NELSON MANDELA UNIVERSITY

# Decision analysis to inform invasive alien plant management in the Garden Route Biosphere Reserve


by

**CURRENT MASUNUNGURE**


A thesis submitted in fulfilment of the requirements for the degree of

**DOCTOR OF PHILOSOPHY**

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## ABSTRACT

Invasive alien plants (IAP) pose significant threats to global economies and biodiversity and are often considered as wicked problems. With an increasing number of IAP and limited resources, their management and decision-making processes are becoming difficult because of uncertainty, multiple and conflicting objectives, and diverse stakeholder views, facts and values. This is particularly challenging given the complex interactions between economic, ecological, and social elements that exist in invaded areas. Consequently, it is important to incorporate new ways of thinking and novel methodologies to improve our understanding of IAP management and the decision-making processes around them, which are currently inadequate. Decision analysis can help with dealing with these challenges and support decision-making under uncertainty. Drawing on the systems thinking approach and the concepts of leverage points, transition management and transformational change, the aim of this thesis was to explore the effectiveness of IAP management and the decision-making process in the Garden Route Biosphere Reserve (GRBR). This was achieved using a mixed methods approach involving: social-ecological inventory (identifying relevant stakeholders); review of literature on the available decision support tools; key informant interviews (stakeholder perspectives on the current decision-making process); and stakeholder workshop and expert consultation (casual loop modelling). The results of this thesis provide evidence that application of the proposed principles of robust decision-making has the potential to overcome the weaknesses of the current decision-making process and as such, enables decision-makers to efficiently allocate resources towards IAS management. A novel causal loop diagram (CLD) was developed to highlight the interconnections between key variables in IAP management and decision-making. This revealed that to transcend ‘policy resistance’ and ‘quick-fixes that fail’ archetypes, and improve IAP management, the stakeholders need to consider deep leverage points, for example, fostering trust and shared understanding among different stakeholder groups. These can be realistically maintained over the long-term and can cause a fundamental change in IAP management, rather than focusing on shallow leverage points that are relatively easy to implement but do not result in significant systemic change. The findings of this thesis are flexible and could guide various stakeholder groups at local, national, and international scales in improving the effectiveness of IAP management and decision-making.

**Key words**: decision-making tools, invasive alien plants, stakeholder perspectives, principles of robust decision-making, systems thinking, causal loop diagram, system archetypes, wicked problem

## ABBREVIATIONS

| | |
|---|---|
| CBD | Convention on Biological Diversity |
| CLD | Casual loop diagram |
| DST | Decision support tools |
| EPWP | Expanded Public Works Programme |
| GRBR | Garden Route Biosphere Reserve |
| IAP | Invasive alien plants |
| IAS | Invasive alien species |
| IPBES | Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services |
| MCA | Multi-criteria analysis |
| NEMBA | National Environmental Management Biodiversity Act |
| NMU | Nelson Mandela University |
| SCLI | Southern Cape Landowner Initiative |
| SES | Social-ecological system |
| SIIPIA | Spatial Invasive Infestation and Priority Analysis |
| TD | Transdisciplinary research |
| WfW | Working for Water programme |

## DECLARATION BY CANDIDATE

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**NAME:** Current Masunungure

**STUDENT NUMBER:** s217735665

**QUALIFICATION:** PhD (Nature Conservation)

**TITLE OF PROJECT:** Decision analysis to inform invasive alien plant management in the Garden Route Biosphere Reserve

**DECLARATION:**

In accordance with Rule G5.11.4, I hereby declare that the above-mentioned thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

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**SIGNATURE:**

**DATE: 19 November 2020**

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First and foremost, I would like to thank God Almighty for giving me this once in a lifetime opportunity and strength to undertake this PhD research journey. Through it all, He has certainly been looking over my mental, physical and emotional health. I am reminded by one of His promises:

> *"I returned, and saw under the sun, that the race is not to the swift, nor the battle to the strong, neither yet bread to the wise, nor yet riches to men of understanding, nor yet favour to men of skill; but time and chance happeneth to the all" [Ecclesiastes 9:11].*

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## DEDICATION

To my late father, Shepherd Andrew Masunungure, this one is for you☺.

# CHAPTER ONE

## General Introduction

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*"They [biological invasions] are so frequent nowadays in every continent and island, and even in the oceans, that we need to understand what is causing them and try to arrive at some general viewpoint about the whole business."*

Charles S. Elton (1958)

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## 1.1 Introduction

Making decisions about the management and conservation of nature is complex and consequently difficult (Bunnefeld et al., 2017). The complexity arises from the various contesting pressures on the natural systems, with their opportunities and benefits for different groups of people, set within uncertain[1] social-ecological systems. Emerging issues, including invasive alien species (IAS), water scarcity and biodiversity loss, are interconnected and influenced by a variety of cross-scale drivers and complex feedbacks (Steffen et al., 2018). Consequently, these challenges and attempts to address them, involve diverse stakeholders with differing needs and interests and are plagued by social, political, and administrative uncertainty (Cash et al., 2006). However, there are also opportunities for better decision-making, leading to better outcomes for all sides. For example, bringing about transformational change, which is a system wide change in the fundamental attributes of a system (Maljean-Dubois, 2014), can help improve decisions. This thesis showcases these set of opportunities to improve our understanding of invasive alien plant (IAP) management and decision-making process in the Garden Route Biosphere Reserve (GRBR).

The rate of IAS introduction worldwide has increased as a result of an increase in the movement of people and transportation of goods (Mooney, 2005; Bradley et al., 2019; Pyšek et al., 2020) and there is no sign of saturation in the accumulation of species (Seebens et al., 2017). The continued expansion in global trade is anticipated to accelerate the rate of new invasions (Hulme, 2009; Seeben et al., 2017). This observed pattern is apparent in IAS from a wide range of taxa (for example, fish, birds and fungi) that occurs in different environments and at various scales (Dyer et al., 2017; Wilson et al., 2018). Although the definitions of IAS vary greatly and are the subject of much debate (Essl et al., 2017), this thesis defines IAS as a species that has the ability to establish in a new area outside its natural range, sustain reproductive populations or communities and have negative environmental and socio-economic impacts (Walther et al., 2009; Pimentel, 2011; Seebens et al., 2017).

The world's governments have recognised invasion science as one of the most important areas for research and assessment under the scope of the

[1] A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Maljean-Dubois, 2014). The Convention on Biological Diversity (CBD) under the Aichi Targets (2010) have put in place global targets to alleviate the effects of IAS (Adams et al., 2018). Vascular plants are amongst the most prolific IAS and pose significant impact on a species, community and ecosystem level (Vilà et al., 2011). Invasive alien plants (IAP) can spread over large areas and possess the ability to reproduce, sustain populations through seed and propagule production (Richardson et al., 2011). Many IAP are aggressive, fast growing species that often have no natural predators or competitors in the recipient area, and the invader is therefore given an opportunity to firmly establish itself (Wonham & Pachepsky, 2006; McGeoch et al., 2010).

Several studies have highlighted that successful invader plants tend to exhibit: i) higher population growth rates; ii) lower levels of herbivore damage; iii) higher shoot/root ratios; iv) higher survival; v) higher plasticity in many functional traits; and vi) higher specific leaf area, in comparison to non-invasive and/or native species (Ramula et al., 2008; Ordonez et al., 2010; van Kleunen et al., 2010; Davidson et al., 2011). However, other studies document contradictory results for many important traits, including plant growth (van Kleunen et al., 2010), seed mass (Ordonez et al., 2010) and plant size (van Kleunen et al., 2010). While, when looked at the individual species and trait level there are idiosyncrasies but when looked at while taking the magnitude and significance of the impacts there is a clearer picture (Moles et al., 2012).

The impacts of IAP on biodiversity, ecosystem services and processes and consequently human well-being are well documented in literature (Mooney, 2005). The threats are deemed to be increasing (Mack et al., 2000; Pimentel et al., 2001; Maxwell et al., 2016). IAP have the potential to cause large economic impacts on livelihood enterprises such as fisheries, grazing, agriculture and forestry (Shackleton et al., 2007; Shackleton et al., 2016), and are a major drain to global resources (Cassey et al., 2018; Early et al., 2016). However, some IAP provide benefits, for example as crops, livestock fodder and for ornamental plants (Ngorima & Shackleton, 2019). The majority of species used in agriculture and forestry production (for example, *Pinus* and *Eucalyptus* species) are alien species, and some are widely used in aquaculture and horticulture (van Wilgen, 2018). It is also suggested that the impacts of IAS are over-exaggerated (Briggs, 2017), although this too is widely refuted (Kumschick et al., 2015; Ricciardi et al., 2017).

In South Africa, it is widely recognised that IAP, and specifically woody IAP, are a significant threat to the country's water resources (Richardson & van Wilgen, 2004; van Wilgen et al., 2008) and have resulted in mean annual runoff reductions of approximately 6.7% (Le Maitre et al., 2000; Le Maitre et al., 2016). Studies document a negative correlation between stream flow and the presence of IAP (Le Maitre et al., 1996), with the eradication of IAP found to improve stream flow and runoff significantly (Versfeld et al., 1998; van Wilgen et al., 2010). IAP's impact on water availability is exacerbated by dry climate and fragile water balance in most parts of South Africa, ultimately presenting negative costs to the country's economy (De Lange et al., 2012). This is an important issue considering that the country's available water resources are reported to be already utilised (DWAF, 2004; Donnenfeld et al., 2018).

While countrywide commitments in South Africa is being made to halt or slow the impacts of IAP, several studies document a sufficient increase in IAP magnitude and distribution (Kotzé et al., 2010; van Wilgen et al., 2012). More than 10 million ha totalling approximately 8% of the land cover across the country is covered by IAP with wide spread species being pines (*Pinus* species) and wattles (*Acacia* species) (van Wilgen et al., 2010; Wilson et al., 2016) and many others. Of these areas, the Western Cape Province has the greatest invaded area with approximately a third of its total area under woody species invasion, followed by Mpumalanga, KwaZulu-Natal, and Northern Cape (van Wilgen et al., 2020). Of particular importance in the Western Cape and GRBR, is the Cape Floristic Region, which is a biodiversity hotspot comprising high biodiversity levels and endemism (Goldblatt & Manning, 2000). Its fynbos biome is heavily invaded by *Acacia*, *Pinus*, *Hakea* and *Eucalyptus* species (van Wilgen et al., 2008).

The global response to threats posed by IAP has been diverse, with some countries making urgent calls to deal with the problem, including using mechanical, biological and chemical control, together with habitat management (McNeely et al., 2001; Gaertner et al., 2017). South Africa for well over a century, has actively implemented diversified approaches to manage and control IAP, and government funding is allocated to address a range of aspects (van Wilgen, 2018). The ultimate goal of these interventions is to reach a maintenance level in as many localities as possible; this concept recognises that eradication is unfeasible in many locations (van Wilgen, 2018). Thus, the problem is reduced to levels where the negative impacts are insignificant under relatively low control costs (van Wilgen, 2018). Currently, the management of IAP species is regulated under a national law, the National Environmental Management Biodiversity Act (NEMBA), 2004 (Act No. 10 of 2004), which seeks to provide for the following aspects: management and conservation of biodiversity, safeguarding of priority species and ecosystems, and the sustainable utilisation of native biological resources.

At the forefront of the IAP control in South Africa is the national Working for Water (WfW) programme, which falls under the Expanded Public Works Programme (EPWP). This EPWP was initiated in 1995, with a two-fold commitment of protecting water resources (by controlling the spread of IAP) and creation of jobs (employing poor people within local communities in IAP control projects). The programme endeavours to increase poverty alleviation and societal upliftment in poor communities (van Wilgen et al., 2012). The WfW is a programme in which the clearing of IAP is done through the use of mostly labour intensive techniques, amongst others (De Lange et al., 2012), consequently creating jobs (Turpie et al., 2008) and stimulating small business development. However, management of IAP can be an expensive operation that creates a considerable fiscal burden to the economy of South Africa (De Lange et al., 2012). The costs for managing individual species is frequently in tens of thousands and often millions of dollars (Robertson et al., 2017). For example, initially the WfW was launched on a national budget of R25 million for the period October 1995 to March 1996 and this grew rapidly over a seven-year period, recording an annual budget in excess of R400 million in 2003/4 financial year (Marais et al., 2004; Turpie et al., 2008). Further to the massive drain on the national budget, the inefficient and ineffective management approaches resulted in the wastage of resources (Kraaij et al., 2017).

While the WfW programme has been applauded for its social and economic development (McConnachie et al., 2012), and substantial employment and poverty relief benefits that it provides (van Wilgen et al., 2002; Magadlela & Mdzeke, 2004), the WfW programme also receives much critic. The lack of an effective system of monitoring and evaluation has resulted in an inability to address questions regarding the effectiveness of WfW operations (Levendal et al., 2008). The sustainability of the programme has also come under great scrutiny. Although the programme has resulted in positive social development, other scholars have argued that it is neither substantial nor sustainable (Buch & Dixon, 2009). In addition, the complex social nature of the programme coupled with rapid growth of the programme and increasing pressures to spend budgets, puts reaching deliverables under substantial pressure (Ground, 2003). The WfW is widely perceived as a job creation scheme and that the programme's other objective of alien clearing for enhancement of biodiversity and water availability, is not regarded as being important (van Wilgen et al., 2011).

Consequently, the management of woody IAP in the GRBR, and many places around the world, is a classic 'wicked problem' for institutions (conservation agencies, parastatal organisations) and for individuals who are accountable for managing woody IAP. These classes of problems are entrenched in complex systems and are often challenging to define, and lack well-defined solutions (Rittel & Webber, 1973). The management of IAP is embedded in a wickedly uncertain and dynamic social-ecological system (SES), embracing non-linearity, various feedback loops, high levels of political, scientific, and organisational uncertainty (Liu et al., 2011a). The wickedness of the problem varies from case to case, region or country, and is closely linked to the different perspectives of the stakeholders involved (Liu et al., 2011b; Woodford et al., 2016). In each case, it is crucial to appreciate how the nature of the problem affects decisions can be made to improve management (Woodford et al., 2016).

### 1.1.1 Rationale

The management of IAP is highly dynamic and complex, consisting of a network of interactions between various dimensions of ecological, social, economic, and cultural aspects, and between diverse stakeholders (Estévez et al., 2015; Shackleton et al., 2019a). Conventionally, the management of IAP is typically approached either as an ecological problem, with social and economic benefits, or as a social problem with ecological benefits (Estévez et al., 2015). This incomplete, linear thinking that views IAP management as a 'tame' (as opposed to 'wicked') problem does not consider the complex interactions between landscapes, species, abiotic resources, behaviour of land users, economic development, infrastructure and governance systems.

Consequently, a traditional linear process is deemed sufficient to produce a workable solution within an acceptable time frame and resisting expansion or modification of problem definition (Conklin, 2005). This may potentially lie at the root of current dissatisfaction amongst stakeholders (including WfW managers, decision makers and local communities) about IAP management strategies in the GRBR.

In addition, the management of IAP tends to predominantly focus on individual parts of the system and consequently disregard the interrelated nature of the SES. The result is that ecological, social, governance and economic elements are managed in isolation; monitoring systems are inappropriate, over-complicated and incomplete; and reflection, learning and adaptation are not seen as productive outputs. Governance systems are perceived as being closed and un-adaptive, and stakeholders tend to de-couple from the system due to inefficiencies and frustration. Yet, there is a need to incorporate stakeholder knowledge (Downey, 2010; Shackleton et al., 2019b) and account for differing experience, knowledge, and bias among stakeholders. This is critical for gaining an all-inclusive understanding of the problem and its possible solutions (Kueffer, 2010, 2017; Novoa et al., 2018), ultimately improving the efficiency and effectiveness of the management of IAP. Land managers involved in managing IAP often have different goals, values, mandates, definitions of the problem and perceptions of acceptable management strategies, and priorities (Conklin, 2005; Waddock et al., 2015) that need to be considered.

While the necessity to improve IAP management activities has long been recognised and emphasised in the Strategic Plan for Biodiversity 2011-2020 (COP 10, 2010), how to achieve this in the most effective and efficient way is highly debatable with no guidance provided (CBD, 2010; McGeoch et al., 2016). The practical use of many of the decision tools designed to provide guidance on improving management effectiveness has often been limited (Dana et al., 2014; Büyüktahtakın & Haight, 2018). The majority of the tools focus on assessing ecological impacts of species, or their ability to modify ecological processes and dynamics; invasiveness, abundance tendencies, current or potential invasion range; or difficulty of managing existent populations (Downey, 2010; Randall et al., 2008; Booy et al., 2017). This is coupled by considerable uncertainty regarding future spread, relative impacts of IAP and uncertainties in the outcomes of different management decisions (Kumschick et al., 2012; Vaz et al., 2017). In most circumstances, a land manager is faced with several invasive species at any given time over large areas and still needs to implement management measures with finite resource budgets (Auld & Johnson, 2014; Ohr et al., 2017). There is a need to approach IAP management in an integrative way in order to capture the complex interaction between causal variables and responses, in addition to lags, feedbacks and limits in social-ecological systems (Biggs et al., 2012; Biggs et al., 2015).

The choice of appropriate and cost-effective courses of action regarding management of IAP can be assisted by Decision Support Tools (DST), hereafter referred as decision tools (Marais et al., 2004). The concept of DST is increasingly used “to indicate any kind of decision aid, whether computer-based or not, and whether the problem it purports to address is more or less well structured” (Ison, 1993: page 112). Decision tools should be able to collectively identify, in the face of considerable uncertainty (Liu et al., 2011b), the order in which areas should be controlled and the timing of the allocation of resources in order to reduce density and extent of invasion. There is wide consensus on what needs to be done: prevent new invasions, detect and eradicate those that get introduced, and reduce the impacts of widespread species where eradication is not feasible (Lodge et al., 2016). Yet, practical methods or tools or approaches to prioritise management, are lacking (Hulme, 2009; Hulme et al., 2013; McGeoch et al., 2016). Such approaches are urgently needed given the complexities and inherent uncertainty involved and must not only consider severity of threat from IAP but incorporate the principles of robust decision-making (Chapter 2– section 2.4 and 4) to improve their effectiveness. Application of principles of robust decision-making can potentially improve the effectiveness of IAP management efforts and decisions by establishing criteria for technical implementation across different stakeholder groups.

