How Decision Support Systems can benefit from a Theory of Change approach

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Abstract

Decision Support Systems (DSS) are now mostly computer and internet-based information systems designed to support land managers with complex decision-making. However, there is concern that many environmental and agricultural DSS remain underutilized and ineffective. Recent efforts to improve DSS use have focused on enhancing stakeholder participation in their development, but a mismatch between stakeholders' expectations and the reality of DSS outputs continues to limit uptake. Additional challenges remain in problem-framing and evaluation. We propose using an outcomes-based approach called Theory of Change (ToC) in conjunction with DSS development to support both wider problem-framing and outcomes-based monitoring and evaluation. The ToC helps framing by placing the DSS within a wider context. It highlights how DSS use can "contribute" to long-term outcomes, and helps align DSS outputs with these larger goals. We illustrate the benefits of linking DSS development and application with a ToC approach using an example of pest rabbit management in Australia. We develop a ToC that outlines the activities required to achieve the outcomes desired from an effective rabbit management program, and two DSS that contribute to specific aspects of decision making in this wider problem context. Using a ToC in this way should increase acceptance of the role of DSS by end-users, clarify their limitations and, importantly, increase effectiveness of rabbit management. The use of aToC should benefit those seeking to improve DSS design, use and evaluation.

Keywords: environmental management; logic models; policy support; rabbit management; Theory of Change (ToC)

Introduction

Environmental and agricultural systems are complex and interwoven, and their effective management requires knowledge of all system components and coordinated actions across a range of levels of management: from individuals to communities and sectors, to regional and national governments. Most environmental and sustainability issues we face in these settings today are known to be wicked or messy problems (Rittel and Webber 1973; Jakeman et al. 2011). These wicked problems are characterized by complexity, uncertainty, interdependence and multiple social perspectives (Davies et al. 2015; Cvitanovic et al. 2016). Although operational managers make 'on-the-ground' management decisions, other stakeholders influence those decisions by creating or modifying the context (e.g. opposition or support) and ultimately influence whether management is effective and sustainable. Stakeholder collaboration has the potential to broaden the scope of action and improve problem solving beyond the capacity of an individual manager. Tools that facilitate integrated knowledge and information transfer and collaboration amongst multiple stakeholders are therefore required to support managers at different levels with their decision-making (Allen et al. 2001; Jakku and Thorburn 2010).

Decision Support Systems (DSS) are now mostly computer and internet-based information systems that can create and assess management alternatives, as well as facilitate knowledge communication between stakeholders (Carmona et al. 2013). A common failure of early DSS was that they were developed by researchers using their scientific paradigm, and so failed to take adequate account of user and other stakeholders' perspectives (Cox1996). In recent times, DSS have been redefined as broader initiatives of knowledge transfer that comprise: i) a development process with active stakeholder involvement (Kerr 2004; McCown 2002b; Van Meensel et al. 2012; Volk et al. 2010); and ii) an interactive (often internet/computer-based) tool that is easy to use, has minimal data requirements (Hayman and Easdown 2002; Shtienberg 2013), can be readily updated (Parker and Sinclair 2001; Voinov and Brown Gaddis 2008), and provides information access, model analysis and decision guidance (McCown 2002a; Parker and Sinclair 2001). Redefined this way, DSS are more supportive and relevant to the end-users' decision-making process (Hayman and Easdown 2002; Walker 2002). They aim to provide multiple benefits including improved communication (van Delden et al. 2011; Volk et al. 2010), collaboration and learning amongst stakeholders and with the development team (Hearn and Bange 2002; Jakku and Thorburn 2010; Walker 2002), use of best practice, and greater influence on management and policy (McCown et al. 2009; van Delden et al. 2011).

