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Using quantitative influence diagrams to map natural resource managers' mental models of invasive species management

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ABSTRACT

Despite the significant effect that invasive species have on natural values, the number and extent of invasions continue to rise globally. At least three dominant reasons explain why policy development and implementation can fail: differences in managers' mental models of invasive species management; cross-agency responsibility; and poor planning and management (i.e., planning–implementation gap). We used a case study of cross-agency management of gamba grass (*Andropogon gayanus*) in Australia to explore the differences in organizational staffs' mental models of management. The gamba grass invasion in northern Australia is continuing to expand and associated effects are increasing; coordinated action across agencies is needed to manage the expansion. Our aim was to examine how staff would represent their mental models as a diagram that we could compare between individuals and groups. We used cognitive mapping techniques to elicit models of 15 individuals from across 5 organizations, represented as an influence diagram, which shows the interrelationships that define a system. We compiled the individual influence diagrams to create a team model of management that captures the common connections across participants' diagrams. The team model revealed that education, science, legislation, enforcement and property management plans were perceived to be the most important management tools to control or eradicate gamba grass. The Weed Management Branch was perceived to have the most central role in gamba grass management, while other organizations were perceived to have specific roles according to their core business. Significant positive correlations (i.e., shared perceptions) were observed across half of the participants, indicating that the some participants have shared models that could be used as a starting point for discussing the team model, clarifying roles and responsibilities, and potentially building consensus around a shared model. Dominant opportunities for improvement identified by participants were better use of management tools, namely education and enforcement, better coordination and collaboration between agencies and increased resourcing. Our research demonstrates the value and validity of using influence diagrams to explore managers' mental models and to create a team model that could serve as a starting point for improved cross-agency natural resource management.

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1. Introduction

Invasive species are known to have a significant effect on natural values, including alteration of ecosystem processes, species composition and potentially species extinctions (Butchart et al., 2010; Ehrenfeld, 2010; Kingsford et al., 2009). Despite the recognized global threat posed by invasive species, the number of invasions continues to rise (Butchart et al., 2010).

Several dominant factors explain why invasive species management (herein referred to as management) can fail. First, differences in managers' perceptions of management, such as perceived differences in management priorities, can constrain effective outcomes (Adams et al., 2003; Biggs et al., 2011; Friedel et al., 2011). These differences can lead to uncertainty, power struggles, disputes among experts, worsening environmental outcomes, litigation and public opposition (de Wit et al., 2001; Friedel et al., 2011; Lewicki et al., 2003; Satterfield, 2002; Selge et al., 2011). For example, in Spain, environmental managers perceptions of how best to manage 49 different invasive alien plant species did not align with those of the public agencies, resulting in local reactive management

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without the support of a national legislative framework to guide action (Andreu et al., 2009). In Australia, regional differences in the growth and fire risk of buffel grass (*Cenchrus ciliaris*) have been observed to affect the government and non-government organization representatives' perceptions of the threat of the species and their preferences for management options (Friedel et al., 2011).

Second, to be successful, invasive species management typically requires collaboration and coordination of management efforts between several government and non-government agencies. Cross-agency policy development and implementation can be confounded by normative differences (i.e., ways of doing things), trust, cultural differences, political priorities and imperatives, subcultures, structural and institutional incentives, and agreement on the seriousness of the problem (Daley, 2009; Drake et al., 2004; Schein, 1996). In the United States, a failure of cross-agency collaboration has been attributed to short-term political cycles that require drastic shifts in priorities, public pressure to manage land for a particular use, resistance to change, logistics and communication (Jacobson et al., 2006; Koontz and Bodine, 2008). In Western Australia, scale has been identified as an important factor in collaboration, including the scale at which different organizations operate, at which planning processes occur and at which individual activities are undertaken (Fletcher et al., 2010).