Accordingly, the overarching research question this thesis seeks to address is: How do we make effective decisions about IAP management and how does IAP management and decision-making interact? The focus is on decisions that are at the strategic or tactical level — about why, where and when, rather than how to clear a given area. In other words, by adopting a systems thinking lens, the research sought to respond to gaps in understanding the complexity of IAP management and decision-making process in the GRBR. Understanding the complex dynamics of the IAP management system helps to identify places in the system to leverage change for effective interventions (Abson et al., 2017). Also, this provides a basis for determining what interventions might be needed with what stakeholders and organisations to improve outcomes (Martin et al., 2012). The study, using GRBR as a laboratory, will complement on-going scientific efforts to improve the effectiveness of IAP management and decision-making to reduce the extent and density of IAP (Forsyth et al., 2012). Land managers must make informed decisions on how to improve their decision-making process in the face of considerable uncertainty (Liu et al., 2011a; Moon & Adams, 2016), inherent risks and achieve optimal return on investment in sites with already widespread IAP. The study approach is aimed at supporting the efficient use of limited resources and providing justification to help gain public-private sector partnerships that support IAP management despite uncertainty and risks (Liu et al., 2011b; Leung et al., 2012).

## 1.2 Research aim, objectives and key questions

### 1.2.1 Aim

The overall aim of this thesis is to explore the decision-making process concerning IAP management and to examine the effectiveness of IAP management in the GRBR. Focus is on the management of woody IAP (mainly species in the genera *Pinus, Hakea, Eucalyptus* and *Acacia*) in the GRBR.

### 1.2.2 Objectives and key research questions:

1. To review the available and/or existing decision support tools for IAS management and assess whether they apply the principles of robust decision-making (Chapter 3).
    a) What are the methods, models or tools that have been used or are currently in use in IAP management?
    b) How can the application of decision support tools be improved?
2. To examine the perspectives on current IAP decision-making processes for woody IAP management in the GRBR (Chapter 4).
    a) What strengths and weaknesses exist in the current IAP decision-making processes related to IAP management?

b) How appropriate are stakeholders' IAP management decision-making processes or approaches to managing ‘wicked problems’?

c) How can current IAP management decisions be improved to achieve more effective decisions, using these insights?

3. To examine the feedbacks and interactions in IAP management and decision-making processes in the GRBR (Chapter 5).

   a) What are the key variables that influence IAP management and decision-making?

   b) How do these variables affect IAP management and decision-making?

   c) What are the feedback and interactions between these variables?

## 1.3 Significance of the research

### 1.3.1 Theoretical significance

Transdisciplinary research (TD) is an emerging body of literature that argues contemporary SES challenges that warrant responses to embrace knowledge co-production between society and science (Van Breda & Swilling, 2019). While TD offers a practical, method-driven means of applying and operationalising complexity in SES research (Jahn et al., 2012), it is seldom applied to IAP management and decision-making. However, over time, invasion biology has advanced into a broader transdisciplinary field of invasion science (Wilson et al., 2016). Several examples of TD research on invasion science exist that have been produced mainly by collaborations between: invasions ecologists and social scientists; evolutionary ecologists and economists, mathematical biologists and decision scientists (Lockwood et al., 2010; Lockwood et al., 2013). Such collaborations are highlighted to serve the pivotal role of humans and their interactions (Wilson et al., 2016). This thesis involves collaboration between the researcher and diverse stakeholders involved in IAP management and decision-making in invasion science. The novelty in the application of TD research in this thesis is that it provides a crucial step towards advancing TD research itself and improving decision-making processes. This potentially contributes to invasion science, through for example reducing the gap between science and practice, as well as sustainable conservation management.

Transdisciplinary research involving broader groups of stakeholders (Chapter 4 and 5) in formal process aimed or designed to improving IAP decision-making processes is important for normative, substantive, and instrumental purposes (Chilvers & Kearnes, 2020). Substantively, stakeholder perspectives can contribute to the generation of valuable knowledge that complements scientific knowledge, ultimately enriching the knowledge-base that is used to guide the decision-making process. Normatively, diverse stakeholder groups, who may be affected by IAP (either positive or negative), have the right to be involved in deliberations about the merits of a species of concern. Instrumentally, the inclusion of interested and affected stakeholder groups in the decision-making processes has the potential to lead to better informed and more widely acceptable decisions. In particular, the importance of this inclusion ultimately lies in the stakeholders being engaged in producing the outcomes as active participants in the implementation and execution of the decisions.

This thesis combines the fields of systems analysis, geography, anthropology, environmental science, invasion biology and ecology to address a complex pressing societal issue (in this case, woody IAP). Scholars have often called for a new form of inquiry that provides solutions to complex problems (Jahn et al., 2012). One of the most widely cited arguments for applying TD research is that it is considered as one way to bridge the gap between science and society, or science and action, or research and practice (Cockburn et al., 2016). This is important in the quest to address societal pressing issues (Cockburn et al., 2016; Sitas et al., 2014). TD research embodies the mission of science with rather than science for society (Seidl et al., 2013). In this research, the framework proposed by Jahn et al. (2012) is specifically applied (Figure 1.1) to guide the operation of a TD research approach. By recognising the gap between societal practice and academic practice, this framework makes it suitable for this thesis in addition to providing specific design principles.

Max-Neef (2005) argues that specific individual disciplines are inadequate in tackling ‘problematiques’ that are defining the new century. This thesis endeavours to bring together knowledge on invasion science, ecological processes, management decisions and stakeholder knowledge in the development of a Causal Loop Diagram (CLD) (transdisciplinary integration, Figure 1.1) to visualise woody IAP management and decision-making in the GRBR. A CLD is a linkage of variables connected by arrows indicating their causal relationships (Chapter 5) and identifies the interactions and feedback in the system structure (Stave & Kopainsky, 2017).

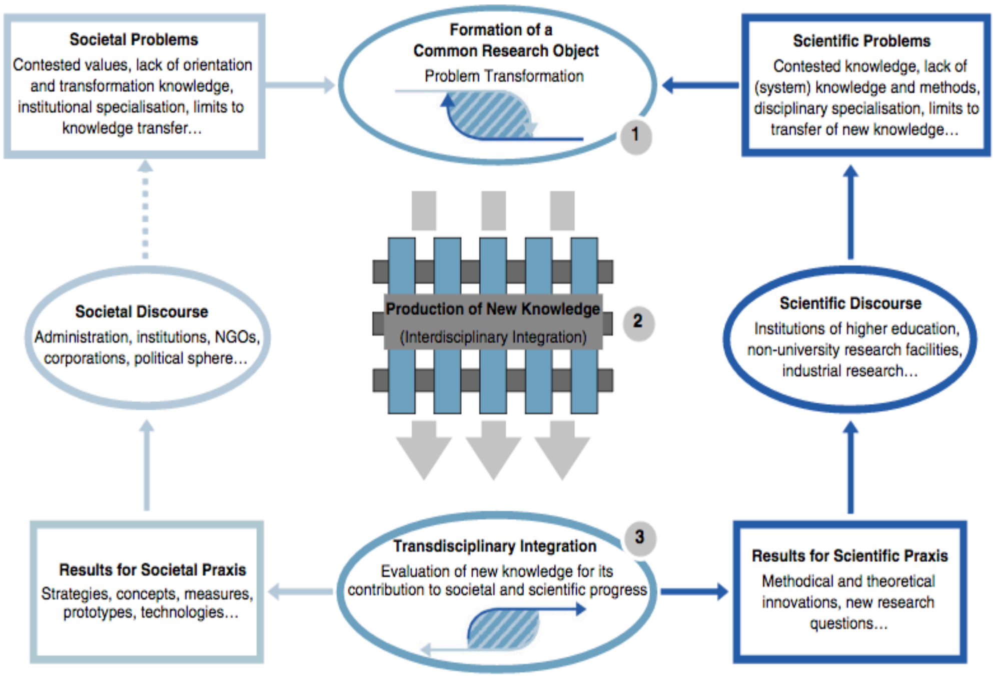


**Figure 1.1** A conceptual framework of transdisciplinary research (TD). The numbers specify the three stages of the model transdisciplinary research process (Source: Jahn et al., 2012)

The application of TD research to develop a CLD is yet to be tried in IAP management and decision-making. One study that has attempted to use systems analysis assessed published studies for the impacts of IAP to ascertain whether the presented evidence is consistent with reinforcing feedback processes (Gaertner et al., 2014). It is interesting to note that 443 studies report impacts of invasive species on ecosystems. In this thesis, a CLD with five main feedback mechanisms is presented to highlight plant invaders with high-impact on ecosystems that should be given high priority for management. The assessments are based on the use of both systems analysis and meta-analysis approaches. This thesis reveals the lack of studies in plant invasions involving the exploration and integration of feedback mechanisms. In addition, the authors are hopeful that their work would motivate future research in this subject, as it is important for prioritising and justifying effective and defendable management actions (Gaertner et al., 2014).

The relevance of this thesis is that woody IAP management practitioners will be in a position to improve their decision-making processes that are appropriate towards managing ‘wicked problems’. Transdisciplinarity research approaches essentially change the scientific process from simple research processes that offer solutions, to social processes that offer potential solutions to problems, through participation, experimentation and learning among stakeholders groups (Hardon et al., 2006; Reyers et al., 2010). By using TD research, this thesis aims to generate knowledge and bring about change by bridging the gap between research and implementation in conservation (Rice, 2013), and by creating windows of opportunities for meaningful dialogue and knowledge exchange between researchers and practitioners (Cockburn et al., 2016), as well as other stakeholders like land owners, foresters found within the GRBR.

### 1.3.2 Practical significance

As noted earlier, managing IAP in GRBR is especially challenging given the complex interactions between social, ecological, and economic elements that exist in the system. Consequently, achieving an effective decision-making process requires a deviation from the traditional approach that views IAP management as ‘tame’ to viewing them as ‘wicked problems’. This thesis aims to build on the existing available data, established platforms, diverse stakeholder knowledge, and to compensate for the existing weaknesses, through stakeholder engagement (key informant interviews, social-ecological inventory and stakeholder workshops) and the application of TD research approaches. Furthermore, the study makes use of abundant available data, stakeholder and/or practitioner insights to propose that the application of principles of robust decision-making and systems thinking has the potential to provide a comprehensive understanding (Van Mai & To, 2015) of the IAP management decision-making process. This is achieved through the development of a CLD that visualises the fundamental systemic structural components. The CLD also provides explanation for both main feedback loops presently influencing the IAP management decision-making process, in addition to sub-dominant feedback loops that are likely to influence IAP management processes in the future (Van Mai & To, 2015).

The main outcome that emanates from this research, is the development of a CLD that could function as a valuable platform for engagement, collaboration, communication and improving decision-making among stakeholders working to improve efficiency in IAP management by facilitating learning (Chapter 5). The network of variables in the CLD is to be used to identify the fundamental system structures, that is, ‘system archetypes’ – which can help the general system behaviour. For instance, ‘fixes that fail’ represent a system archetype where situations in which managerial response to a problem is short-term (Sterman, 2000), that makes the symptom of the problem to go away. However, such solutions work in the short-term (balancing effect), and are often associated with unintended consequences that usually exacerbate the original problem (reinforcing effect) (Sterman, 2000). For example, pressure to hastily find a solution to the water hyacinth problem resulted in poor management decisions as there are no quick fixes for this weed (Julien, 2008). Ironically, attempting quick-fixes has been noted to invariably lead to squandering of resources and time in the management of biological invasions (Julien, 2008; Vicente et al., 2014).

### 1.4 Scope and limitation of the case study

Due to the sheer extent (covering an area of approximately 698 363 ha) of the case study, that is, the GRBR (Figure 1.2) as well as time limitations, it was not possible to conduct systematic and exhaustive research in all areas of the GRBR where IAP infestations occur. A combination of purposive and snowball sampling (Chapter 4 and 5) was adopted. Thus, the thesis uses the GRBR as a laboratory to develop an approach to improve effectiveness and efficiency in IAP management by facilitating learning and collaboratively developing a CLD and testing the application of principles of robust decision-making.

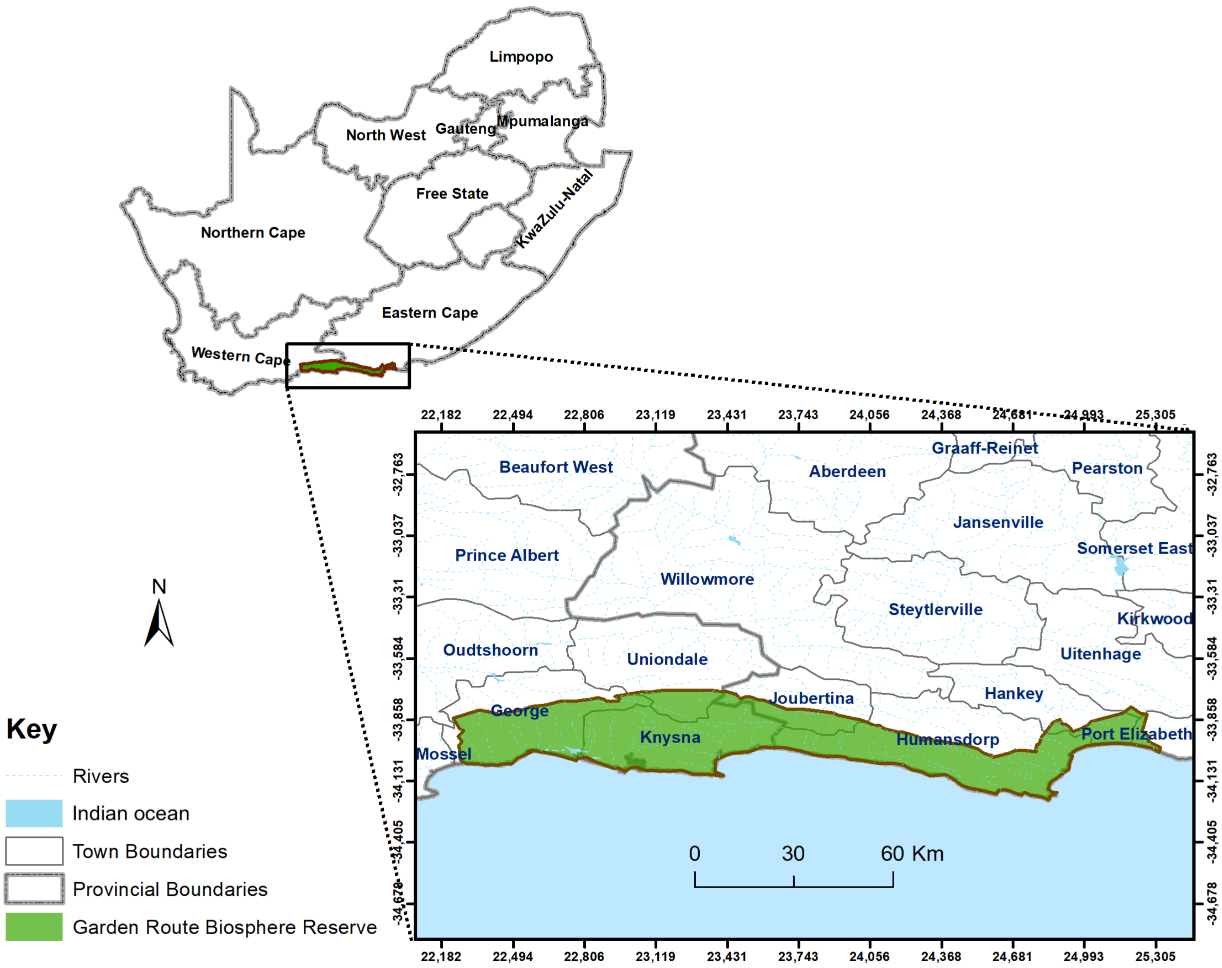


**Figure 1.2** The location and extent of the Garden Route Biosphere Reserve (GRBR) within the context of South Africa and its provinces

The approach taken in this thesis is intended for woody IAP, but a similar methodological process can be used for other invasive taxa. Although the results of this thesis may not be assumed to be representative of the preferences of the entire GRBR, the significance of this thesis is in the development and use of the end-user CLD as a learning tool.

## 1.5 Ethical consideration

Since this thesis involved diverse stakeholders with different institutional affiliations and some in their own personal capacity, it was important to adhere to universally recognised moral norms and values as defined by professional bodies or organisations (Hallowell at al., 2004). For this reason, this thesis was conducted in accordance with the Nelson Mandela University Ethical Standards guidelines[2] (H18-SCI-SRU-003, Appendix A) and only commenced once the Ethics Committee had approved the ethics application. Throughout the research, the researcher observed ethical awareness and strictly upheld the values of ethical research conduct (Mosberg & Eriksen, 2015). The following aspects were particularly, clearly adhered to throughout the research:

- Informed consent of subjects: The researcher obtained informed consent from the participants who were willing to participate in the project. A written consent form was used (refer to Appendix B for a copy of the consent form). All the key informant interviewees were literate and competent in the English language; thus, the written consent form was in English.
- Anonymity of subjects and confidentiality of data: The researcher guaranteed the confidentiality of the information given to him. In addition, the researcher recorded all responses as accurately as possible and a non-extractive approach to data collection was followed throughout the research. All respondents in this thesis were kept unidentified for their protection, and pseudonyms are used to guarantee anonymity (Nielsen & Randall, 2012).
- Research results feedback: To communicate research findings, the researcher compiled the results onto an information sheet that was provided to interviewees as well as local government officials and local leaders. This fact sheet was written in simple easy for all to understand English.

## 1.6 Structure of the thesis

The thesis is composed of the following parts (Figure 1.3): an introduction (current chapter) which provides an introduction and overview of the study, and the conceptual and theoretical framework of the study is provided in Chapter 2. This is followed by the empirical research chapters (3, 4 and 5) which are written as individual papers with the intention for submission in peer-reviewed journals (indicated in each chapter title). Consequently, there is some degree of repetition in content among these chapters, especially across the introductions and methods. The final chapter of this thesis

[2] http://rcd.mandela.ac.za/Research-Ethics/Research-Ethics-Committee-Human-(REC-H)

(Chapter 6) provides a synthesis of the findings, any limitations of the study design, recommendations and suggested implications of future work to improve our understanding of woody IAP within GRBR and beyond.