Despite this more holistic definition of DSS, many environmental and agricultural DSS remain underutilised and ineffective (Díez and McIntosh 2009; Matthews et al. 2008; Volk et al. 2010). In the wicked problem settings that DSS are often used in it is not enough to get participation by direct users (e.g. farm and conservation land managers). Instead, decisions of these users may also often need to be matched by those of other decision makers operating at different scales (e.g. policy makers) to ensure DSS outputs are of benefit (Diez & McIntosh 2009). Because many of these complex situations require a range of concurrent actions in the real world to solve the problems in question stakeholder expectations are often focused on a broad range of outcomes, and these can differ from the more modest information-based outputs that DSS typically deliver to decision-makers (Matthews et al. 2011). Further, two related areas of DSS development are seldom addressed in respect of these larger settings: i) project planning – clearly scoping and defining the problem during the early stages of the system's development (Díez and McIntosh 2009; Jakeman et al. 2011; van Delden et al. 2011); and ii) evaluation, particularly of outcomes – i.e. the real-world changes intended as a result of the project, as opposed to simply recording its outputs (Matthews et al. 2011). Often, too little time is devoted to planning and evaluation during DSS development, and guidelines for achieving these steps are inadequate (Jakeman et al. 2011; Matthews et al. 2011; van Delden et al. 2011).

To address these issues we propose the use of an outcomes-based approach known as 'Theory Of Change' (ToC) (Connell and Kubisch 1998; Vogel 2012a). We first describe a ToC and how it can be used in conjunction with DSS development. We then illustrate its use in practice by describing how we (the DSS development team) applied a ToC approach when developing two DSS to support rabbit management on both agricultural and conservation lands in Australia. We end with a discussion of potential benefits and challenges from using a ToC for DSS development.

A ToC outcomes-based approach

A useful starting point for facilitating challenging work programs that cut across many work groups and multiple stakeholders is to find ways to articulate and guide the multiple activity streams required. Many managers do not have the tools to easily set out, document and communicate complex goals, activity strategies and intended outcomes. Developing a ToC can assist by supporting diverse stakeholders to work together and plan for outcomes by envisaging a 'big picture' view of how and why a desired change is expected to happen in a particular context.

Theory of change is both a process and a product (Vogel 2012a, Taplin et.al. 2013). It involves practitioners and stakeholders in a facilitated process of analysis and reflection. At the same time a ToC inquiry results in a diagram (called a logic model) and narrative to provide a guiding framework for the project team and stakeholders. It is not a one-off exercise to be used in the design (or evaluation) phase of a research and development initiative, but implies that those involved are entering into an ongoing process of learning and adaptive management that continues throughout the life of the initiative.

From a DSS development perspective, a ToC approach (Fig. 1) requires developers and stakeholders to work together to clearly define the program as a sequence of inputs, activities and outputs that lead to the desired outcomes (Morra Imas and Rist 2009; Weiss 1995). Importantly, developing a ToC requires stakeholders to articulate the assumptions (or evidence) they are using to explain the change process they have mapped out (Anderson 2005). Applying a ToC approach encourages an adaptive strategy to management by encouraging on-going questioning of what might influence change in the particular program context, and drawing on evidence and learning (via evaluation) during implementation (Vogel 2012a).

