easily updated as new evidence becomes available.

Moving the concept of decision triggers forward requires the conservation community, both scientists and decision makers, to work together to ensure decision triggers are as robust as possible but also able to be implemented within the realistic management contexts faced by management organisations.

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