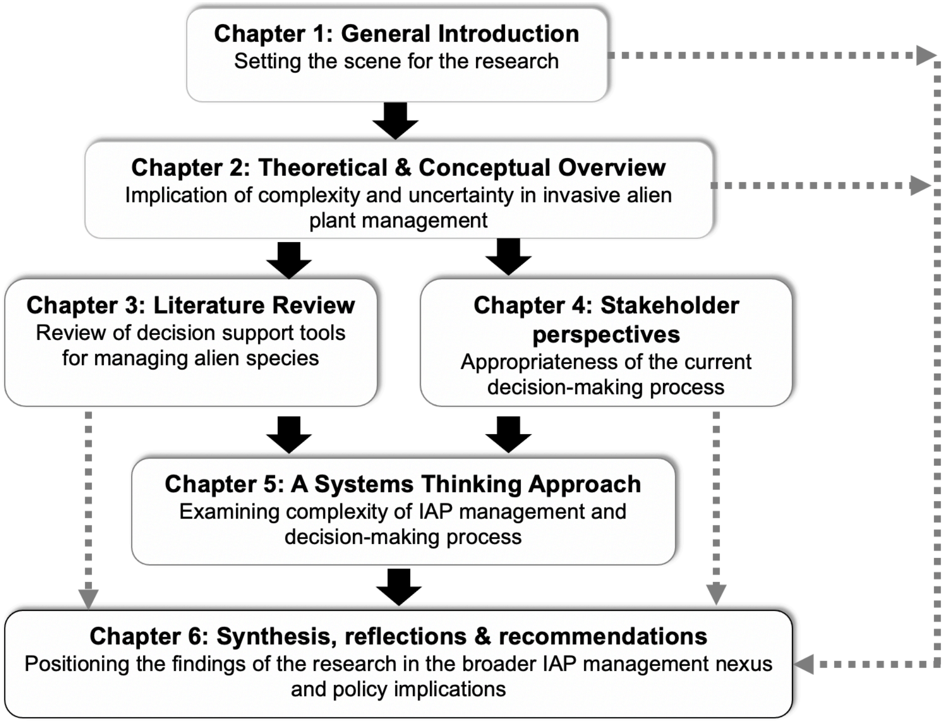


**Figure 1.3** Schematic thesis structure with broad aims of each chapter and how they are linked together within the thesis

# CHAPTER TWO

## Conceptual and theoretical overview: Implication of complexity and uncertainty in invasive alien plant management

### Overview

This chapter aims to provide insights on the conceptual and theoretical frameworks used to frame and guide this thesis and their implications in understanding the complexity of invasive alien plant (IAP) management in the Garden Route Biosphere Reserve (GRBR). The underlying logic is that conceptual and theoretical framing informs methodology, which informs research design and methods. The implications of complexity and uncertainty for IAP management are discussed, and the concept of leverage points is applied in order to highlight the need to identify places in the system that would enable transitions and transformation in the IAP management system. In addition, this chapter places the research within the context of current invasion science literature.

## 2.1 Theoretical and conceptual orientation

Ecological studies have been examining the phenomenon of invasive alien species (IAS) increasingly since the middle of the 20th Century (Kapitza et al., 2019). However, progress towards satisfactory prediction, explanation, and management of IAS continue to be challenging (Moles et al., 2012; Heger et al., 2013a) with some scholars increasingly calling for an improvement in the implementation of existing knowledge into policies and management (Lodge et al., 2006). More socio-ecological systems (SES) research is needed to develop effective IAP management strategies (Andreu et al., 2009). Consequently, researchers should be clear about the conceptual orientation which informs their research approaches (Newing, 2010; Creswell, 2013) to improve the effectiveness of applied and basic research *(*Heger et al., 2013a), particularly on invasive alien species (IAS).

A clear conceptual orientation is particularly important when conducting social-ecological systems research, which is by nature interdisciplinary, and may not obviously conform to a single conceptual paradigm (Evely et al., 2008; Stone-Jovicich, 2015). A conceptual framework is useful when prevailing theories are not sufficient or applicable enough in designing a firm research structure (Akintoye, 2015). Also, it provides a structure that best explains the likely flow of the phenomenon under examination (Adom et al., 2018). Concepts, critical theories and empirical research are linked in a conceptual framework and are useful when supporting and systemising the knowledge taken up by the researcher (Peshkin, 1993).

This thesis draws on the paradigm of systems thinking (Meadows, 1999; Senge, 2006) as a guide to research on complex SES, in this case, IAP management (Figure 2.1). This paradigm emphasises engagement with diverse stakeholder groups (Chapter 4 and 5) and acknowledges that challenges in IAP management need novel approaches in the production of knowledge which ensure that decision-making processes are more transformative (Lang et al., 2012). For example, the general public often has limited knowledge on the subject of IAS and further evaluation of the impacts of IAP invasions are not homogenous across stakeholder groups (Rotherham & Lambert, 2011). New transformative approaches should seek to reduce such disparate perceptions and aim to be inclusive of, for example, social and economic requirements into IAP invasion research and management (Brundu et al., 2018). The application of systems thinking approach in Chapter 5 provides a comprehensive understanding of IAP management in the Garden Route Biosphere Reserve (GRBR) and discusses avenues to improve the effectiveness of decision-making.

### 2.1.1 Invasive alien plant management

As mentioned in Chapter 1, IAP management is typically approached either as an ecological problem, with social and economic benefits, or as a social problem with ecological benefits. For example, instead of also considering the socio-economic aspects, a study on the impact of dense stands of Port Jackson willow (*Acacia saligna*) only documented the decline soil-stored seed banks of native plants, leading to local extinction of native species (Holmes & Cowling, 1997; Richardson & Van Wilgen, 2004). This incomplete, linear thinking that views IAP management as a 'tame' problem tends to ignore the complex interactions between landscapes, species, abiotic resources, the behaviour of land users, economic development, infrastructure and governance systems. Notably, IAS processes are difficult to analyse, explain and predict (Heger et al., 2013a), and are complex (Hayes & Barry, 2008) and context-dependent (Blackburn et al., 2010). Linear thinking presents major obstacles in addressing these difficulties associated with IAS. This creates the necessity for methods, for example, that have the ability to provide explanation and prediction of the multiple interacting influences (Heger et al., 2013b). Further, they should account for the history of current invasions in their explanation (Cassey et al., 2005).

Addressing this incomplete linear thinking requires societies to tackle interacting ecological, economic, and social dimensions of societal challenges (Folke et al., 2016; Norström et al., 2020). But the dominant discourses in science address incomplete linear thinking from mostly disciplinary perspectives (Abson et al., 2017). Early ecological research investigating IAS mainly focus on ecological characteristics of biological invasions, for example, principles of the invasion processes (Pyšek et al., 2008; Vaz et al., 2017) and impacts of IAS on ecosystems (Stricker et al., 2015). The solutions are often investigated independently with the focus being on proximal problems and 'quick fixes' rather than on the underpinning drivers of current trajectories (Ehrenfeld, 2004; Van Mai & To, 2015). This may lie at the root of current dissatisfaction amongst stakeholders (including Working for Water managers, decision makers and local communities) about IAP management strategies (van

Wingen et al., 2012). Also, another root problem is how strategies are translated of into sustained action and the lack of self-correction when issues emerge. Consequently, it is imperative to examine more deeply the root causes of challenges in IAP management decision-making and identify solution-oriented approaches to improve the current IAP management and decision-making process.

### 2.1.2 Decision-making theory

Recognising this, the decision-making theory was brought in as a conceptual and methodological process to guide interdisciplinary and engaged knowledge co-production with different stakeholders (Jahn et al., 2012; Lang et al., 2012). In particular, the principles of robust decision-making (Section 2.3.5; Chapter 4) are applied to evaluate whether the current woody IAP decision-making process is appropriate for managing 'wicked problems'. The concept of leverage points was then employed to identify avenues for transition management and transformational change within the GRBR, with the development of a CLD being the output (Chapter 5). This is an attempt to create approaches to transdisciplinary research practice, and thus co-producing potential solutions to IAP management challenges that ultimately address socio-economic and environmental needs (Jerneck et al., 2011; Turner et al., 2016). In addition, the inclusion of diverse stakeholder perceptions, particularly the public, reduces the gap between stakeholders' interests and the dynamics of biological invasions' processes (Kapitza et al., 2019). The sections below discuss each of the aspects in the conceptual framework (Figure 2.1) arguing for their relevance and value to this thesis and showing how they are mutually reinforcing.

## 2.2 Complexity and uncertainty

The ongoing research is increasingly recognising that our society is facing a number of persistent problems, referred to earlier in this thesis as 'wicked problems'. These are seemingly intractable problems that are rooted in complex systems that are often difficult to define and lacking clear solutions (Rittel & Webber, 1973). Most importantly, natural resource management particularly IAP management, takes place in the settings of incomplete knowledge coupled with complexity and high uncertainty (Walters, 1990; Gunderson & Holling, 2002). In this thesis, complexity is used to refer to a more general understanding of complex systems which focuses on relationships (non-linear) between variables/factors, boundary problems, systemic interaction, emergence, and adaptation (Cilliers, 2005). It requires the understanding of the relationships between the whole and the parts, thus, when dealing with complexity, the conventional approaches offer little hope (Cilliers et al., 2013) and need to be augmented. For instance, despite being usually extremely complex, IAP management tends to be approached as conventional and cause-effect problems that are regarded as 'tame' problems. Management actions rarely result in predictable outcomes; responses tend to be complex, and may be subject to time lags, drastic escalations, slow declines, or even cyclical changes of, for example, available funding budgets (Walters & Holling, 1990; Kraaij et al., 2017).

Approaching IAP management as complex, nuanced problems instead could aid in identifying windows of opportunities for improving the IAP management approaches. Complexity is distinctive of a system and results from the interaction and relationship between components of a system (Cilliers, 2005; Cilliers et al., 2013). Studying a complex system by decomposing it into individual components alters the system properties and thus, complex systems such as SES must be studied as intact systems (Cilliers et al., 2013). The robustness of conservation decisions is often affected by the dynamics of SES in which interventions are to be implemented (Miller et al., 2012). SES are complex adaptive systems consisting of biophysical and social components organised in multiple subsystems that interact at numerous temporal and spatial scales (Ostrom, 2009). The emergence of the science of complexity offers the hope of an alternative methodology that has the ability to tackle such problems (Heylighen, 1997; Cilliers, 2005). This methodology is especially important if applied in the GRBR where fynbos vegetation is threatened by many external pressures (for example: human activities, urbanisation and climate change) and expanding woody IAP (Latimer et al., 2004; Roura-Pascual et al., 2009).

As mentioned earlier, 'wicked problems' are *complex* in that they are deeply entrenched in our societal structures, *uncertain* as a result of non-reducible structural uncertainty, *difficult to manage* due to a diverse array of actors with variety of interests and *hard to grasp* in that they are difficult to interpret and ill-structured (Rotmans & Loorbach, 2009). With these characteristics in mind, the conceptual orientation of this thesis has its foundations in systems thinking, decision-making theory (principles of robust decision-making) and draws on the ideas of leverage points, transition management, and transformative change. The integrated conceptual framework

(Figure 2.1) used in this thesis provides a better understanding of the complex interactions among variables that influence the dynamics of IAP management and the interplay with wider socio-political issues (Roura-Pascual et al., 2009). Despite large investments in IAP management, there is lack of clarity on the success of control operations in reducing the magnitude of the problem (Roura-Pascual et al., 2009). Thus, the need to provide insights through engagement with diverse stakeholders to improve the decision-making process.

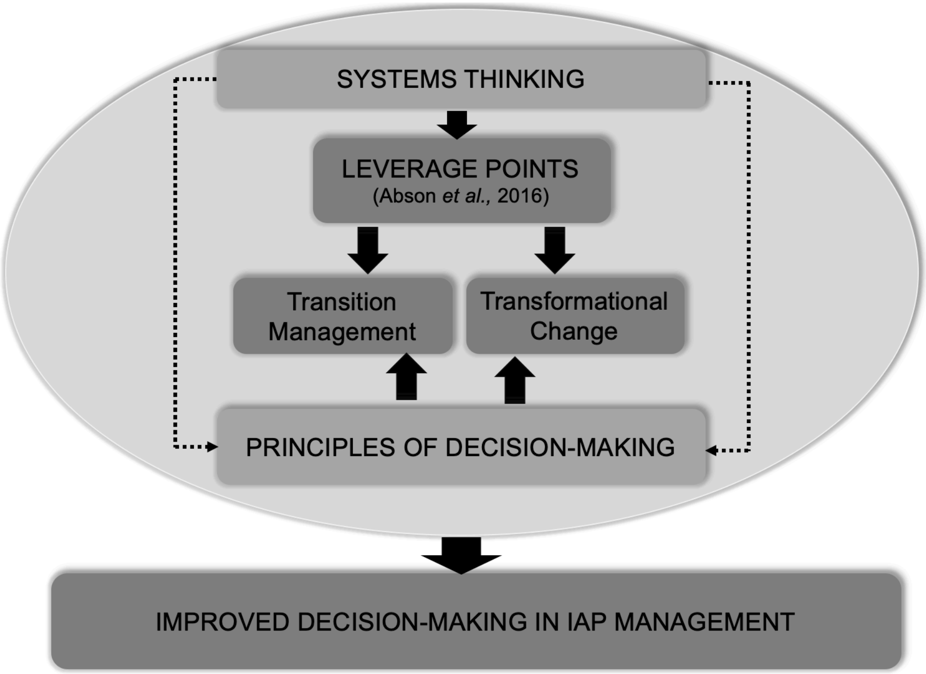


**Figure 2.1** An overview of the conceptual framework underlying this thesis used to provide insights for improving decision-making in IAP management

### 2.2.1 Managing complex adaptive systems

Invasive alien plant management exhibits the characteristics of a complex adaptive system, that includes the following attributes:

i. are open systems that have the ability to interact with their surroundings ; the general public can refuse to participate in, or even counter, management interventions concerning IAS, in some circumstances, where their perspectives are not considered or misunderstood (Woodford et al., 2016);

ii. consist of variables that are inter-linked through their mutual interactions; though in many cases, decision-makers and scientists may hold what they deem to be superior views in relation to IAS nativeness and abundance (Fischer et al., 2014). Rural communities in South Africa, for instance, perceived higher densities of an invasive cactus species as positive (Shackleton et al., 2007);

iii. contain both positive and negative feedback loops which can have an amplifying or damping effect on the response of a system; disregarding species interactions when eradicating an IAS can lead to major unintended changes to other ecosystem elements, and potentially create unwanted impacts (Ballari et al., 2016);

iv. exhibit strongly non-linear behaviour, which nests and encompasses various levels of aggregation; global trade networks and other socio-cultural activities (horticulture or fishery) do not only result in challenges for the management of IAS, but also create the necessity to integrate socio-cultural sciences into research (Tatem, 2009);

v. have a variety of components and interactions between components; managing IAP is particularly challenging, for example, in urban areas because of the diversity in landscapes, mandates, threats, land-use, pressures, and current management frameworks for dealing with IAP (Gaertner et al., 2016; Gaertner et al., 2017); and

vi. have patterns that emerge unexpectedly as a result of interactions between components; interactions between species are essential variables when evaluating the outcomes of control efforts, and understanding species interactions should be a top priority (Courtois et al., 2018).

### 2.2.2 Complexity and invasive alien plant management

Complexity in terms of management of IAP and decision-making means that one does not consider complexity as a barrier but embraces the interactions and interrelationships. By improving our understanding of the drivers, dynamics and patterns in that complexity we can gain insights into potential leverage points for improving IAP management. Although systems thinking embraces complexity, it has largely ignored 'Where in the system should one intervene to change its overall behaviour?' (Abson et al., 2017). In a quest to answer this question, this thesis draws on Meadows (1999) intervention points for leveraging change.

The notions of stocks, flows and feedback loops to construct a detailed analysis of leverage points provides an explanation of why some efforts to intervene in a system are more likely to result in change than others (Easterbrook, 2014). Meadows (1999) identifies twelve leverage points in order to influence the behaviour of a complex system. These leverage points range from 'shallow' places where interventions are comparatively easy to implement to 'deep' leverage points which represent those that are often more difficult to alter although, these result in transformational change (Section 2.7; Abson et al., 2017).

Drawing on the notions put forward by Meadows (1999), this thesis argues that many IAP management decisions applied to date have focused on highly tangible, but relatively weak leverage points. For example, decisions on managing IAP have often been informal, that is, based on experience and ad hoc stakeholder consultations, or short-term emergencies or opportunities (Gaertner et al., 2016). The Four Levels of Thinking as a framework for systemic intervention can be likened to an iceberg to demonstrate the conceptual model Maani & Cavana's (2007). Most decisions and interventions in IAP management are currently taking place on events or symptoms (easily identifiable issues). These only represent the observable part of the iceberg that is above the waterline, which offer 'quick fixes', an easy way out with no long-term provisioning of lasting solutions. This approach to decision-making potentially wastes already limited resources and often fails to address the diverse and spatial variability in IAP management challenges (Potgieter et al., 2018b). Decision-making in IAP management should go beyond, for example, identifying the most heavily infested areas ('tip of the iceberg', Chapter 5) to also include a comprehensive understanding of the complexity of management decisions, conservation benefits and the possibility of management success for a particular level of investment (cost-effectiveness) and social preference (CBD, 2010; Dawson et al., 2015; Seebens et al., 2017).

There is a need to restructure, improve the decision-making process and reconsider priorities by perhaps focusing on less obvious, but potentially influential areas of intervention. Management approaches for IAP are often confounded, and in some cases disrupted, by conflicts of interests that arise from asymmetric valuation of benefits or harm by the same species (Shackleton et al., 2007; Gaertner et al., 2016).

This thesis proposes the development of a CLD that visualises the underpinning systemic structural components of IAP management at the quaternary catchment level. This is potentially a deeper (fourth) level of thinking that, in most cases, hardly ever comes above the waterline and is referred to as “mental models of individuals and organisations that influence why things work the way they do” (Maani & Cavana, 2007: page 13). The large financial costs of IAP management coupled with limited readily available resources (Le Maitre et al., 2000; van Wilgen et al., 2012) further emphasises the need to focus on less obvious interventions. For example, when making decisions to manage IAP in high altitude areas, the main objective should be to monitor the presence of IAP along roadsides and constrain their spread (Pauchard & Alaback, 2006). Easterbrook (2014) argues that changes in the way of thinking about the system often results in the highest leverage, particularly in terms of the goals that are adopted. Furthermore, the most effective type of leverage points are often the hardest to use since they attack the most deep-seated structure of a system (Abson et al., 2017).