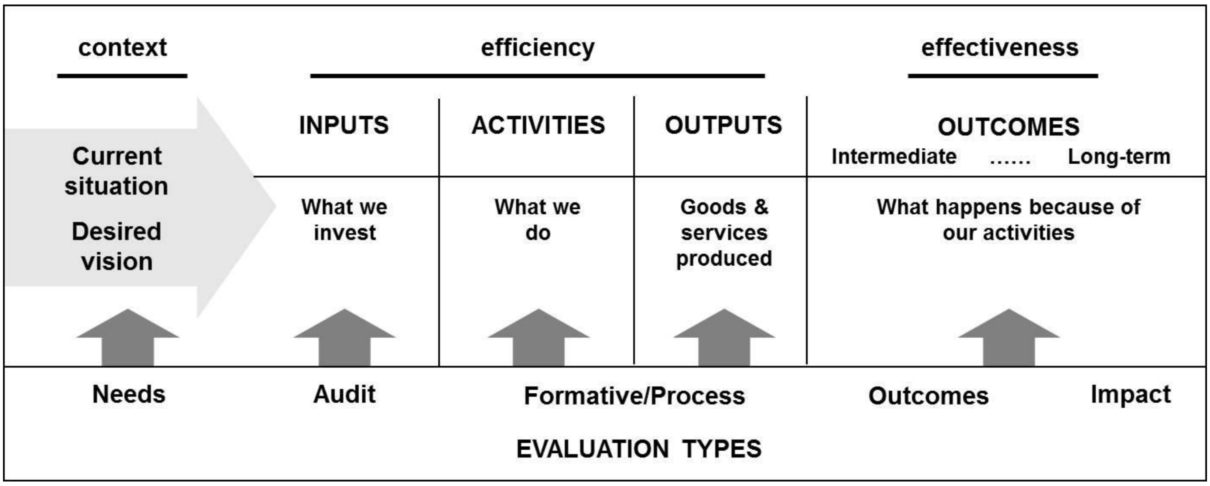

Fig. 1 Key project elements (inputs, activities, outputs and outcomes) and suitable monitoring and evaluation types for each element phase of a ToC approach

Under a ToC approach (Fig.1), the *inputs* are the required resources including money, staff, equipment and infrastructure (usually measured as counts, such as hours of staff time or dollars spent). *Activities* are the interventions and actions that need to be undertaken to achieve specified outputs. *Outputs* are the tangible results. *Outcomes* can be split into intermediate (short- and medium-term) and long-term outcomes, and are usually specified in terms of sequential preconditions:

- Short term: changes in individuals and groups – learning, including enhancements to knowledge, understanding, perceptions, attitudes and behaviours (‘social’ outcomes)
- Medium term: changed skills and practices – changed behaviours to accomplish results, or capabilities
- Long term: changed conditions or states – economic, social, biological or physical changes in a system.

Short-term outcomes may include initial changes that highlight stakeholder awareness, capacities and skills that can support practice, and behavioural changes (for example, knowledge that is gained or retained, attitudes and aspirations that are changed, and skills acquired). Medium-term outcomes describe the extent to which the practices and behaviors of stakeholder groups have changed, often accounting for the extent to which these changes have scaled up and out to reach the larger community of stakeholders. Long-term outcomes include desired goals, such as increased ecosystem health and crop production, and can be assessed over multiple value areas including social, cultural, economic and environmental. Outcomes should be specified as SMART: specific, measurable, attainable, relevant and time-bound (Jones et al. 2012). The strength of the ToC approach lies in the need to articulate narratives and other evidence that help those involved to think through the connections between activities, outputs and sequential sets of outcomes (Weiss 1995).

Once agreed, the ToC should be documented by including diagrams that illustrate how the project elements fit together, along with complementary text that provides more detail on each element, and outlines critical measures for evaluation. We suggest using logic models as illustrative tools (Kellogg Foundation 2004), with multiple 'nested' logic models, capturing different levels of detail, scope, and context. At the higher level, a logic model should sketch out the 'big picture' view of the wider program, outlining all elements necessary to achieve the desired vision for the program and indicating how a DSS (or any other activity stream) can contribute to the desired longer-term outcomes. At a sublevel, logic models can be used to focus on the elements that are specific to any one activity stream in greater detail. This nesting approach is a helpful way of placing a DSS (or any other specific activity stream) in its wider context (Hernandez 2000). Ideally, each logic model should be displayed on a single page with sufficient detail that it can be explained relatively easily and understood by a wider, non-specialist readership.

The ToC also aids the development of monitoring and evaluation plans to help stakeholders to assess and adapt progress towards the achievement of desired long-term outcomes (Blackstock et al. 2007). Once an initiative has been described in terms of desired outcomes and key program elements through a logic model, critical indicators of performance can be identified and monitored. This iterative process can be seen as adaptive management – integrating project planning, management, and monitoring and evaluation to systematically examine interventions to adapt and learn (Stem et al. 2005). The aim of adaptive management is to adapt and learn in a systematic way, often referred to as 'learning by doing' (Walters and Holling 1990; Allen et al. 2011)

As Fig. 1 illustrates, the aim of evaluation is not solely to estimate the degree of change that has occurred through the intervention, but also to understand why and how that change was (or was not) produced, and so to support learning and adaptive management. Accordingly, different types of monitoring and evaluation are needed to address the different questions raised in the various elements of the program. For example, *needs assessments* verify and map the extent of a problem. *Audits* address whether the program is using resources adequately and is being implemented as planned. *Formative evaluations* inform ongoing program implementation management, which is important – especially in participatory initiatives, to gauge how different stakeholders carry out their activities. In DSS development, attention needs to be paid to the quality of the proposed system's usability, reliability, validation and relevance, as outlined by Matthews et al. (2011).