Third, implementation of invasive species management plans can sometimes fail due to inadequate planning and implementation, whereby plans do not translate into effective on-ground outcomes (sometimes referred to as the planning–implementation gap) (Biggs et al., 2011; Knight et al., 2008). Failure can occur when: planning and management costs and feasibility are not accurately assessed; adequate funding is not secured; implementation and management success is not monitored; the administering agency does not have authority to enforce cooperation; and when effective program leaders are not maintained (Panetta, 2007; Panetta et al., 2011; Simberloff, 2009). In the Galapagos Islands, for example, only four of 30 plant eradication projects were successful, with project failure attributed to a lack of continuity of agency resources and unrealistic project goals (Gardener et al., 2010). In South Africa, failed eradication of invasive alien plant has highlighted a need for management agencies and stakeholders to set clear and achievable eradication targets, develop a learning culture and create adaptable management systems (van Wilgen et al., 2012). Meanwhile, on Oahu, Hawaii, invasion of the plant Koster's curse (*Clidemia hirta*) has been blamed on an inappropriate response to the incursion: despite well-documented evidence of its invasion elsewhere, the responsible government agency did not develop or implement an eradication plan, opting instead to attempt species control, which ultimately led to the spread of the species to the five main Hawaiian islands (Mack and Lonsdale, 2002). These implementation failures could have been due to the above points, such as inaccurate beliefs held by managers (e.g., whether control was more feasible and beneficial than eradication) or due to conflicts in perceptions across agencies (e.g., funders setting unrealistic project goals compared to managers on ground capacity).

Understanding these dominant factors could help to minimize contentiousness and increase the likelihood of management success through informing the development of coherent cross-agency policies and programs (Andreu et al., 2009; Friedel et al., 2011). Surprisingly, not much research has been published on the interactions between these factors, in particular, agency staff perceptions of who should be responsible for managing invasive species; how they should manage invasive species; and for what outcomes.

Our aim was to examine how organization staff would represent their perceptions of invasive species management in a diagram that could be compared between individuals and groups. Often termed mental models (Craik, 1943; Johnson-Laird, 1980), these physical representations of a person's perceptions are particularly useful in understanding invasive species because they can reflect the personalized interpretations of the complex and uncertain interactions between the biophysical and social systems that define such management (Abel et al., 1998; Jones et al., 2011; Liu et al., 2007). They have been used to examine how evidence should be integrated into management (Newton et al., 2007), how management decisions should be made (Murray-Prior, 1998), and how management is influenced by uncertain and complex social and political processes (Meliadou et al., 2012).

We use cognitive mapping techniques to elicit mental models, specifically by using quantitative influence diagrams, which generate a graphic map of the perceived web of interrelationships that define a problem or system (Abel et al., 1998; Diffenbach, 1982; Pearson and Moon, 2014). The aim of the influence diagram is to make these interrelationships visible so they can be understood and compared between individuals and groups to identify areas of similarity and difference to assist with planning and management for invasive species (Diffenbach, 1982). When used in this way, influence diagrams can be illuminate the stated opinions of individuals; they are not intended to measure how correct those opinions are. Thus, they contribute to understanding the extent to which conflicts in mental models across individuals and groups tasked with management exist (Abel et al., 1998); alternative research approaches would be needed to assess whether mental models and associated perceptions accurately reflect best practice recommendations.

We used an invasive species management case study in Australia, which requires cross-agency planning and coordination, to explore how the factors noted above are influencing management outcomes. By actively engaging with and involving invasive species management staff and relevant stakeholders to understand differences in their mental models of management, we anticipate the results will encourage and support self-review and contribute to improved invasive species management.

2. Methods

2.1. Case study: gamba grass in the Northern Territory, Australia

High biomass invasive grasses, such as the African grass *Andropogon gayanus* Kunth (gamba grass), pose a major threat to savannas globally, in particular in the Neotropics and Northern Australia, and to a lesser degree, at least to date, in Africa (Brooks et al., 2004; Foxcroft et al., 2010; Setterfield et al., 2010). For some of these invasive grasses, including gamba and buffel grass, a fire-invasion feedback loop has been demonstrated, where invaded ecosystems experience changes in the frequency, intensity and spatial extent of fires resulting in grass dominated systems, loss of canopy cover, and negative consequences for the native savanna biota (Miller et al., 2010; Rossiter et al., 2003; Setterfield et al., 2010). In Australia, the threat of gamba grass is recognized at a national level; it is one of five species of tropical invasive grasses that have been listed as a National Key Threatening Process in the Environment Protection and Biodiversity Conservation Act 1999 for Australia, and the species was listed as an Australian Weed of National Significance in 2012.

Gamba grass is a perennial C4 grass that forms large tussocks in excess of three meters high and displaces the much shorter native vegetation (Brooks et al., 2010) (Fig. 1). The most significant ecological effect of gamba grass invasions is increased fire severity, leading to a reduction in the tree canopy and degradation of the understory (Brooks et al., 2010; Rossiter et al., 2003; Setterfield et al., 2010). Changes in fire severity also has economic effects; for example changes in the fire danger index due to changes in fuel load and fire severity has resulted in increased costs of fire management

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