Systems thinking paradigm, methodology and the concept of leverage points embrace a different type of thinking that moves stakeholder groups from the event level to profound levels of thinking and moreover, provides a systematic framework to deal with complex problems (Maani & Cavana, 2007; Abson et al., 2017), such as the IAP management and decision-making problem in the GRBR.

## 2.3 Systems thinking

The recognition of complexity and uncertainty in SES (Gunderson & Holling, 2002), has witnessed increasing calls for system-oriented and integrated approaches to navigate complexity in social-ecological systems (Abson et al., 2017). The approach of systems thinking considers any given complex issue, in this case IAP management decision-making process, as a whole, with particular emphasis on inter-relationships between components rather than individual components themselves (Patana et al., 2018). As mentioned in Chapter 1, research findings reveal that IAP management is a highly dynamic and complex issue, which is characterised by a network of interactions between multiple dimensions of social, ecological, economic, cultural and political aspects, and between multiple stakeholder groups. Conventional approaches to understanding IAP management tend to focus on particular parts of the system thus neglecting the interconnection within the system. This in many instances results in failure to provide a comprehensive understanding of the complexity of the system and its fundamental rationale. These conventional or traditional approaches focus on environmental and ecological aspects with little attention on social dimensions (García-Llorente et al., 2008).

Systems thinking is applied in this thesis as one way to gain more insight into the nature and complexity of IAP management and the decision-making process in the GRBR (Chapter 6). Systems thinking not only considers outcomes but also inputs, processes and outputs that lead to the outcomes, which is an important aspect in this thesis. A conceptual systems approach suggests a framework to analyse interrelations between existing actors, structures, perceived problems and possible solutions (Loorbach et al., 2008).

In IAP management, systems approach implies integrated approaches that consider forms of governance, variety of stakeholders at different levels, and offers effective means of facing real world issues. By so doing, systems thinking offers itself to a critical approach since it supports the notion that any system can be viewed as a component in a bigger system (Easterbrook, 2014). For example, the available management activities and practices should not be viewed in isolation, but rather be combined appropriately and strategically implemented collaboratively by affected parties (van Wilgen et al., 2011).

Since complete eradication of all IAS is an unattainable and/or unrealistic goal in any ecosystems, excepts some island examples (Davis et al., 2011), there is a need to unite widely divergent lines of evidence about biological invasions (Moles et al., 2012). Systems thinking does this by offering a way of transcending boundaries of disciplines by highlighting the different dynamic inter-relationships of elements that shape complex issues (Abson et al., 2017; Patana et al., 2018). It has documented to be useful in many discourses that include economics, public administration, development programs and the social sciences (Ostrom, 2007; Lich et al., 2017; Mavhura, 2019). Head and Alford (2008) further provide insights that systems thinking is an analytical discipline that is helpful in dealing with complexity, but it is not an approach which in itself constitutes a method of dealing with ‘wicked problems’. Influential concepts that are closely linked to, or stem from, systems thinking include resilience thinking (Folke, 2006), transition management (Kemp and Loorbach, 2003) and transformational change (Wiek et al., 2012). The last two concepts are of relevance to this thesis and are developed in greater detail.

## 2.4 Decision-making amid uncertainty

Complex systems pose a number of distinctive attributes that include uncertainty, surprise and nonlinearity (Berkes & Jolly, 2002; Walker et al., 2004). Decision-making practices that are based on assumptions of stability and predictability are unhelpful when dealing with complex systems (Cundill & Fabricius, 2009). Traditionally, a technical decision-making process follows a linear path of goal identification, exploration of challenges and opportunities, selection of the most desirable solution and then implementation of the management decision (Lynam et al., 2007; Fabricius & Cundill, 2014).

However, in complex systems, decisions are often made with imperfect knowledge resulting in limited ability to forecast the future in any linear exact way (Walker et al., 2004). For example, the ability to forecast when and where IAP exerts strong ecological impacts remains weak (Hulme et al., 2013). This uncertainty is coupled by the fact that decision-makers themselves become part of the system, making long-term forecasting more problematic than anticipated (Cundill & Fabricius, 2009).

Dealing with uncertainty is a recurrent theme in this thesis and many studies that relate to IAS as uncertainty cuts across the invasion process (Liu et al., 2011b; McGeoch et al., 2016; Essl et al., 2017). Uncertainty is as a result of various reasons, such as the lack of adequate information, conflicting evidence, context dependence or imprecise definitions and framing of the problem (Vanderhoeven et al., 2017), or how SES may change in the future. Uncertainty can be reducible (for example, through gathering more information) or irreducible (for example, probabilistic outcome as a result of natural selection which is beyond human control) (Leung et al., 2012). Even in instances where uncertainty is reducible, the sheer size of the problem (which is the case in GRBR) in terms of extent of invasion, volume of species and pathways translate into an inability to gather sufficient evidence to provide high confidence in the decision-making process (McGeoch et al., 2016). A further challenge to IAP management is that decision-makers are often under considerable pressure to divert resources towards management of widespread species (Woodford et al., 2016). This dilemma is caused by the impacts of widespread species being more apparent and immediate, while those of new or emerging species are less apparent, less certain and usually only emerge years after the initial invasion (Brancatelli & Zalba, 2018). However, even in such cases, management decisions must still happen despite inherent uncertainty and pressures (Sutherland & Burgman, 2015).

This thesis seeks to provide an important step towards improving IAP decision-making process that is applicable despite a lack of data and incomplete knowledge, and can adapt as more data and knowledge are acquired. There is an increasing need to develop effective methods to improve decision-making and the degree to which decisions are deemed prudent by relevant stakeholders with focus on IAP management. This is essential in gaining support and ensuring commitment to action which in turn facilitates learning and reflection (Shackleton et al., 2015). In many situations, stakeholder groups' interests and personal biases such as arrogance, are unavoidable mediators of decisions that affect management outcomes (Essl et al., 2017). Different stakeholder groups perceive IAP impacts differently, that is, the invasion of an IAP can be regarded as harmful invasive (CBD, 2010), beneficial, neutral, or simply irrelevant (Estévez et al., 2015). These variations impact on how IAS are framed and perceived, and ensuing conflicts between stakeholders and uncertainty, generate significant challenges in decision-making (Estévez et al., 2015).

## 2.5 Dealing with uncertainty and 'wicked problems': Robust decision-making principles

Dealing with uncertainty is in not common in many studies relating to IAS athough uncertainty occurs across the invasion process (McGeoch et al., 2011; Essl et al., 2017). Uncertainty arises from, for example: lack of information, conflicting evidence, context dependence or imprecise definitions, and guidance (Van derhoeven et al., 2017). The resulting multitude of conflicting perspectives, values, management goals, and objectives has the potential to make the problem almost impossible to differentiate, let alone solve, to the satisfaction of all the stakeholder groups (Woodford et al., 2016). This thesis highlights that ineffectiveness in IAP decision-making processes, valuation of impacts and priority setting are attributable to strong differences in the framing of the problem. These classes of challenges were first recognised in the field of policy and planning by Rittel and Weber (1973) as 'wicked problems’. Therefore, it is important to recognise such underlying principles and frame IAP management as ‘wicked problems’.

This thesis identified from the literature, seven principles (summarised in Table 2.1) to deal with ‘wicked problems.’ When combined, and if these principles are adopted, they should: i) help guide the management of IAP; ii) improve the current decision-making process; and iii) help land users to view IAP management as a ‘wicked problem’. The principles are the result of distillation of principles and concepts presented in scientific literature (similar to Essl et al., 2017). Together, these principles of decision-making yield a more robust IAP management decision-making process that ensures the integration of knowledge and transference of information and fostering collaboration and coordination amongst diverse multiple stakeholders. A robust decision-making process is thereafter defined as a process that supports decision-making under conditions of high complexity, uncertainty, interdependencies and allows learning from and explanation of the logic behind decisions. This definition is irrespective of decisions not leading necessarily to the intended outcomes.

The first three of these principles (Table 2.1) address values, environmental ethics and trust, but also decision-making biases related to mental action or processes of obtaining knowledge and understanding through experience, thought and senses (Montibeller & Von Winterfeldt, 2015). The principles in this domain relate to the fundamental values in the decision-making process. The remaining four principles relate primarily to the science domain, representing characteristics of change as a result of taking the impacts of IAP into account in the decision-making process.

**Table 2.1** Seven principles of robust decision-making for valuing the IAP decision-making process, corresponding description and key references

| No | Domain | Principle | Description | Key references |
|---|---|---|---|---|
| **1** | **Ethics, values and trust domain** | Participatory | -Involvement of all interested and affected stakeholders in the decision-making process<br>-Beyond the inclusion of usual suspects can result in effective, high quality and more reliable decision-making processes | Bäckstrand (2003); Davies et al. (2015) Millennium Ecosystem Assessment (2005); Reed et al. (2009); Novoa et al. (2018) |
| **2** | | Transparent | -A communication enabler among a diverse stakeholder group<br>-Facilitating information sharing and learning making decisions more socially acceptable<br>-Important for making the decision-making process visible and provides clarity with which the reasoning behind decisions is communicated | Davies et al. (2015); Bäckstrand (2003); Lockwood et al. (2010); Novoa et al. (2018) |
| **3** | | Flexible | -Adapt decision-making process in response to new scientific information<br>-A degree of flexibility allows experimentation of new methods and approaches thereby improving the decision-making process | Roux & Foxcroft (2011) |
| **4** | **Science domain** | Adaptive or iterative | -Involves a cyclical process of goal formulation, hypothesis setting or alternatively modelling, action, monitoring, learning and adaptation<br>- Process allows stakeholders to collect information from attempts at a solution and use it to inform consequent attempts | Roux & Foxcroft (2011); Martin et al. (2011) |
| **5** | | Science-based | -Decisions that are grounded in and consistent with the current scientific discourse | Lubchenco (1998);<br>Clark (2005) |

| | | | | |
|---|---|---|---|---|
| **6** | | Structured and consistent | -Integrating a range of environmental values into IAP management as these different value systems and stakeholder's perception of risk may result in conflict<br>-Provides a multi-criteria decision analyses process that can be applied to IAP management | Hammond et al. (2002); Salwasser (2002); Potgieter et al. (2018b); Liu et al. (2011a) |
| **7** | | Documented | -Important in designing and improving transparency and at the same time reinforcing the benefits that results from a structured process<br>-Allows one to revisit and assess previously made decisions in light of new information | Funtowicz & Ravetz (1992); Ravetz et al. (2018) |

The failure of conventional command and control approaches and nature of complex decisions has steered calls for making the decision-making process participatory by involving all interested and affected stakeholders and being more transparent (Bäckstrand, 2003; Davies et al., 2015). Stakeholder participation in environmental decision-making process is important for several reasons:

i. Broader stakeholder participation can contribute knowledge at a range of scales by allowing inclusion of different perspectives; shared understanding of the problem, and agreement of the proposed strategy, priorities and/or actions; and effectively representing diverse social values of groups not traditionally involved in technocratic decision-making (Bäckstrand, 2003; Gadgil et al., 2003).

ii. Participation by diverse stakeholders can result in effective, high quality and more reliable decision-making (Millenium Ecosystem Assessment, 2005).

iii. Stakeholder engagement can improve the efficiency with which the decision-making process is implemented (Davies et al., 2015), and can also avoid/reduce conflict (Novoa et al., 2018).

The participatory decision-making process should involve engaging stakeholders in a transparent, interactive and iterative manner which facilitates information sharing and learning. According to Davies et al. (2015), transparency is a communication enabler among a diverse stakeholder group. The transparency of a decision-making process and the resulting decisions are intimately tied to the trust that stakeholders invest in the process and its outputs, in turn, making the decisions more socially acceptable (Bäckstrand, 2003). The lack of transparency in the decision-making process can lead to conflict - a situation that can lead stakeholders to mistrust government agencies (Shackleton et al., 2015). Such conflicts typify the extent to which IAP management, especially in human-dominated areas such as the GRBR, is increasingly viewed as a ‘wicked problem’ (Rittel & Webber, 1973) as there are rarely win-win solutions (Potgieter et al., 2018a).

Critics argue that natural resource managers do not utilise enough scientific evidence when making day-to-day decisions (Ntshotsho et al., 2015). Thus, inclusion of science-based decisions is also another principle of a robust decision-making process.

Science-based decisions are those decisions that are grounded in and consistent with the current scientific discourse. Lubchenco (1998) and Clark (2005) propose a new social contract of science with the argument that solutions to complex societal problems can be achieved through ‘more comprehensive information, understanding, and technologies for society’. As more reliable scientific information becomes available, the uncertainty surrounding an issue gets reduced, ultimately reducing the complexity of the problem (Salwasser, 2002). However, findings by Ntshotsho et al. (2015) suggest that most scientific input and/or collaboration tends to be a high-level concern, in the hands of primarily a few people. This entails that science-based decisions do not enter directly through the input of individuals, rather through policies ultimately slowing down the uptake of new scientific knowledge (Ntshotsho et al., 2015).

The need to account for learning, reflection, adaptation and re-design associated with ‘wicked problems’ (Roux & Foxcroft, 2011) has led to calls for an adaptive or iterative element into the decision-making process. This essentially involves a cyclical process of goal formulation, hypothesis setting or alternative modelling, action, monitoring, learning and adaptation (Martin et al., 2011). This process allows stakeholders to collect information from attempts at a solution and use it to inform consequent attempts. These incomplete solutions are not necessarily failures but rather viewed as previous attempts that bring about present learning opportunities (Roux & Foxcroft, 2011). In this case each attempt at a solution brings out context and definition of the problem and a clearer picture of what constitutes better or worse decision. Incorporating an adaptive/iterative approach ultimately allows decision-makers to be flexible in adapting their decision-making process in response to new scientific information (Martin et al., 2011). A degree of flexibility would allow for experimentation of new methods and approaches thereby improving the decision-making process.

The importance of flexibility has long been recognised (Hammond et al., 2002; Salwasser, 2002), however, without undermining the equal importance of structured and consistent decisions. Structured decision-making methods are useful in integrating a range of, for example, environmental values into IAP management as these different value systems and stakeholders’ perception of risk can result in conflict (Potgieter et al., 2018b). Furthermore, structured decision-making provides a multi-criteria decision analysis process that can be applied to IAP management (Liu et al., 2011). Documented decisions, as they are being made, are important in designing and improving transparency and at the same time reinforcing the benefits that results from a structured process. In addition, documentation of decisions allows one to revisit and assess previously made decisions in light of new information (Funtowicz & Ravetz, 1992; Ravetz et al., 2018).The principles of robust decision-making acknowledge that applicable design; suitable planning and implementation of IAP interventions; adequate knowledge, understanding of specific social contexts; and adequate stakeholder involvement contribute to improved decision-making outcomes (Gann et al., 2019). Application of, and a shared understanding of the principles has the potential to improve effectiveness of IAP management and decision-making efforts by establishing criteria for technical implementation across different stakeholder groups.

The principles of robust decision-making also offer a framework that enable stakeholders to engage and respect, for example, socio-economic, cultural and knowledge system differences among stakeholder groups. Principles can improve IAP management and decision-making, whether used to guide stakeholder groups engaged in planning, implementation, and monitoring of IAP management interventions. Alternatively, they can be used to guide stakeholder groups involved in designing, supporting, funding, and evaluating IAP management projects at any scale (Gann et al., 2019). Thus, the use of clear and carefully considered principles in IAP management can reduce the risk of unintended consequences to ecosystems and native biodiversity and help make high-quality decisions amenable to dealing with IAP management as a ‘wicked problem’.

## 2.6 Transitions

The concept of leverage points is also applied in order to identify transitions in the system. According to Rotmans et al. (2000), a transition is defined as a structural change in a societal (sub) system and is the result of a co-evolution of socio-economic, ecological, institutional and technological advances at various scales. A transition is said to have led to a transformation when there is a change in the state variables that define the system (Rotmans et al., 2000). Rotmans and Loorbach (2009) argue that transitions cannot be driven in command-and-control fashion because of complexity and uncertainty, as discussed earlier. However, transitions can be manipulated in terms of the speed and direction of the process which is called transition management and is an important concept in this thesis and is explained in the following section.

### 2.6.1 Transition management

According to Rotmans and Loorbach (2009), transition management is a relatively new management concept which assumes complexity and uncertainty. It is occasionally recognised as co-evolutionary management, which involves adjustment, adaption and influence. As this thesis seeks to develop a CLD to be used as a learning tool in IAP management, it is of particular importance to this thesis that transition management is not directly focused on solutions, rather it is explorative and design oriented. Transition management is important because it views complexity and uncertainty as triggering mechanisms of societal innovation rather than as obstacles that need to be controlled (Rotmans & Loorbach, 2009). For instance, for IAS management to be successful, it needs coordination and collaboration of management efforts between stakeholder groups (Moon & Adams, 2016). One hypothesis for IAP is that no full control and management of the problem is necessary as in the organisation there is a combined searching and learning process focusing on long-term solutions (Rotmans & Loorbach, 2009). However, this is not so in conventional IAP management or with 'tame' problems.

Transition management addresses complex, persistent, and unstructured problems of a specific type that "cannot be solved with simple, short-term solutions" (Loorbach, 2010: page 164). Transition management has been applied and assessed in several transition experiments, including transition projects on regions, industry, and businesses, as well as within societal sectors (for instance, the health and energy sector) (Loorbach & Rotmans, 2010). However, applications of transition management in IAP management are still lacking, due in part to the long-term nature of transition experiments (Wiek & Lang, 2016). Transition management experiments with many relevant aspects of a range of management and policy form and attempt to integrate and combine the associated instruments. Experiments are mainly related to the integration of short and long-term processes, multi-scale levels, different stakeholders, perceptions of the problem by diverse actors, a wide range of possible solutions, a variety of learning processes and different types of instruments (Wiek & Lang, 2016). The integration of aspects of diverging management forms results in a new paradigm that considers complexity and uncertainty in time, space and domain. For example, in Western Australia, scale has been identified an aspect in collaboration of IAS management, including scale at which different stakeholders and planning processes operate, and at which individual activities are undertaken (Fletcher et al., 2010). This supports insights by Loorbach et al. (2008), that transition management is a governance approach based on governance and complex systems theory as much as upon practical experiment and learning.