Taking a longer-term view, *outcome evaluation* looks to assess, amongst other things, program effectiveness and how much difference has been made. From a DSS perspective, a focus on outcomes requires an understanding of how, and under what conditions, the information produced is interpreted and successfully used by stakeholders (Matthews et al. 2011). Although desired long-term outcomes may take some years to emerge fully, indicators and accompanying targets can be developed in advance for each outcome area to assess the scale of impacts achieved and to refine future planning.

Indicators may be quantitative or qualitative – or a combination of both in some cases. Development of performance indicators may seem a huge undertaking, especially for complex management programs that contribute to a range of economic, social and environmental outcomes. It is impossible for stakeholders to measure everything, so it is important to identify the 'vital few' indicators that can provide a general assessment of performance of the initiative (Jones et al. 2012).

Linking ToC and DSS development: a rabbit management example

We use a rabbit management case study to demonstrate how a ToC approach has contributed to planning for an ongoing DSS development program. Below we provide some background to the need for pest rabbit management, followed by a description of the steps involved in applying a ToC approach to underpin the development and application of two DSS.

Rabbit management context

Introduced European rabbits (*Oryctolagus cuniculus*) threaten ecological, agricultural, forestry and production values in Australia and New Zealand, as well as in several oceanic islands where they have become established pests (Lees and Bell 2008; Norbury and Reddiex 2005; Vere et al. 2004; Williams et al. 1995). For much of the 19th century rabbits were controlled with limited success using trapping, shooting, poisoning and fencing (Williams et al. 1995). During the mid-20th century, large reductions in rabbit numbers were achieved in Australia with the release of the myxomatosis virus (Ratcliffe et al. 1952; Williams et al. 1995). In the late-1990s, rabbit hemorrhagic disease (RHD) escaped quarantine during field trials (Cooke 2002). The initial impact of the disease reduced rabbit populations by more than 90% but, like myxomatosis, RHD efficacy proved geographically patchy (Cooke 2002; Mutze et al. 1998). More than a decade later, the efficacy of RHD is now waning and rabbit numbers are once again increasing (Cooke 2012).

Effective, long-term rabbit management requires an integrated management approach incorporating additional social, scientific and legislative elements, which need to be considered holistically (Cooke 2012; Williams et al. 1995). While individuals in pest research and management possess wide knowledge, this information often remains fragmented

(Allen et al. 2001). Decisions about rabbit management are not simple, and although they are ultimately made by land managers, there are many other key stakeholders (e.g. government staff, scientists and policymakers) who influence, support, or oppose proposed actions (Allen et al. 2001). Rabbit management thus provides a good example of a wicked problem, where the issue is complex, and generating action is not straightforward and cannot be brought about solely by any single actor, policy or intervention (Patterson et al. 2015).

DSS planning and development

Numerous rabbit DSS have been developed in Australasia since 1990, but there have been ongoing challenges in ensuring their widespread use and usefulness (McGlinchy 2011; Murray et al. 2014). We were commissioned to develop two DSS: i) a conservation land DSS to guide where funding is allocated for rabbit management on public land within the Australian Capital Territory (ACT); and ii) a production land DSS as a learning tool to highlight the costs versus the benefits of alternative control protocols on farms in the center tablelands region of New South Wales (NSW), Australia (described in detail in Cruz et al. 2016). We (the authors and DSS development team) brought an interdisciplinary perspective including pest management, wildlife ecology, decision support, population modeling, decision theory, participatory research and evaluation. We worked with a range of stakeholders, including local farmers, LandCare group representatives, conservation managers, facilitators (from Local Land Services, integrated catchment groups and regional Natural Resource Management organizations) and agency staff (Department of Primary Industries biosecurity officers).

We engaged with these stakeholders in both Australian states (ACT and NSW) during the DSS development process through workshops, and via phone and email discussions. Initial workshops determined the issues that stakeholders of each DSS considered most important to achieving effective rabbit management (summarized in Table 1). Stakeholders then agreed collectively on: i) the needs they wanted addressed as priorities; and ii) how they envisioned that a DSS could help address them.

Some of the needs listed by the participants could be directly supported with a (computer/internet-based) DSS. These included helping to identify priorities, providing technical and environmental knowledge, and demonstrating impacts on social, economic and environmental assets. The subsequent development of the two DSS to support rabbit management in agricultural and conservation lands is detailed by Cruz and colleagues (2016) in an earlier paper. The DSS for conservation lands has been developed to guide funding allocation for rabbit management on public lands in the Australian Capital Territory (ACT). Although designed specifically for use by ACT Parks and Conservation Service (ACTPCS), this DSS can be downloaded and adapted by other agencies that need to make decisions on where to allocate limited funding to achieve the best rabbit management outcomes. The DSS prioritises areas for rabbit management based on relative conservation, economic and social assets, current levels of rabbit abundance, and prior investment on rabbit management. It is available to stakeholders for implementation and for other groups to adapt to their own situation at http://www.pestsmart.org.au/pest-animal-species/european-rabbit/dss-for-rabbit-management/conservation-land-dss/. The DSS for production lands aims to encourage effective rabbit management and best practice approaches by informing the target audiences (farmers and agency extension staff) of the potential cost-benefits of various rabbit control methods. This acknowledges that if farmers are to invest in rabbit control they need to ensure the cost of control will be offset by the benefits gained through increased pasture biomass and resultant wool and meat production. This DSS is currently at the late stages of development (i.e. prototype testing) and will be available via www.pestsmart.org.au early in 2017.

Table 1: Issues considered important for successful rabbit management by stakeholders engaged in development of DSS for conservation and production lands in south-eastern Australia.

- Empower individuals
- Encourage collective action
- Capture complexity of issues and help identify priorities
- Influence 'fresh' or 'next-generation' land managers
- Promote best practice, integrated management, and sustained efforts
- Highlight short- and long-term benefits of rabbit management
- Promote peer-level consistency and assist collaboration across farms (being a good neighbor)
- Build capacity – provide technical and/or environmental knowledge
- Recognize and address key barriers – limited awareness, motivation, funding, time and capacity to carry out control
- Motivate absentee land owners, corporate land owners and multiple land owners in subdivisions
- Demonstrate economic, environmental and social impacts of different levels of rabbit control
- Recognize and support multiple agency collaboration and coordination

We assessed relevance, interpretability and usability of these DSS tools iteratively with stakeholders as part of a formative evaluation process during development. These three factors are similar to the DSS 'development phase' elements outlined by Matthews and colleagues (2011). However, as these authors (ibid) point out the evaluation of outcomes – changes in the real world that arise – at least in part – from the use of the DSS remains a challenge that needs to be met.

Other issues fell well outside the capabilities and remit of either DSS (e.g. agency collaboration, motivation of absentee landowners, integrated control, collective action, capacity building). Thus, these workshops also provided the first steps to gaining a full appreciation of the range of requirements for achieving effective rabbit management – of which a DSS is just one element. Clarifying how these different activities and their outcomes link together is addressed through the development of the ToC outlined in the next section.