## 2.7 Transformation change

The quest for transformational change has emerged as a guiding theme for managing problems such as climate change, resource depletion, food security, biodiversity loss, or social inequalities (Leach et al., 2012; O'Brien, 2012). Transformation change theory finds its origin in social sciences and suggests a shift both in the focus of research and in the understanding of the scale of the challenges modern societies are facing (Görg et al., 2017). The concept of transformation in complex systems was applied in order to identify places in the IAP management system which contain leverage points (Figure 2.1). These leverage points would enable stakeholder groups to devise appropriate intervention strategies that can help manage IAP effectively, that is, a directional shift from conventional approaches (Few et al., 2017). Importantly, transformation is about change, but is not synonymous with change (Few et al., 2017), which can occur at different levels of governance. It implies change that is more than routine: a fundamental alteration of state (Few et al., 2017). Fundamental alteration of state in IAP management can be applied at multiple leverage points by a variety of stakeholder groups, such as government, citizen, non-governmental organisations and community groups, and local communities, science and educational organisations, and the private sector, depending on the context (IPBES, 2019). However, managing IAS is quite costly, and decisions need to be made on sound basis to avoid wasting of resources (Koch et al., 2016). Improving existing IAP decision-making process through interventions that are integrative, inclusive, informed, and adaptive, using strategic policy mixes and learning from feedback loops, could aid transformational change.

The IPBES global assessment on biodiversity and ecosystem services echoes that transformative change is critical if nature is to continue to contribute to people's health and wellbeing (Díaz et al., 2019; IPBES, 2019). Transformation has the power to create a fundamentally new system as a result of changes in ecological, economic, or social structures becoming untenable to the existing system (Walker et al., 2004). For instance, the gravity of IAP impacts may result in SES no longer being able to support indigenous vegetation. Thus, understanding the ways in which transformation can be initiated and monitored is very crucial (van der Brugge & van Raak, 2007; Loorbach et al., 2008). On-going processes of collaboration and learning have been emphasised to be critical in initiating transformation (Olsson et al., 2006). Another example is the incorporation and understanding of cultural and social perspectives in IAS research, and considering biological invasions as SES has been noted to be important for their sustainability, that is, both ecologically and socially, through successful management (Kueffer, 2017).

Several scholars have noted that transformation change involves key changes in fundamental processes within a social-ecological system in response to shocks or other stimuli (Olsson et al., 2006; Olsson et al., 2008), in this case IAP. Gunderson and Holling (2002) argue that such surprises and crises seem to create an enabling space for reorganisation, renewal and novelty as well as providing new ways of doing things. Deeper leverage points for transformational change include re-evaluating existing structures, processes, priorities, and institutions (Rickards, 2013) considering the risks and uncertainty posed by IAP. Transformational change offers potential in playing a key role in changing systems to help trigger more fundamental change in response to IAP impacts. O'Brien (2012: page 673) reinforces this argument of the need to re-evaluate the status quo, by arguing that research in geography has focused mostly on adapting to changes that are underway instead of focusing on research that helps to comprehend how to "deliberately transform systems and society in order to avoid the long-term negative consequences of environmental change". For this to happen, practitioners involved in IAP management need to incentivise critical reflection, promote on-going learning and revision of actions. While such shifts may be challenging, they are necessary if IAP management decisions are to be effective to meet the challenges presented by the rapidly changing world.

Inevitably this means that IAP management research requires further attention to mechanisms of social change including shifts in underlying values, assumptions, politics, and power in order to set them on a sustainable trajectory. This requires actors or stakeholder groups to have a common intent or, at least, a collective vision (Abson et al., 2017; Colloff et al., 2017). Several authors reckon that this should ideally be supported by regional and national policies that encourage collaborative management efforts (Kerkhoff et al., 2006; Armitage et al., 2009). In South Africa, for example, failed eradication of IAP has highlighted the need for management agencies and stakeholder groups to set clear and realisable eradication targets, foster a learning culture and create adaptable management systems (van Wilgen et al., 2012). Nonetheless, finding transformational solutions and implementing them in specific context will likely involve re-thinking the ways in which we approach the production, the flow and use of these complex diverse types and sources of knowledge (Abson et al., 2017).

Understanding these factors can help increase the likelihood of achieving management effectiveness and trigger transformational change. A CLD can serve as a valuable platform for engagement, collaboration and communication among interested stakeholder groups, indicating where they can undertake mutual action to pursue their common interest in managing IAP (Graham & Rogers, 2017; Graham, 2019). For instance, such an approach allows scientists involved in IAP research to engage with a wide array of stakeholder groups from different domains of society, not only to improve the collective understanding of coupled systems (in particular, the human component), but also to develop joint and coordinated interventions for how to come up with solutions to sustainability problems (Kerkhoff et al., 2006) – management of IAP.

## 2.8 Conclusion

The world is facing pressing social-ecological challenges, locally and globally, that requires new approaches to improve the effectiveness of how decisions are made. Invasive alien plant management is one of the increasingly important challenge, and is interconnected, seemingly intractable and influenced by an array of cross-scale drivers and complex feedback mechanisms. The question of how to understand the complexity of social-ecological challenges such as IAP management remains inadequately addressed. Here, the research proposed that systems thinking, and principles of robust decision-making have a role to play in addressing these and ultimately improve the IAP decision-making process. However, attempts to address IAP management challenges involves multiple stakeholders with diverse needs and interests and are affected by socio-economic, and political uncertainty. This also creates the need for transdisciplinary research, which is applied in this thesis and contributes to the growing number of research in this direction.

The application of the principles of robust decision-making and systems thinking approach potentially provides an improved understanding of the interrelations in IAP management and decision-making process. Also, this application helps to identify places in the system to leverage change. This approach uses available data, stakeholder knowledge and science-based techniques to improve how decisions are made in IAP management in the GRBR. Given the growing awareness of the prevalence of uncertainty in complex systems calls for more collaborative approaches to IAP management where those who have a stake in IAP management can participate and contribute to decision-making.

## CHAPTER THREE

## Review of decision support tools for managing invasive alien species

This chapter is intended for submission to Biological Invasions as: Masunungure, C; Kraaij, T; Fabricius, C. Review of decision support tools for managing invasive alien species

### Abstract

Invasive alien species (IAS) are a global threat to economies and biodiversity. With rising numbers of species and limited availability of resources, their management must be carefully prioritised; yet agreed methods or tools to assist decision-making and their application are currently inadequate. Decision-making involves selecting appropriate actions and methods from a toolbox of different methods. Thus, there is need for simple decision support tools (DST) that guide stakeholder groups to optimise their investment based on objective and quantifiable criteria. This chapter reviews DSTs for IAS management to assess their availability and application of principles of robust decision-making. The aim is to provide guidance towards adopting the principles of robust decision-making to improve applicability and practical use of DST. A literature search was used to identify relevant studies that report on DST in biological invasion. The analysis indicates an increase in the availability of DST; however, available studies are largely biased in geographical, habitat and taxonomic focus. The results also show challenges in the practical use of existing tools as most of them do not apply the principles of robust decision-making. Application of the principles of robust decision-making has the potential to overcome the weakness of the current decision-making process and as such, enable decision-makers to efficiently allocate resources towards invasive alien species (IAS) management. A call is made for more consideration and adoption of principles of robust decision-making when developing DST for IAS invasions.

**Keywords:** decision-making, management efficiency, practical use, principles of robust decision-making, prioritisation

### 3.1 Introduction

In the last decade, there has been an increasing need to improve decision-making processes and prioritisation of investment in management of biological invasions (Danaet al., 2014; McGeoch et al., 2016). Decision-making involves selecting appropriate actions and methods among alternative toolbox of different methods. The development of decision support tools (DST) can help stakeholder groups in the management of biological invasions and prioritise interventions and provide guidance on how they can make effective decisions (Pimentel, 2011). This is complex and challenging due to a variety of disciplines involved (for example, ecology, politics, sociology, and engineering), diversity within a given landscape (for example, different stakeholder interest which may lead to conflicts of interest) and the need to consider human skills and economic resources available (Dana et al., 2014; Gaertner et al., 2017).

Major challenges include a continuous rise in the number of invasive alien species (IAS) globally and their increasing rate of spread, with only a small proportion currently being managed (Hulme, 2009). Also, the environmental, social and economic impacts of IAS are increasing (Pimentel et al., 2001; Pimentel, 2011; Brunel et al., 2013) and in some countries, such as South Africa there are funding insecurities in public institutions responsible for conservation of nature (Gaertner et al., 2017). It is therefore crucial to interrogate how decisions about prioritising the management of IAS and areas under invasion are being informed to optimise investments (Kumschick et al., 2012). This need resonates with calls to monitor invasive alien species (IAS) that pose significant socio-economic threats as well as threats to ecosystems, habitats and species and to implement information systems that compile data on species that have significant environmental threats, as their management is a crucial topic in conservation (Baker, 2017; IPBES, 2019).

The environmental and socio-economic threats of IAS (Auld & Johnson, 2014; Gaertner et al*.,* 2016) further justify the need for user-inspired DST (Chapter 2), to inform effective and meaningful management efforts to be implemented (Courtois, et al., 2018). Several strategies have been suggested to confront the challenges posed by IAS (Vaz et al., 2017; Courtois et al., 2018). These strategies embrace a wide spectrum of activities, including: the exclusion or prevention; rapid detection and eradication; and containment and reduction of impacts of widespread invading species (Hulme, 2009; Auld & Johnson, 2014; Table 3.1). Currently, broadly adopted and standard approaches to the prioritisation of IAS for managing biological invasions are lacking, although there are several schemes and models in use (Brunel et al., 2010; Essl et al., 2011; Kumschick et al., 2012).

The prioritisation of IAS management is challenging and quintessentially a 'wicked problem' because of the complex issues, for example, a lack of cooperation among key stakeholders (Seidl et al., 2013), that must be considered in decision-making and the diverse stakeholder groups involved in the process (Shackleton et al., 2019a). IAS may also have positive effects, as the majority were introduced deliberately such as within the agricultural, forestry, restoration or horticultural species (Pyšek et al., 2010; Kumschick et al., 2012; Shackleton et al., 2019b) with their respective social, environmental and economic benefits (Kumschick et al., 2012; Novoa et al., 2018). Targeting such species, regarded as either detrimental in some aspects (for example, biodiversity) or beneficial (for example, forestry) can result in a conflict of interest among stakeholder groups (Kumschick et al., 2012; Novoa et al., 2018). The introduction to South Africa of Australian Acacias to provide timber and tannins without anticipating their long-term impacts on water (Ngorima & Shackleton, 2019), provides a classic example.

Stakeholder groups, including policy makers, non-governmental organisations, conservationists and land managers are often faced with uncomfortable decision-making dilemmas, such as: which management strategies should be used; and how best to allocate limited resources; and where they should be spent , when managing multiple species, pathways and sites (McGeoch et al., 2016). Therefore, management actions need to be prioritised (Stone & Andreu, 2017). Progress indicators, schemes and models are useful in dealing with prioritisation to improve management effectiveness (McGeoch et al., 2016). Prioritisation is a complex process because natural resource management decisions involve complex ecological dimensions intertwined with social, political, and economic considerations (Bunnefeld et al., 2017) and therefore require a transdisciplinary approach (Dana et al., 2014). Despite acknowledging the complexity and transdisciplinary nature (Chapter 2) of IAS management, decisions still need to be made with no one-size-fits all approach. For this reason, the easy-to-use DST can guide managers to apportion conservation budgets and optimise their investments in an objective and measurable way (Forsyth et al., 2012; Kumschick et al., 2012; Dana et al., 2014). DST has the ability to assess decision-making alternatives, facilitate knowledge exchange and improve communication between stakeholders (Carmona et al., 2013). This is important in situations where stakes are high, values are contested, and knowledge is asymmetric and uncertain (Carmona et al., 2013).

Despite advancements in understanding or improving management strategies, management efficiency and DST for biological invasions, a synthesis of available published literature on the issue is currently lacking (Forsyth et al., 2012). To this end, there is need to gain a better understanding of the application of DST in IAS management and prioritisation. The emphasis of this thesis is to analyse the availability of practical, user-friendly DST to prioritise IAS management. In particular, the aim of this thesis is to identify research patterns regarding publication trends, methodological approaches and to test the application of principles of decision-making in DST for managing IAS.

Principles of decision-making (summarised in Table 2.1, Chapter 2) have considerable strength when dealing with complex 'wicked problems' (Pressey et al., 2007), and are used as a benchmark to assess application of the available DST. The rationale behind this approach is that when applied together in designing a DST, the principles can result in a more robust decision-making process, which is defined as a process supporting decision-making under conditions of inherent complexity, uncertainty and risks. For instance, there is an increasing demand for tools that guide stakeholder groups to make the decision-making process *transparent*, answering questions about where, when and how one can efficiently realise conservation goals (Pressey et al., 2007).

A transparent, well-*documented* DST can also be an efficient tool for communicating decisions, and can help make management of IAS more analytical and easy to follow (Forsyth et al., 2012, Randall et al., 2019). DST affords one the opportunity to explain decisions more easily and provides for consideration of concerns about several conflicting criteria for a decision-making process (Gamper & Turcanu, 2007; Forsyth et al., 2012). An appropriately designed DST can be used as part of a *collaborative* decision-making process that facilitates involvement of a broader stakeholder base.

For example, local communities have been noted to actively participate in biological invasion management when management interventions are targeted at the species prioritised by them (Boudjelas, 2009). A collaborative decision-making process therefore ensures that stakeholders assume ownership of the plan and feel a sense of responsibility (Shrestha et al., 2019).

This review analyses the availability of DST in IAS management and the application of practical and readily usable DST for IAS management. We acknowledge that there are several toolboxes with different and divergent tools for IAS management actions at different levels of infestation and stages of IAS invasions. The chapter investigates potential biases of the existing studies with regards to geographic, taxonomic and habitat focus. Also, the review highlights strengths and weaknesses of these tools by investigating how often published articles have considered the principles of robust decision-making, as explained below and also in Chapter 2. Understanding these gaps, especially by testing the application of the principles of robust decision-making, provides an important step towards improving the practical use of DST, and thus may contribute to efficient allocation of resources towards IAS management.

## 3.2 Methods

### 3.2.1 Literature search

A literature search was performed in the online database Web of Science in March 2019 to obtain a sample of relevant articles on DST for the management of biological invasions. This database was used because of its ability to access articles from over 10 000 journals world-wide (Reuters, 2013). A keyword-based search was conducted and included only peer-reviewed English journal articles to ensure comparability (Kapitza et al., 2019), while acknowledging that non-English keywords would have yielded a wider range of articles. In addition, the aim of the literature search was to include research on the application of DST in IAS management and therefore only peer-reviewed research articles are included. Being mindful of the use of different terms to describe invasive species in different scientific disciplines, invasive alien species is used in this literature search. For keywords relating to efficiency or effectiveness of IAS management, the following were used: management efficiency and decision making. Thus, the four different search key words were:

i. management efficiency* AND invasive* AND species* (n= 310);

ii. decision making* AND invasive* AND alien* AND species* (n= 407);

iii. combine search 1 and 2 (n= 63); and

iv. biological invasion* (n= 24 014) – general biological invasion research.

The of terms such as "non-native” was excluded because it would have yielded a large volume of irrelevant horticultural and crop production literature. An additional keyword search number four was carried out to establish the total number of articles on biological invasions. The literature search was not limited to a fixed period. This follows approaches used by other authors reviewing the topic of invasion biology, conservation management and forms of engagement (Estévez et al., 2013; Lowry et al., 2013; Vaz et al., 2017). A total of 31 original relevant research articles were identified following a strict screening process which involved two stages. The first stage was for records that were not peer-reviewed and which were excluded (n=11). The second stage included 21 articles that did not focus on the subject matter of the application of DST in IAS management and thus were removed by screening the abstracts. Other articles that were relevant although not returned in the literature search (for example, Liu et al., 2010; Forsyth et al., 2011; Liu et al., 2011a; Convertino et al., 2013; McGeoch et al., 2016) were not considered for analysis as the aim is for a repeatable approach (Dana et al., 2014). The compilation of an exhaustive list of all possible relevant publications is not the goal of this thesis but rather to examine a relevant sample of the scientific research domain (Dana et al., 2014).

For each article in the sample, the scope and context is noted, including the year of publication; geographical focus (using the following scales: local in South Africa, regional in Africa but excluding South Africa, and global for all non-African articles); focal habitats (terrestrial, freshwater, marine); and taxonomic groups (plants, vertebrates, invertebrates, microorganisms). Such information is not available for all the articles in the sample. The 31 articles were furthermore categorised in terms of whether one or more of the seven decision support tools were applied to the management of IAS (Clout & Williams, 2009), such as:

i. cost-benefit analysis decision support tools;

ii. multi-criteria analysis (MCA) decision support tools;

iii. quarantine or border inspection decision support tools;

iv. risk analysis (assessment of the risk of invasion, potential impact of invasion) decision support tools;

v. eradication, containment or control decision support tools (decision support tools to manage invasive alien species already present);

vi. internet-based applications and other integrated software decision-support tools for managing IAS;

vii. mathematical and numerical modelling decision support tools; and

viii. decision support tools not falling within any of the seven categories.

Also, a quantitative data analysis of multiple variables around five criteria (Table 3.1) was conducted. This was carried out to determine the application of the DST across the spectrum of activities in the management of IAP (Auld & Johnson, 2014) in the sample of articles.

**Table 3.1** The spectrum of activities involved in IAP management (adapted from Auld & Johnson, 2014)

| Criteria | Explanation |
|---|---|
| Quarantine | To exclude species entirely from entering a country or region |
| Eradication | Complete removal of species |
| Containment | A strategy adopted were eradication is not feasible or has been unsuccessfully attempted |
| Impact reduction | Once containment is no longer economically feasible, efforts may still be made to reduce impact |
| Asset protection | Once a species is widespread it may no longer be economically rational to focus on but rather to focus on the areas from its invasion |

A deductive approach was followed to categorise the 31 articles based on whether one or more of the following seven principles of robust decision-making (Chapter 2) were applied. These are whether:

i. there is *participation* of all interested and affected groups;
ii. there is inclusion of multiple perspectives: knowledges, agendas, needs and concerns that make the decision process *transparent*;
iii. there is a degree of *flexibility* in the decision-making process when there is inconsistent available information;
iv. there is a learning element in the decision-making process – *adaptive/iterative*;
v. whether decisions are grounded in and consistent with existing *scientific* knowledge;
vi. decisions are made in a *structured and consistent* manner; and
vii. there are provisions to return to the decisions and assessing it in light of new information obtained through *documented* decisions.

## 3.3 Results

### 3.3.1 Context and scope of reviewed literature

The 31 articles considered were published between 1998 and 2019. A notable increase in the number of publications reporting management efficiency and DST has occurred over the last decade, particularly since 2015 (Figure 3.1a).

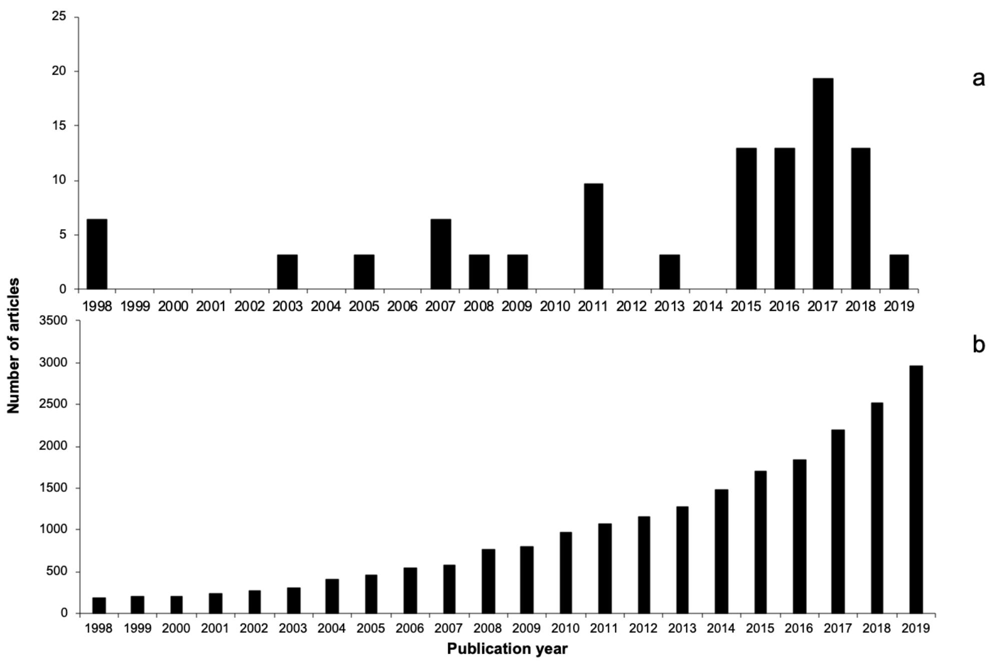


**Figure 3.1** (a) Number of articles included in this literature review per year; and (b) the total number of articles on biological invasions in general since 1998

The majority of the articles (over 60%) included in this review were published in the last five years, which follows the general trend of a steady increase in published articles on biological invasions in general (Figure 3.1b). However, this increase is insignificant when compared to the total number of articles published on biological invasions in the same period (Figure 3.1b).

There is a disproportionate representation in geographical, habitat and taxonomic focus in the 31 articles sampled (Figure 3.2). The research in the sampled articles is dominated by studies conducted in non-African (87%) countries, with only a few studies conducted locally (10%) (Figure 3.2a). The habitat focus of the articles is predominantly terrestrial (68%), with none being in the marine habitats (Figure 3.2b). Approximately 10% of articles cannot be assigned a habitat focus (for example, Cacho & Hester, 2011; Batabyal & Nijkamp, 2016; Lombaert et al., 2018). Also, 65% of the articles include in this thesis focus on plants, followed by vertebrates (26%) and invertebrates 16% (Figure 3.2c). Thus, a typical study on DST for IAS focuses on a particular terrestrial plant species that is invading or has already invaded, local (South Africa) or global (Australia).

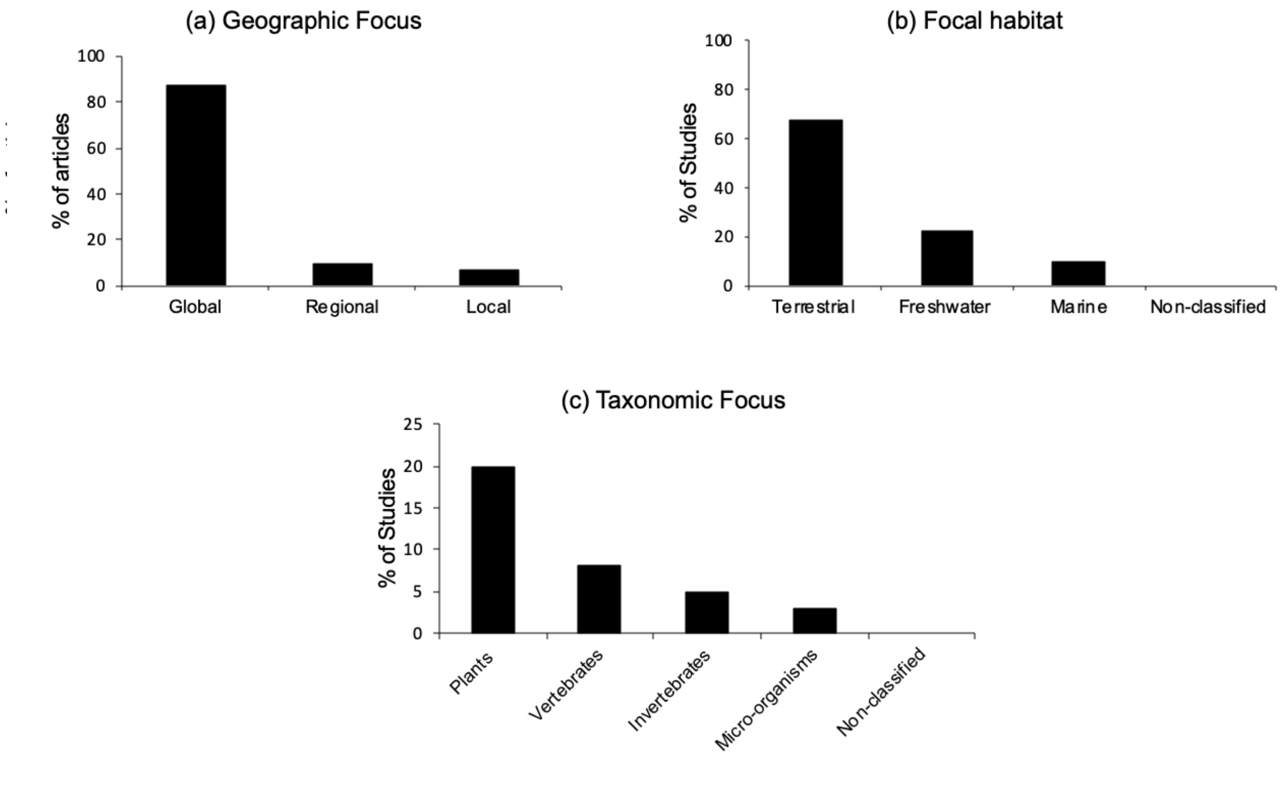


**Figure 3.2** Study articles distinguished by (a) Geographical focus, (b) Focal habitats and (c) Taxonomic focus in the review

### 3.3.2 Use of decision-support tools

The DST used in the sample articles is dominated by eradication, containment/control tools (55%) and modelling tools (48%) whereas multi-criteria analysis tools (3%) are used less frequently. Despite calls for the need for effective tools to optimise the management of IAS, the results show that few cost-benefit analysis or MCA tools are applied and there were no internet-based support tools. Three articles that applied cost-benefit analysis and one MCA tools in the analysis of the sample articles were identified (for example, Robertson et al., 2003; Chornesky et al., 2005; Visconti & Pressey, 2011; Baker, 2017). However, the majority of articles used multiple types of DST and tools were often integrated or applied in combination with each other.

Because MCA and cost benefit analysis consider costs and benefits of management actions, they are often applied in conjunction with eradication, containment, or control tools. Studies may include risk analysis tools to assess the benefits of management actions. Of the eight studies that used risk analysis frameworks, five also applied eradication, containment, or control tools. The other two either applied modelling and/or quarantine/border control tools. Furthermore, the articles analysed in this thesis refer differently to the spectrum of activities involved in IAP management. The majority of studies have the DST applied to impact reduction (55%), followed by quarantine activities (39%), eradication (3%) and asset protection (3%) (Table 3.2).

**Table 3.2** Number of articles and percentage per spectrum of management activities included in this review and examples of application

| Management spectrum | Reference | Example of application |
| --- | --- | --- |
| Impact reduction (n=17; 55%) | Lohr et al. 2017 | A new software, the 'Island DSS' was developed to prioritise a mix of management actions that are targeted at mitigating biodiversity loss. The model incorporates species population growth, interaction, and management efficacy. |
| | van Wilgen et al. 2007; Nel & Rouget, 2007 | A geographic information system map was used to map the distribution of priority catchments to reduce impacts of IAP in South African rivers. |
| Quarantine (n=12; 39%) | Cacho & Hester, 2011 | A spatio-temporal model is applied to allocate surveillance and resources towards isolating a newly discovered invasion. |
| Eradication (n=1; 3%) | Renteria, 2017 | A ranking tool was designed to provide a rapid method to prioritise the management towards the eradication of new potentially invasive species in South Africa. |
| Asset protection (n=1; 3%) | Gosper et al. 2015 | An asset-led approach using comprehensive flora survey data identifies the main predictors of contemporary alien presence, with the aim of minimising alien occurrence across the asset of a relatively little-disturbed landscape. |
| Containment (n=0; None) | - | - |

### 3.3.3 Application of the principles of robust decision-making

Application of the principles of robust decision-making showed clear differences among the articles considered in this review (Table 3.3 and Table 3.4). Science-based (48)[3], structured and consistent (45) are the principles frequently considered or incorporated in the sample of articles. For example, Shrestha et al. (2019) report on the importance of science-based approaches in designing schemes for the prioritisation of alien plants. The sampled articles on DST for managing IAS show clear trends, mainly referring to the comprehensive application of the principles of robust decision-making. Application of a minimum of two principles is quite common among the articles reviewed. A minority of the articles (3) (Robertson, 2003; Cowie et al., 2009; Stone & Andreu, 2017) include all the seven principles of robust decision-making in the design/application of their respective DST. These DST sought to address various management challenges, including a prioritisation process on 212 IAP

[3] Frequencies exceed the number of articles sampled due to single papers including multiple categories.

which thrives in the Tuscan Archipelago, in Central Italy; reducing the impacts of invasive species on sustainable forestry; predicting high-risk species from donor region; and prioritising IAP for management interventions.

**Table 3.3** Summary of articles on the interaction between the application of robust decision-making principles and decision support tools

| **Decision support tools (number of studies)** | **Principles of robust decision making (no.)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Participatory** | **Transparent** | **Science-based** | **Adaptive or Iterative** | **Flexible** | **Structured and consistent** | **Documenting** |
| 1. Cost benefit analysis (3) | - | - | 3 | - | 1 | 3 | - |
| 2. Multi-criteria analysis (1) | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3. Quarantine or border inspection (5) | 1 | 1 | 4 | | 1 | 4 | 1 |
| 4. Risk analysis (9) | 3 | 2 | 9 | 2 | 4 | 8 | 5 |
| 5. Eradication, containment or control (17) | 3 | 3 | 14 | 3 | 5 | 13 | 9 |
| 6. Modelling (15) | 3 | 3 | 15 | 3 | 9 | 10 | 4 |
| 7. Internet-based (0) | - | - | - | - | - | - | - |
| 8. Other (6) | 2 | 3 | 6 | - | - | 6 | 1 |
| **Total number** | **13** | **13** | **48** | **9** | **21** | **45** | **21** |

Notably, the articles considered in this review that are able to apply the full set of robust decision-making principles were in the following DST categories: eradication, containment or control decision tools (3); modelling decision tools (3); risk analysis decision tools (2); and MCA decision tools (1), although application is noted to be in varied levels of detail. For example, Stone and Andreu (2017) briefly report on how an easy-to-use and customised tool was designed with land managers, applying all the principles of robust decision-making. Others chose to apply few principles of robust decision-making. For example, Baker (2017), by incorporating two principles, describes a deterministic spatiotemporal model of IAS dynamics that identifies the best possible management strategy across a variety of situations.

## 3.4 Discussion

### 3.4.1 Trends and procedures currently used in decision-making

Despite the increasing need for effective and efficient tools to optimise allocation of limited resources towards the management of IAS (Bunnefeld et al., 2017). This thesis shows that research on DST in the field of IAS management is still in its early stages. For instance, whereas Lowry et al. (2013) identified approximately 300 articles per year between 2009 and 2010 that investigated biological invasions, this review of the application of DST in the context of IAS management identified only two articles in 2009 and none in 2010. However, as shown by publication trends, results indicate a steady increase in the number of articles reporting DST in IAS management, with the majority recorded in the last five years (2014-2019). Thus, researchers have responded to calls by the Aichi Target 9 (UNEP, 2009) by designing and implementing experiments, collecting and analysing data, and developing and parameterising models to better understand and predict the nature of environmental and ecological systems (Ascough et al., 2008).

The findings show that focal habitats, geographies, taxonomic groups and scales were disproportionately represented in the sampled articles. The disproportionate representation found are not peculiar as they largely reveal general imbalances in research on invasive species (Pyšek et al., 2008; Latombe et al., 2017; Watson et al., 2017). The results of this chapter show that relatively few studies focused on the local scale with the majority in Europe and Australia. Pyšek et al. (2008) also show that more than half of the studies on IAS have been conducted in North America. This under-representation of the local scale studies is not only problematic for the local scale, but also for the global scale, because IAS established at the local scale are likely to spread to regional and global scales. Taxonomic imbalances for example, can be partly explained by the lack of comprehensive ecosystem and biological data for many species, which in turn lessens the opportunity for the use of published studies to inform management (Cacho & Hester, 2011). To address this gap, future research should re-align scientific research to those regions with insufficient research attention (Watson et al., 2017) in order to generate unbiased policy relevant outcomes (Donaldson et al., 2017). Research should also include other under-represented taxa, and develop a multitaxa approach to broaden focus beyond emblematic or threatened taxa (Harihar et al., 2011).

### 3.4.2 Current use of IAS decision-making tools

While well-developed DST are still lacking (Dana et al., 2014), we found that researchers or practitioners have increasingly applied and/ developed decision tools for managing IAS as shown by the publication trends, especially in the last five years. Our results are consistent with those of Estévez et al. (2013) who report an increase in decision-making research in their analysis of the capacity of Multi-Criteria Decision Analysis (MCDA) methods in capturing the social impacts in environmental decision applications. However, this analysis reveal that certain DST are more commonly used, for example, eradication, containment or control and largely pay little or no attention to others in addressing IAS management challenges, for example, internet-based.

In the results, it is shown that the following are the main decision tools in the majority of the studies on DST for managing IAS: eradication, containment and control decision tools; modelling decision tools; and risk analysis decision tools. These findings align with Essl et al. (2011) and Vanderhoeven et al. (2017) who show that risk assessment or analysis decision tools receive considerable attention compared to their counterparts. The methodological approach in risk analysis is shown to be useful in applying expert-opinion and in using modelling for guiding management (Roura-Pascual et al., 2009; Dorrough et al., 2018). In addition, risk analysis tools take advantage of the capacity of consensus assessments to consolidate and to reach an agreement between stakeholders involved in the decision-making (Turb et al., 2017). The findings of this study also show that several approaches have recently emerged to help address the challenges faced in IAS management, ultimately improving the representation of less common decision tools in this field. For example, in the sample, economic cost-benefit and cost-effectiveness are used to assess the case for undertaking management of biological invasions (Chornesky et al., 2005; Visconti & Pressey, 2011; Baker, 2017).

Contrary to Dana et al. (2014), results from the analysed articles largely under-represent cost benefit tools and MCA tools for managing IAS. This lack of wider representation of certain DST is partly explained by a possibility of calibration needs, ease of use of the tool, and how the decision tool is easily adapted (Dorrough et al., 2018). Despite the under-representation in this review of MCA tools, these tools can overcome the limitations associated with other tools, for example, such as cost benefit tools and supporting the IAS policy and management (Born et al., 2005). MCA decision-making tools provide a method for identifying optimal solutions to complex problems where assessment criteria are expressed mostly in conflicting perspectives, including when only incomplete or inaccurate information is available, or where stakeholder evaluation is required (Kahraman, 2008; Forsyth et al., 2012). By clearly structuring complex problems and explicitly evaluating multiple criteria, these techniques have the advantage of allowing the comparison of alternate options and can lead to more informed decisions (Liu et al., 2010; Liu et al., 2011b). The ability of a multi-criteria evaluation to combine scientific knowledge, stakeholder knowledge and economic evaluation offers new avenues of devising up with policy-relevant interventions rather than intensifying a purely monetary evaluation which is a mono-dimensional approach (Born et al., 2005). This lack of comprehensive application of decision-making approaches is mirrored by a lack in simultaneous consideration of the principles of robust decision-making in the sample articles.

### 3.4.3 Application of principles of robust decision-making: opportunities

The findings of this study reveal that the majority of articles in the sample do not generally apply principles of robust decision-making. The limited practical use of existing decision tools (Dana et al., 2014) is accounted for by the observed limited application of the principles. Apart from biological, economic, social and ecological complexities (Novoa et al., 2018; Shackleton et al., 2019a), the management of IAS benefits if the principles of robust decision-making are considered concurrently in DST. For example, using the Spatial Invasive Infestation and Priority Analysis (SIIPIA) model, Stone and Andreu (2017) demonstrate the application of the model at different scales and with different land management objectives for effective and efficient prioritisation of IAS treatments. Their study demonstrates that applying all the principles of robust decision-making improves the practical application of the decision tool by, for example, creating an easy to use (*flexible*) and easy to customise (*adaptable*) tool for managers. To address this gap, future research and design of decision tools should include the principles of robust decision-making as this may be key for an integrated and robust decision-making process.

The current lack of comprehensive DST that applies the principles of decision-making, as shown in the results, may be attributed to a lack of effective communication between managers, politicians, the general public as well as scientists (Andreu & Vila, 2010). This in turn, is partly caused by challenges in finding a common ground (Dana et al., 2014). To resolve the challenges and address imbalances, Stone and Andreu (2017) recommend a *transparent,* objective and *consistent* application of criteria for a prioritisation framework. In addition, precise *documentation* assists in revisiting the use of models in the future, allowing a review of decisions and aiding in planning (Stone & Andreu, 2017). The results of this study demonstrate that incorporating principles of robust decision-making at the centre of design and implementation of DST, provide a workable approach to efficiently allocate resources towards IAS management. This concurs with Carrasco et al. (2010: page 1304) that 'it is necessary to develop more comprehensive models' in the management of invasive alien species'. By design, the aim of this approach is optimising invested resources while accounting for diverse stakeholder knowledge, scientific knowledge, relative costs and benefits, and explicitly considering management objectives and constraints (Dana et al., 2014).