Developing a Theory of Change

We combined knowledge on factors contributing to successful rabbit management from the workshop discussions with the development team's collective experience in pest management, and a review of rabbit management literature. This was used to define and document key program elements (activities, outputs and outcomes), along with underlying assumptions related to our theory of change for rabbit management. We set these elements out in a logic model (Fig. 2) which placed the DSS clearly within the wider context of rabbit management. This recognizes that effective rabbit management requires a range of concurrent activities – far beyond just what the DSS can provide – and that land managers and policymakers manage rabbits to achieve wider system outcomes. For example, farmers are concerned with increased stock production or forage supply, while conservation managers focus on increased biodiversity or reduced land cover degradation. This logic model outlines the rabbit management context in terms of three main program areas: i) the activities that stakeholders need to take collective responsibility for, including the DSS, coordination and leadership, control operations, training and the development of wider policy and funding infrastructure; and ii) the related outputs (goods and services) that enable the achievement of iii) the desired outcomes. Short-term outcomes include improved awareness of the problem (including monitoring), useful knowledge, decision-making skills, and capacity building as prerequisites that can contribute to medium- and longer-term outcomes. Collectively, these intermediate outcomes are expected to influence a reduction in rabbit numbers directly through the adoption of best control and monitoring practice, collaboration between land managers, and appropriate supporting legislation and funding.

As part of the ToC process, a summarized version of the DSS development process is included in the grey area of the big-picture model (Fig. 2). This enables stakeholders to gain a clear representation of where the DSS fits within the wider decision-making system, and how it 'contributes' to the ultimate outcomes.

There is no single way to develop a ToC, and the final form and content should always be governed by the users and their needs. The process of engaging participants in developing a ToC begins by encouraging them to clarify and agree the program boundaries and vision. This is followed by facilitating an iterative process of discussing and mapping activities and outcomes in a logic model. Beginning with activities encourages questions about "why these activities would lead to desired outcomes?", while beginning with desired outcomes encourages questions about "how can these be achieved?". The strength of developing logic models in a ToC approach lies in the way an iterative and facilitated dialog process around these two questions highlights the thinking of different participants. Clarifying and discussing underlying assumptions and ideas around what enables successful change helps those involved to come to a collective decision whether the logic driving the initiative seems reasonable. It is this logic and the assumptions that underlie it that represent the theory of change.

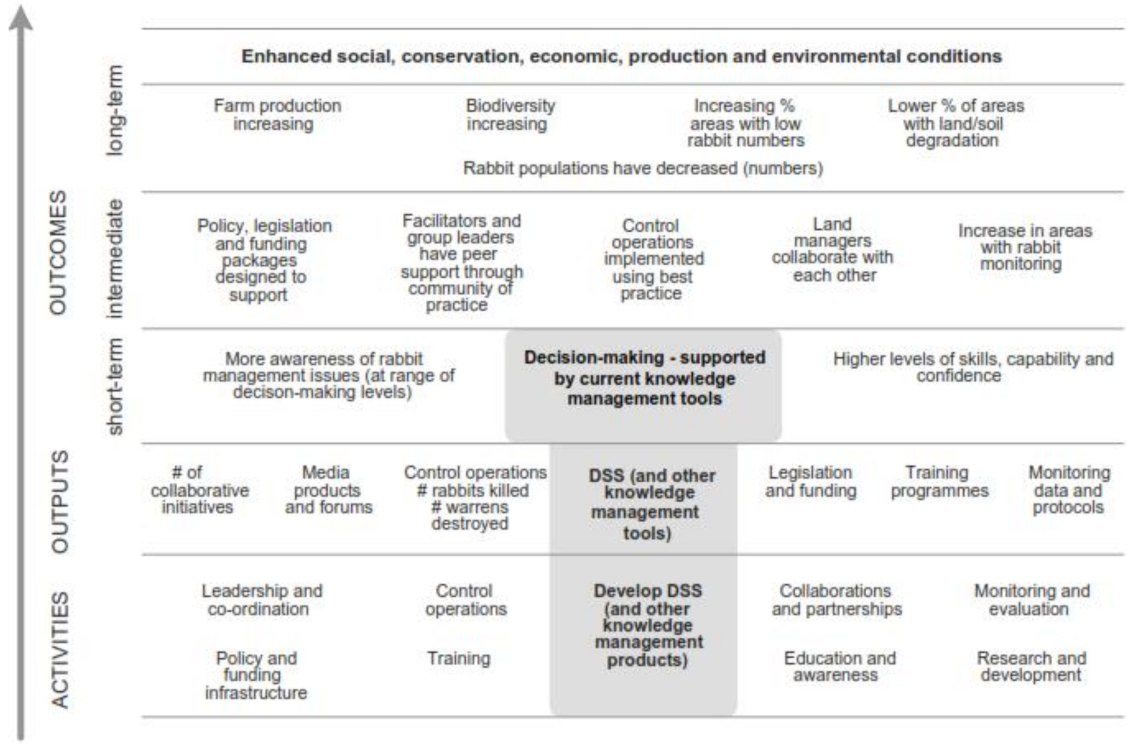

Fig. 2 A logic model displaying the elements required to achieve the desired vision (top line) for an effective rabbit management program in southeastern Australia. The grey area bounds the elements to which our DSS project contributes

In our model causality is not thought to be simple and linear, and we use a single directional arrow to represent the direction of change rather than try to show the range of influences that many of the elements contribute to. This acknowledges that many elements have a recursive rather than unidirectional influence (Rogers, 2008). The development of higher-level outcomes will often interact with the implementation of lower level activities and outcomes. Many activities and lower level outcomes will contribute to the realization of multiple higher level outcomes which represent the desired changes we want to see in the real world. This reminds us that evaluating the progress of any individual activity or outcome is often more about assessing contribution, rather than direct causality. However, the benefit of using a ToC approach is that it provides a systematic way of assessing what needs to be measured to ascertain progress across the wider rabbit management initiative.

The ToC approach also helped us begin to outline and plan for outcome-based evaluation activities that go beyond the short-term outcome indicators of DSS awareness and use. We drafted tentative indicators and accompanying targets for evaluation of SMART outcomes to be provided to the stakeholders as part of the ToC documentation. These initial evaluation targets and indicators provide a platform for discussions with stakeholders on future outcome evaluation. The focus was on the operational outcomes (short- and medium-term) that the DSS contributes to, including management, policy and budget outcomes, which are linked to specific stakeholder groups so that progress can be more directly measured. While it is hard to demonstrate the desired impact (long-term outcomes) over the short time frames of any individual project, evaluating short-term and intermediate outcomes can begin to demonstrate the value of outcome evaluation to the key stakeholders involved, which is beyond the scope of our DSS development project, but which remains crucial to ensuring stakeholders work in a coordinated manner across a number of management activities to achieve their desired vision for effective rabbit management.

Discussion

A ToC approach has been used to guide project planning and evaluation for research, community-based management and international development programs for many years (Connell and Kubisch 1998; Vogel 2012a,b; Stein and Valters 2012). Here, we applied it in a DSS development context. Rather than being seen as a prescribed methodology ToC provides a flexible approach to help stakeholders think through fundamental questions about the impacts of their initiatives and make the underlying assumptions explicit (Vogel 2012b), and look at their role in change as a small part of a larger whole – rather than change as a linear process (James 2011). Used in this way it can be seen to complement the use of a wide range of more specific strategic thinking and planning methodologies. In our case it also helped us address three broad issues that impact on DSS use, particularly when they are applied to the complex and wicked problem situations often found in environmental and agricultural settings. These are addressing diverse stakeholder expectations, problem scoping and evaluation – particularly of outcomes.

While conducting initial workshops with stakeholders, the gap between stakeholder expectations and DSS outputs became apparent. It was clear that stakeholders had a whole-system view of rabbit management, with a focus on achieving an ultimate vision of protecting environmental and economic assets from rabbits, and expected more than the DSS outputs (e.g. which control tool to use). In our example, the ToC approach provided a framework that enabled the DSS developers and stakeholders to work together to discuss and identify the range of resources, activities, intended outcomes, and underlying causal assumptions underpinning wider program success. The use of a logic model provided a framework to help make these visible, and to indicate different levels of outcomes. In this way, the ToC facilitated structuring of the rabbit management problem, identifying the additional management and policy elements needed to achieve the desired outcomes and to clarify how the DSS can contribute to achieving these. While each program element is important, effective management of complex problems needs to recognize and implement all elements of the system, and requires collaboration of multiple stakeholders to both provide information and help change practice. We believe if the DSS are not used in concert with the other necessary management actions required for effective rabbit management, then these DSS (like so many previous ones) will fail to be effective.