However, without the assistance of analytical tools that incorporate or consider the principles of robust decision-making, management decisions continue to rely heavily on subjective information and are based on inadequate information (Liu et al., 2010). For example, Kumschick et al. (2012) advocated for combining stakeholder views and scientific information in a prioritisation system in order to ensure that the outcome of management has little bias.

A review of how IAP management decision tools have developed in time and how they incorporate the principles of robust decision-making is a first step in providing insights into improving the effectiveness of IAP management, however, this has some shortcomings that could be potentially addressed in future studies. For instance, the review only examines a limited number of articles following the search criteria included in the systematic review methodology. Other alternative review methodologies might better explain the observed trends in the application of decision tools in IAP management (Huang et al., 2011). Unlike Huang et al. (2011), who conducted a comprehensive review of multi-criteria decision analysis in the environmental field, this thesis did not aim to compile an exhaustive list of all possible relevant publications.

### 3.5 Conclusion

While there is recognition in peer-reviewed scientific literature on the need to improve management of IAS, as shown by increases in numbers of publications on the topic, more effort is necessary to develop integrated decision tools that incorporate the principles of robust decision-making. Despite the substantial advancements that have been attained, enormous challenges lie in the practical use of existing tools, even when they are available. This is because they often do not apply the principles of robust decision-making, which, in my opinion, potentially help to overcome the weakness of the current decision-making process and as such, enable decision-makers to efficiently allocate resources towards IAS management. More consideration and adoption of principles of robust decision-making when developing DST for IAS invasions is required. Such an approach provides a promising way to facilitate the practical application of decision tools and possible starting point for improving decision-making in IAS management.

**Table 3.4** Reference list of the sampled articles (the references are not exhaustive as this was not the goal of the literature search)

| Reference | Descriptive information | | | | Decision support tools | Principles of robust decision-making | Purpose of system |
|---|---|---|---|---|---|---|---|
| | Publication year | Geograp-hical focus | Focal habitat(s) | Taxonomic group(s) | | | |
| Shrestha et al., 2019 | 2019 | Global-Nepal | Terrestrial | Plants | Other: stakeholder consultations | Participatory, transparent, science-based, flexible | Prioritisation of invasive alien plants |
| Baker et al., 2018 | 2018 | Global-Europe | Terrestrial, Freshwater | Plants, Vertebrate | Mathematical modelling and optimisation; Eradication | Flexible, adaptive/iterative, science-based, structured and consistent documenting | Effort allocation |
| Dorrough et al., 2018 | 2018 | Global-Australia | Terrestrial | Plants | Statistical modelling; Risk assessments | Iterative, participatory (expert-opinion), science-based, transparent, flexible | Prioritise invasive alien plants |
| Lombaert et al., 2018 | 2018 | Global | - | - | Modelling- simulation; Quarantine/border control | Science-based, structured | Reconstruction of introduction routes |
| Geerts et al., 2018 | 2018 | Global-Europe | Freshwater | Vertebrates (Fish) | Other: DNA extraction methods | Science-based, structured | Protocols for detection |
| Renteria, 2017 | 2017 | Local | Terrestrial | Plants | Modelling: Species distribution; Risk analysis | Science-based, flexible, Structured and consistent | Prioritisation |
| Stone & Andreu, 2017 | 2017 | Global | Terrestrial | Plants | Modelling: GIS model; Control | Science-based, flexible, adaptive/iterative, structured and consistent, documenting, participatory, transparent | Prioritisation |
| Lohr et al., 2017 | 2017 | Global | Terrestrial | Plants | Dynamic modelling (Software- Islands DST); Control | Science-based, structured | Prioritisation of management actions |
| Turb et al., 2017 | 2017 | Global-Europe | Terrestrial | Vertebrates | Risk analysis; control | Science-based, structured, documenting | Impact assessments for invasive alien species |
| Marchante & Marchante, 2017 | 2017 | Global-Europe | Terrestrial | Plants, Vertebrates | Risk analysis | Participatory, adaptive, flexible, structured, science-based | Risk assessment protocol |

| Reference | Descriptive information | | | | Decision support tools | Principles of robust decision-making | Purpose of system |
|---|---|---|---|---|---|---|---|
| | Publication year | Geograp-hical focus | Focal habitat(s) | Taxonomic group(s) | | | |
| Baker, 2017 | 2017 | Global-Australia | Terrestrial | Plants | Modelling; control; cost-benefit analysis | Structured, science-based | Identifying optimal management - strategies or cost-effective allocation of resources for management |
| Batabyal & Nijkamp, 2016 | 2016 | Global | - | - | Modelling; border control | Structured, science-based | Compliance protocol |
| Lazzaro et al., 2016 | 2016 | Global | Terrestrial | Plants | Risk assessments | Structured, science-based | Priority invasive alien plants |
| Guyen et al., 2016 | 2016 | Global | Freshwater | Vertebrates | Modelling: The butterfly model; control | Participatory (scientists and decision makers), science-based, transparent, structured | Integrating priorities |
| Copp et al., 2016 | 2016 | Global | Freshwater | Vertebrates | Risk assessment; control | Structured, science-based, documenting | Assessment protocols |
| Yemshanov et al., 2015 | 2015 | Global | Terrestrial | Invertebrate | Modelling: maximum expected coverage problem (MECP); control | Science-based, structured | Allocating scarce survey resources |
| Gosper et al., 2015 | 2015 | Global | Terrestrial | Plants | Other: species and asset-led approach | Science-based, structured | Priorities in alien plant management |
| Vanderhoeven et al., 2015 | 2015 | Global-Belgium | Terrestrial | Vertebrates | Other: Harmonia system (Python programming language) | Participatory (scientists, decision and policy makers), science-based, structured, transparent | Tackling the management of alien species |
| Murguía & Pacheco, 2015 | 2015 | Global-Mexico | Terrestrial | Plants | Modelling: probability of invasion; control | Science-based, structured, documenting | Identifying areas of high invasion risk |
| Gallado & Aldridge, 2013 | 2013 | Global | Freshwater | Invertebrates and vertebrates | Risk assessment; control | Science-based, structured, documenting | Priority setting |
| Visconti & Pressey, 2011 | 2011 | Global | Freshwater | Plants | Cost benefit analysis; modelling; control | Science-based, structured, flexible | Prioritising multiple management actions |

| Reference | Descriptive information | | | | Decision support tools | Principles of robust decision-making | Purpose of system |
|---|---|---|---|---|---|---|---|
| | Publication year | Geograp-hical focus | Focal habitat(s) | Taxonomic group(s) | | | |
| Schaefer et al., 2011 | 2011 | Global | Terrestrial | Plants | Other: DNA analysis | Science-based, structured and consistent | Priority species |
| Cacho & Hester, 2011 | 2011 | Global | - | - | Modelling: Spatiotemporal; control | Science-based, structured and consistent | Effort allocation |
| Cowie et al., 2009 | 2009 | Global-USA | Terrestrial | Invertebrates | Quarantine; risk assessment | Science-based, participatory, flexible, structured and consistent, transparency documenting | Priority quarantine |
| Moffitt et al., 2008 | 2008 | Global | Terrestrial | Plants | Modelling; Quarantine/ Border inspection | Science-based, structured and consistent | Inspection protocols |
| Mgidi et al., 2007 | 2007 | Regional - Southern Africa | Terrestrial | Plants | Modelling: climate modelling; control | Science-based, structured, documenting | Prioritising emerging invaders |
| van Wilgen et al., 2007 | 2007 | Local | Terrestrial | Plants | Other: GIS integrated system | Science-based, documenting, structured and consistent, transparent | Prioritisation of control operations |
| Chornesky et al., 2005 | 2005 | Global-USA | Terrestrial | Plants | Cost benefit analysis | Science-based, Structured and consistent | Priorities for reducing threat |
| Robertson et al., 2003 | 2003 | Local | Terrestrial | Plants | MCA; control | Science-based, documenting, participatory (expert opinion), structured and consistent flexible adaptive/iterative transparent | Prioritising management |
| Ricciardi & Rasmussen, 1998 | 1998 | Global-North America | Freshwater | Invertebrates | Risk assessments; control | Science-based, structured and consistent, documenting | Predicting identity and impact |
| Fensham & Cowie, 1998 | 1998 | Global-Australia | Terrestrial | Plants | Quarantine | Science-based | Priorities for control |

# CHAPTER FOUR

## Stakeholder perspectives on the current decision-making process of invasive alien plant management

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### Abstract

Effective management responses to different risks posed by invasive alien plants (IAP) rely on the ability to assess the appropriateness of the decision-making process involved. IAP management is highly dynamic and complex – involving diverse stakeholders, and it remains unclear whether the current decision-making processes are appropriate for managing IAP. Although, there have been some notable successes both locally and elsewhere in the world. Here, 30 key informant interviews were conducted with private landowners (7), natural resource managers from government parastatals (7), private sector (5), non-governmental organisations (NGO) practitioners (6) and researchers (5) involved in IAP management, to better understand the perspectives on the current decision-making process. In addition, the compliance of the current IAP decision-making process to the principles of robust decision-making was assessed. The study was carried out in the Garden Route Biosphere Reserve. The findings demonstrate how infrequent the principles of robust decision-making are incorporated in the current IAP decision-making process. Incorporating the principles of robust decision-making offers an avenue for improving the decision-making process for invasive alien plant management.

**Key words:** decision-making principles, decision support tool, invasive alien plant management, stakeholder groups

## 4.1 Introduction

Globally, invasive alien plants (IAP) are among the major threats to biodiversity conservation, sustainable delivery of ecosystem services and consequently human well-being (Mooney, 2005; Maljean-Dubois, 2014; Clusella-Trullas & Garcia, 2017; Díaz et al., 2019). Reported threats include substantial changes in: native species diversity; extinction probabilities and abundance; ecosystem productivity; trophic networks; soil nutrient levels and nutrient cycling; water quality and quantity; habitat structure; and disturbance regimes (Pyšek et al., 2008; Brunel et al., 2013; Ricciardi et al., 2013). For these reasons, practitioners and researchers are realising that it is more cost-effective to proactively deal with IAP problems and to restore natural ecosystems, than it is to source alternative ecosystem services and goods or to respond reactively (van Wilgen et al., 2012). This has led to the development of prevention strategies against new species introductions and controlling existing invasions and developing supporting legislation and management plans (van Wilgen et al., 2012; McGeoch et al., 2016), with considerable resources being expended (van Wilgen et al., 2012).

Invasive alien plants can be regarded as negative when they have detrimental effects or positive when they provide beneficial ecosystem services and economic value or insignificant or conflicting if they have none or both, respectively (Kumschick et al., 2012; Luyet et al., 2012; Ngorima & Shackleton, 2019). This conflict of interests often requires complex trade-offs to be made by institutions and/or individuals involved in management and decision-making or the implementation of such decisions (Cvitanovic et al., 2016). Thus, IAP management is a 'wicked problem', inherently resistant to easily identifiable predefined solutions (DeFries & Nagendra, 2017) and embedded in complex systems that lack clear solutions and are difficult to define (Rittel & Webber, 1973). For instance, although it is recognised that operational conservation agencies and decision-makers make on-the-ground management decisions, other relevant stakeholders, such as private landowners, media and non-governmental organisations also influence decisions by either supporting or opposing management actions (Davies et al., 2015; Novoa et al., 2018). Such an influence on decisions by these stakeholders affects the effectiveness and sustainability of the overall management of IAP (Davies et al., 2015). This added social complexity escalates the seemingly intractable nature of the problem (Conklin, 2005).

Decision Support Tools (DST) have considerable potential for guiding management strategies or decisions when problems are complex and uncertain (Potgieter et al., 2018b, Chapter 3) and have the potential to explicitly incorporate the principles of robust decision-making (Table 4.1). The concept of DST is increasingly used "to indicate any kind of decision aid, whether computer-based or not, and whether the problem it purports to address is more or less well structured" (Ison, 1993: page 112). In relation to IAP management, DST that are compliant with robust decision-making principles, can create and assess management alternatives and facilitate knowledge communication between multiple stakeholders (Carmona et al., 2013; Shackleton et al., 2019a). By so doing, DST can assist managers in prioritising among conflicting multiple management needs and assign limited resources across multiple problems. Indeed, DST are useful for IAP management decisions because they set transparent standards for evaluation, allow synthesis of information, and provide users with an objective way to communicate findings (Fedra, 1995; Forsyth et al., 2012). However, this thesis sought to provide a clearer understanding of the strengths and weaknesses of the current decision-making process applied in IAP management is needed to improve future decision-making. This is also essential in designing an appropriate DST that can be widely accepted by different stakeholders.

Invasive alien plant management is highly dynamic and complex, consisting of a network of interactions between various dimensions of ecological, social, economic and cultural aspects, and between multiple stakeholder groups (Estévez et al., 2015). Consequently, decision-making should appropriately incorporate the seven principles (summarised in Section 2.5 and Table 4.1). Together, these principles of decision-making should yield a more robust IAP management decision-making process, that should ensure the integration of knowledge, transference of information and fostering collaboration and coordination amongst diverse stakeholders (Estévez et al., 2015; Bennett et al., 2017). A robust decision-making process is defined in this thesis as a process that supports decision-making under conditions of high complexity, uncertainty and risks. This process allows learning from and provides an explanation of the logic behind decisions. The design of a DST incorporates the robust decision-making principles in a synthesised way that is useful to stakeholders and is pivotal in improving the current IAP decision-making process. The principles are the result of a distillation of principles and concepts presented in scientific literature (similar to Essl et al., 2017) and should result in improving the decision-making effectiveness.

**Table 4.1** Principles of robust decision-making (Chapter 2, section 2.5 for detailed explanations and Chapter 3)

| Principle | Explanation | Key references |
|---|---|---|
| Participatory | -Involvement of all interested and affected stakeholders in the decision-making process;<br>-Beyond the inclusion of 'usual participants' can result in effective, high quality and more reliable decision-making process. | Bäckstrand 2003; Davies et al. 2015; Millennium Ecosystem Assessment 2005; Reed et al. 2009 |
| Transparent | -A transparent process is a communication enabler among a diverse stakeholder group;<br>-Facilitates information sharing and learning making decisions more socially acceptable;<br>-Visible and provides clarity with which the reasoning behind decisions is communicated. | Davies et al. 2015; Bäckstrand 2003; Lockwood et al. 2010 |
| Science-based | -Decisions that are grounded in and consistent with the current scientific discourse. | Lubchenco 1998; Clark 2005 |
| Adaptive or Iterative | -Involves a cyclical process of goal formulation, monitoring, learning and adaptation;<br>-Allows stakeholders to collect information from attempts at a solution and use it to inform consequent attempts. | Roux & Foxcroft 2011; Keith et al. 2011 |
| Flexibility | -Adapts decision-making process in response to new scientific information;<br>-Allows experimentation of new methods and approaches thereby improving the decision-making process. | Roux & Foxcroft 2011 |
| Structured and consistent | -Integrates a range of environmental values into IAP management as these different value systems and stakeholder's perception of risk may result in conflict;<br>-Provides a multi-criteria decision analyses process that can be applied to IAP management. | Hammond et al. 2002; Salwasser 2002; Potgieter et al. 2018a; Liu et al. 2011a |
| Documented | -Allows for one to revisit and assess previously made decisions in light of new information. | Funtowicz and Ravetz 1992; Ravetz et al. 2018 |

Globally, there has been inadequate attention on assessing the effectiveness of IAP interventions (Kettenring & Adams, 2011) and the decision-making processes on which they are based. Several factors have been shown to affect the effectiveness of IAP management interventions and decisions (Kraaij et al., 2017). For example, stakeholders involved in prioritising the allocation of IAP management resources often have different goals and definitions of the problem, and perceptions of acceptable management strategies and priorities (Conklin, 2005; Waddock et al., 2015). Although some studies characterise the differences in perspectives on IAP management in general terms (Foxcroft, 2004; McPherson, 2004; Renz et al., 2009), some consider one or two factors influencing perceptions of IAP (Estévez et al., 2015).

The majority of studies to date have only evaluated specific aspects of IAP control and management operations, for example, assessment of: the use of adaptive management in IAP management (Foxcroft, 2004); economic benefits of IAP management (Hanley & Roberts, 2019); effectiveness of control alternatives (Leppanen et al., 2019); economically optimal level of management effort; and the timing of control efforts (Sims & Finnoff, 2013). There is a paucity of information or empirical studies on the perspectives on the current decision-making process with respect to woody IAP management, particularly in the Garden Route Biosphere Reserve (GRBR).

Current knowledge shows that no study has undertaken targeted assessments of the appropriateness of a decision-making process in IAP management. In this thesis, the perspectives on the current decision-making process for woody IAP management in the GRBR are characterised and the compliance of the process with the principles of robust decision-making evaluated as outlined in Table 4.1. In particular, the following questions were considered:

i. What strengths and weaknesses exist in the current decision-making process related to IAP management?

ii. How appropriate are stakeholders' IAP management decision-making processes or approaches to managing ‘wicked problems’?

iii. How can current IAP management decisions be improved to achieve more effective decisions, using these insights?

## 4.2 Methods

### 4.2.1 Study area

The study was carried out in the GRBR, which is an area of 698 363 ha (Pool-Stanvliet et al., 2018), which is largely located in the Western Cape Province and extends into the Eastern Cape Province of South Africa (Pool-Stanvliet et al., 2018). The GRBR was designated as a UNESCO Biosphere Reserve in 2017 (Pool-Stanvliet et al., 2018) and occurs within an important biodiversity hotspot, namely: the Cape Floristic Region. Biosphere reserves that are designated by UNESCO Man and Biosphere are "areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use" (UNESCO, 2016: page 175).