As our rabbit management example also demonstrates, the ToC approach provides a clear mechanism for problem scoping and structuring., – These are key areas of DSS development that remain challenging (Matthews et al. 2011; van Delden et al. 2011). The multi-step methodology for DSS development outlined by van Delden et al. (2011) started with a clear definition of the project's scope and ended with implementation, use and maintenance. The ToC approach is complementary to this methodology, but provides a more detailed approach for: i) achieving the first step of 'defining scope' by providing an avenue for initial framing of the problem under a whole-system view; ii) developing clear definitions of ultimate outcomes: and iii) developing the necessary steps to achieve them (i.e. activities and outputs), including those outside the scope of the development team.

The ToC approach also supports evaluation planning, and helps those involved to define suitable measures and indicators to provide guidance and accountability as stakeholders move towards desired outcomes (Anderson 2005; Vogel 2012b). Importantly, performance indicators relate not only to meeting achievable outputs, as is the common focus of current DSS evaluation (Matthews et al. 2011), but also allow definition of assessments of short-, medium- and long-term outcomes. The ToC approach therefore begins to answer questions raised by Matthews et al. (2011) about which outcomes are significant, what and who influences them, and how to evaluate them. Outcome evaluation remains the most challenging step in the DSS development process. However, the mapping of project elements through logic models leads naturally to constructive discussions about evaluation designs, methods and indicators, and encourages an ongoing cycle of planning and reflection. This mapping is likely to result in a combination of quantitative and qualitative approaches to outcome evaluation.

With the benefit of our own experiences working as an interdisciplinary team, we recognize that it takes both time and skills to facilitate the reflective dialogue that underlies a participatory approach to implementing a ToC process. This effort can help all involved to see the bigger picture, and how their own efforts can contribute to achieving the desired outcomes. However, developing an understanding of different viewpoints and knowledge systems is not just a matter of bringing people together (Allen et al. 2014). If these collaborations are to be successful they require time to be invested in building a culture of trust and respect between disciplines and stakeholder representatives alike (Haapasaari et al. 2012). Time is needed both to wrestle with unfamiliar concepts, cultures and vocabularies, and also to develop the friendship and collegiality that Campbell (2005) reminds us is so important to integrative success. However, we recognize that working in this way increases project costs and the size of the DSS development team.

A key challenge will be how to get agencies and other stakeholders that collectively manage specific problems (in this case invasive rabbits) to recognize and accept that there is more to effective management than having a computer or internet-based information system that helps them decide when, where, and how to manage one component of the system. Although such a tool (DSS) helps this process, and makes a significant contribution, by itself it will not deliver what is required because there are other key elements of management that must also be considered and actioned at the same time. To identify these other key elements and where the DSS might fit in the "whole system" requires an outcomes-based approach – such as ToC – to be implemented. For many projects, particularly those with limited resources, this may be a stretch as Matthews et al. (2008) remind us, unless we can better manage stakeholder expectations of DSS tools and other science-based interventions, and help those involved to implement wider outcomes-based approaches to management.

Concluding comments

As stakeholders in complex programs work together to build a more unified and in-depth understanding of the wider system, they also learn to communicate more effectively, providing a more reflective approach that supports learning and adaptive management. Our approach to DSS development using a ToC approach benefited from the complementary skills of members of the development team, and proved useful in developing a shared understanding across different disciplines and experiences of the development team and key stakeholders. Some critical factors for embedding DSS development within a wider ToC outcomes-based approach include:

- effective processes to support the development team and key stakeholders in the use of outcomes-based planning and evaluation
- effective communication across different disciplines and knowledge cultures, and to place problems and information in their wider context
- project time to allow for developing a common context and language, and for outcome evaluation.

To take up these challenges successfully, interdisciplinary research and development initiatives need to move beyond teams with technical competencies to include personnel with complementary skills in the management of multi-stakeholder participatory processes and ToC outcomes-based approaches to planning and evaluation.

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