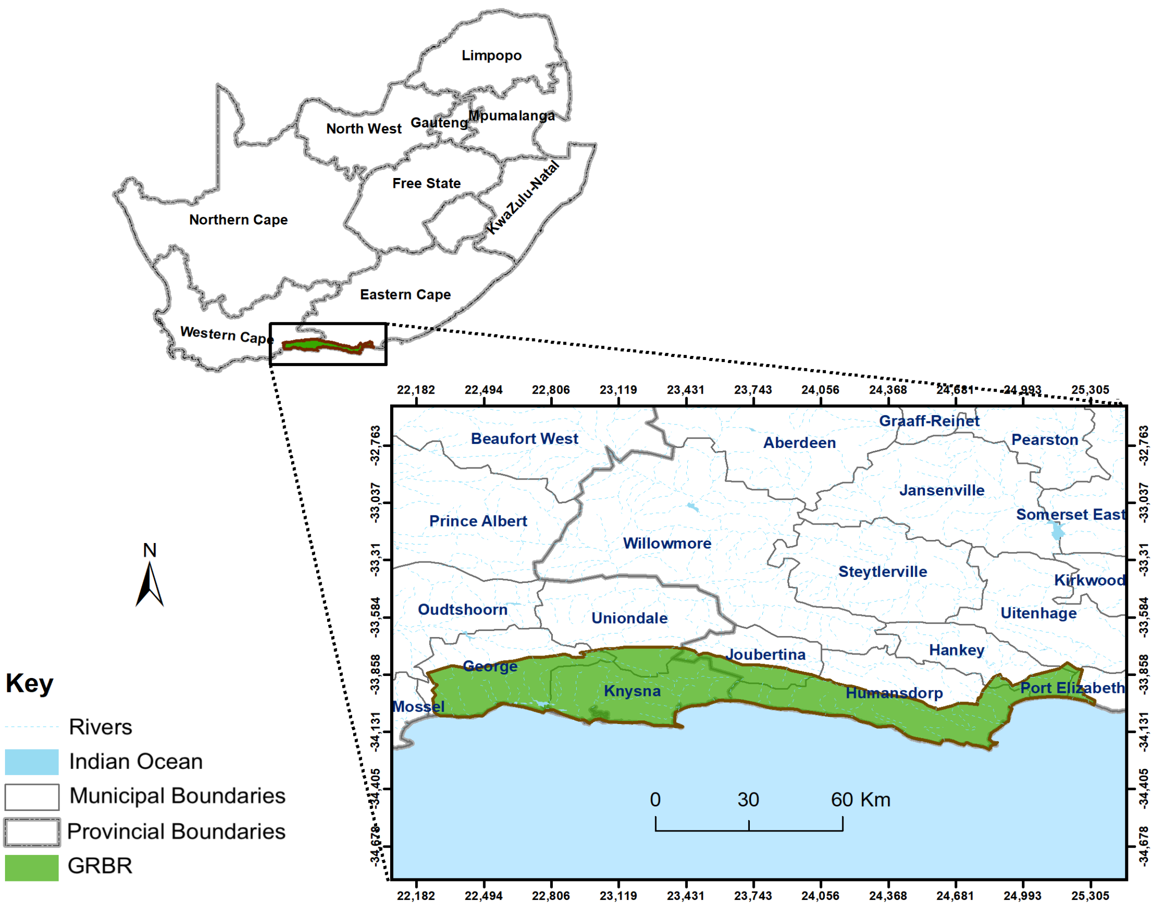


**Figure 4.1** Map showing the extent of Garden Route Biosphere Reserve (GRBR)

The study focused on woody IAP management in the GRBR for two specific reasons. Firstly, IAP are regarded as the single biggest threat to the loss of biodiversity (Kraaij et al., 2017), agricultural productivity (Reyers et al., 2009) and tourism opportunities

(Davey, 2011). Secondly, IAP management in the GRBR is particularly challenging due to a lack of effective management frameworks and paradigms for dealing with IAPs (van Wilgen et al., 2016; Kraaij et al., 2017). Forestry activities as well as horticulture are among the primary drivers of introductions and dissemination of IAP (Le Maitre et al., 1996). Often there is conflict between stakeholders interested in producing IAP for timber, and those interested in biodiversity conservation. The GRBR has networks of the private sector, municipal, parastatal, governmental and academic role players, who are concerned about IAP problems (SALGA, 2017). Despite the existence of these networks in the GRBR, there is a lack of systematic and structured coordination between role players. Municipal and government role players are disconnected, and there is an inadequate synthesis of available data, to inform decision-making related to IAP management (SALGA, 2017).

#### 4.2.2 Data collection

For this thesis, analysis is restricted to stakeholders in GRBR involved in IAP management activities and decision-making. Semi-structured interviews (Newing, 2010) are more appropriate than questionnaires or structured interviews because the researcher has knowledge about the topics to covered but does cannot anticipate all the likely responses and so design a set of specific questions for a questionnaire. A total of 30 individual key informant interviews were conducted from June 2018 to December 2018. Respondents were selected using criteria adopted from Tompkins et al. (2008), in other words, those with direct personal stake in IAP impacts (residents, businesses, natural resource users, private land owners) and those with a role in governance of natural resources.

An initial list of 17 key informants satisfying these criteria was purposefully selected from existing contact lists used for community engagement activities and compiled and updated over the past decade by a local research group (namely, the Nelson Mandela University's Sustainability Research Unit). After this initial sampling, a combination of chain referral sampling techniques, namely, snowball sampling and respondent-driven sampling (Morgan, 2008; Newing, 2010) were used to expand the interview pool to 30 key informants. For snowball sampling, names and details of anyone recommended or suggested were recorded and approached, and for respondent-driven sampling, each respondent was asked to let others know of the scope of the research and to indicate their willingness to take part (Newing, 2010).

The frequency with which stakeholders are referred to by their counterparts emphasises their actual influence in the system that is being analysed (Newing, 2010). The initial contact with the key informants was made via email or telephone call advising them of the background to the thesis and explain the intention to conduct an interview with them if they are willing. It was made clear that the research was purely for academic purposes and therefore no incentives were used to engage participants, hence relying only on the goodwill and interest in the subject. In addition, the concept of saturation (Newing, 2010) was adopted to determine whether or not to proceed with additional interviews. Saturation is a criterion for discontinuing data collection when no additional data are being found (Newing, 2010).

The interviews sought to identify issues or influences on current IAP management decisions and to evaluate the current decision-making process against the principles of robust decision-making. The respondents were further asked whether and how a DST could be useful in their work to determine what they saw as their most pressing needs. The responses were coded for mention of the principles recommended for a robust decision-making process (Table 4.1) In other words, their descriptions of the process were coded for any mentions of the principles. The respondents were also asked about the current decision-making process specifically about IAP management with which they were involved.

The interview guide consisted of open-ended questions (Appendix C) and was divided into three sections, namely: issues influencing management decisions (Section A); current decision-making process (Section C); and opportunities for improving the decision-making process (Section D). The interviews allowed an in-depth two-way communication between the researcher and the informants (Creswell, 2013). Initial responses to each question were followed up with comments, prompts and further questions to initiate conversation (Newing, 2010). This was essential to clearly define the current context in which IAP management decisions are made.

Considerable effort was made to avoid leading questions by ensuring that the questions are acceptable to the target population (Newing, 2010). Furthermore, the points on the interview guide were first standardised to make a comparison across the respondents, and therefore standard wording and a fixed order of questions were used. In order to do this, the interview guide was pilot tested on a small number of respondents and then refined (Newing, 2010). The semi-structured interviews lasted between 45 minutes and 90 minutes and the researcher was cautious to explicitly inform respondents in advance of the anticipated length of the interview. When all the points on the guide were covered, the informant was asked if they would like to provide additional information. This allowed other useful information to be mentioned that was not captured in the interview guide.

The research project was carried out in accordance with the Nelson Mandela University Ethical Standards guidelines[4] (H18-SCI-SRU-003, Appendix) and only commenced once the Ethics Committee had approved the ethics application. All identities are protected by means of pseudonyms (Mosberg & Eriksen, 2015).

### 4.2.3 Data analysis

All the interviews were audio recorded and transcribed. Coding was used for thematic analysis. The respondents were categorised into five groups, namely: private landowner (7); government departments (7); non-governmental organisations (6); private sector (5) and researchers (5). Detailed notes taken during the interviews were also used to inform coding.

Coding involves grouping data into different major themes obtained from sub-themes refined to make inferences about the data (Gibbs, 2007; Teddlie & Tashakkori, 2009). A combination of inductive and deductive coding was adopted in this thesis (Newing, 2010). For inductive coding, no hypothesis is specified. Instead, coding is informed by a set of broad questions or issues, and data are used to generate a theory (or hypothesis) once adequate evidence has been collected. In contrast, in deductive coding, specific theory is specified by the researcher where a hypothesis is determined and then the codes are designed to test it (Newing, 2010). Content analysis software called Atlas ti (Scientific Software Development, 2013) as well as manual techniques were used to run the coding in the thematic analysis process.

To verify the accuracy of the researcher interpretations, a summary of the results was distributed to participants who in turn were invited to respond by email, telephone or

[4] http://rcd.mandela.ac.za/Research-Ethics/Research-Ethics-Committee-Human-(REC-H)

schedule a face-to-face meeting. Quantitative data were statistically analysed using statistical software SPSS v 22.0 (SPSS Inc, 2015) to obtain a summary statistics for all variables. Kruskal-Wallis and Fisher Exact tests were used to assess variability across the five stakeholder groups with a significance level of 5%.

## 4.3 Results

### 4.3.1 Strengths and weaknesses in the current IAP decision-making process

The strengths and weaknesses in the current decision-making process for IAP management are in the interaction between ecological, economic, and social factors. For purposes of this thesis, the strengths and weaknesses identified across the stakeholder groups are discussed.

#### *4.3.1.1 Strengths*

Five factors were identified which mentioned the strength of the current decision-making process, with only one associated with the principles of robust decision making. The availability of a plethora of management plans (23), science-based decisions (24), the creation of jobs (26), flexible process (29), and coordination (29) were frequently identified strengths. Although coordination was happening in the GRBR, respondents in government departments (n=5) and NGO’s (n=5) indicate that there is a lack of leadership or champions to coordinate and collate IAP management activities. These champions are regarded as dedicated individuals in various leadership positions to lead in the coordination of IAP management activities. This lack of champions is attributed to a duplication of efforts. This indicates no definitive formulation of the problem across the stakeholder groups. One respondent from a private consulting company who works with many stakeholders mentioned that:

> *Although a lot of talking to each other is happening in the area, there is a lack of champions to coordinate activities. Often enough organisations working in the same area are seen duplicating activities and lack a common vision. [Private sector 4]*

There were no significant differences in how stakeholders identify the strengths mentioned in the current decision-making process (Table 4.2). The respondents show consistency in the identification of strengths of the current IAP management decision-making process.

*4.3.1.2 Weaknesses*

Twelve factors were identified and mentioned as the weaknesses of the current decision-making process. Results show much more diversity in the identification of weaknesses with several significant differences among the stakeholder groups in identifying weaknesses (Table 4.2). Several weaknesses (5) related to the principles of robust decision-making (Table 4.1) were mentioned. For example, lack of stakeholder buy-in/*participation* where individuals and/or organisations do not work alongside one another *"watching their very own piece of the pie"* [Private land owner] with *"everyone doing their own bit"* [NGO], is one of the most identified weaknesses in the current woody IAP management, with no significant difference across the stakeholder groups. When prompted to elaborate on the underlying drivers of lack of stakeholder buy-in/participation issues such as a lack of trust among stakeholder groups, a lack of champions to assume leadership roles and unfamiliarity of who is doing what and where came out frequently. Understanding these underlying drivers can be a strong leverage to dealing with the weaknesses in the current IAP management. One respondent noted that:

> *A lack of understanding of the importance of participation is a huge problem as it is fuelling distrust in government discourses around ecological infrastructures rehabilitation and ecosystem-based adaptation [Researcher 3].*

Weaknesses other than those related to the principles of robust decision-making were also identified (7). For example, the lack of long-term ecological data in catchments where IAP management is taking place also differs significantly across stakeholder groups with researchers (100%) strongly indicating this weakness. The lack of ecological data is, however, underreported by private land users (1). The majority of researchers (4/5) consequently lament that this makes it difficult to evaluate changes in the ecosystem after IAP management and to ultimately be in a position to document success stories.

**Table 4.2** Respondents' strengths and weaknesses in woody IAP management across the five stakeholder groups

| Strengths and weaknesses of the current woody IAP management | Stakeholder groups (Number of times mentioned) | | | | | Total number of times mentioned | $\chi^2$; *p-values* |
|---|---|---|---|---|---|---|---|
| | Private landowner (n=7) | Government departments (n=7) | NGO's (n=6) | Private sector (n=5) | Researchers (n=5) | | |
| **Strengths:** | | | | | | | |
| Coordination | 7 | 6 | 6 | 5 | 5 | 29 | 5.00; *p*= 0.51 |
| Flexible | 7 | 7 | 6 | 4 | 5 | 29 | 2.22; *p*= 0.29 |
| Creation of jobs | 6 | 6 | 5 | 4 | 5 | 26 | 3.59; *p*= 0.70 |
| Science-based decisions[¥] | 7 | 6 | 6 | 4 | 5 | 24 | 1.72; *p*= 0.52 |
| Plethora of management plans | 4 | 7 | 4 | 4 | 4 | 23 | 1.81; *p*= 0.42 |
| **Weaknesses:** | | | | | | | |
| Lack of structure and consistency[¥] | 6 | 6 | 4 | 4 | 5 | 25 | 8.22; *p*= 0.70 |
| Lack of stakeholder buy-in/participation[¥] | 6 | 4 | 5 | 5 | 4 | 24 | 3.25; *p*= 0.46 |
| Social and political pressure | 1 | 7 | 6 | 5 | 5 | 24 | 19.76; *p*< 0.01** |
| Bureaucracy | 1 | 7 | 6 | 5 | 5 | 24 | 5.47; *p*< 0.01** |
| Lack of capacity and knowledge | 4 | 7 | 4 | 4 | 4 | 23 | 3.88; *p*= 0.42 |
| Lack of planning, monitoring and evaluation | 3 | 7 | 4 | 4 | 4 | 22 | 3.66; *p*< 0.01** |
| Lack of transparency[¥] | 2 | 7 | 5 | 4 | 4 | 22 | 7.27; *p*= 0.04* |
| Lack of documentation[¥] | 3 | 7 | 4 | 4 | 4 | 22 | 5.47; *p*< 0.01** |
| Non-adaptive[¥] | 3 | 7 | 4 | 4 | 4 | 22 | 4.22; *p*< 0.01** |
| Lack of integration of fire and alien vegetation activities | 4 | 7 | 2 | 3 | 4 | 16 | 4.42; *p*=0.04* |
| Lack of long-term ecological data | 1 | 4 | 2 | 4 | 5 | 16 | 10.72; *p*= 0.03* |
| Tendering process | 1 | 4 | 2 | 3 | 3 | 13 | 4.18; *p*=0.04* |

The Kruskal–Wallis (K–W) test was used to assess the variability across the five stakeholder groups at p< 0.05; [¥]Principles of robust decision-making; Significant differences: **p*<0.05; ***p*<0.01

One respondent indicated that:

> *There are no proper systems in place to intercept new potential invasive species with no monitoring data at almost all the international entry points of South Africa" [Researcher 7].*

Integration of fire and alien vegetation management activities, that is combining fire control and alien clearing, varied significantly across the stakeholder groups, with private land users underreporting this weakness (1). The highest proportion identifying this weakness were government departments (86%) followed by researchers (80%) who attributed this weakness mainly to ignorance, with one responded cited as saying:

> *The woody alien plant species that were introduced to the Western Cape originate from fire prone environments and their ecology is intrinsically linked to fire and thus fire and alien vegetation invasions have to be managed in a joint or integrated operation to be really effective [Researcher 11].*

In addition, one government respondent emphasised that little or poor coordination between the Working for Water (WfW) (a programme that simultaneously promotes conservation and poverty relief through IAP control in the country) and Working on Fire (WfF) (government-funded, job-creation programme that focuses on implementing integrated fire management in the country) who work independently of each other. One respondent put this across as:

> *The Working for Water's system (Water Information Management System) that we use do not take into consideration the role of fire in the local environment... Often enough no provision is set aside to deal with the fuel loads generated by most clearing operations [Government 27].*

The tendering process (the government calls for offers to do alien clearing work through a bid process designed to ensure that the work to be done is given out in a fair way) after generation of a contract identified as a weakness to woody IAP management shows significant differences across the stakeholder groups, also with private land users underreporting this weakness (1). When prompted to elaborate, the respondents explained that delays in the tendering process were identified to be caused by a number of factors including bureaucracy, corruption, political motives and poor governance structures. However, the respondents from the government category indicated that not all contractors adhered to the WfW standards, and/or accurately spent budgets or followed the annual plan of operation. Often enough "the contract would have been awarded to inexperienced contractors or the project manager will not be competent enough" [Researcher 11]. This was also mentioned to be intricately "related to social and political pressure in awarding the contracts" [Government 23]. As Working for Water (WfW) and Working for Fire are funded by the Expanded Public Works Programme (EPWP) which aims to create employment to the marginalised communities, an important consideration in the programme is employment creation.

#### 4.3.2 Current decision-making process

The results show no significant differences among stakeholder groups in how the respondents characterise their current IAP decision-making process, with infrequent mention of the principles of robust decision-making (Figure 4.2). Relatively few respondents among the five stakeholder groups refer to how the inclusion of documentable, transparent, participatory and structured/consistent decision principles are part of their current decision-making process. Although the respondents are aware that engagement with other parties is key, they explained that given the diversity of the stakeholders involved in woody IAP, it is important to engage with other parties and at the same time *"acknowledging each other's uniqueness and dynamism of the IAP problem" [Researcher 2].*

When prompted to unpack stakeholders involved in the decision-making process, responses ranged from the general public, namely: researchers (4), government (5) and non-governmental organisations (NGO) (4), to various corporate organisations to government agencies (local to national). The NGO and government stakeholder groups indicate substantially more interaction with the general public than researchers.

Respondents also identified characteristics other than the previously described robust decision-making principles in Table 4.1. These are expressed by respondents as part of the current decision-making process. The first characteristic is coordination which takes place between respondents' agencies (mostly researchers, private sector and NGOs) and other interested groups. Researchers, government and NGOs place emphasis on the role of coordination between multiple stakeholders or agencies and also the important role expert knowledge plays in IAP management decision-making process. However, government (3) and NGO (2) respondents state that coordination mostly happens unofficially and among individuals sharing a common vision, acting as *"champions of change" [NGO 20].* The second characteristic includes a spatial analysis component (allows stakeholders to understand visually, for example, 'where' alien clearing resources could be optimally utilised) in the decision-making process and is mentioned by researchers, government and private sector.

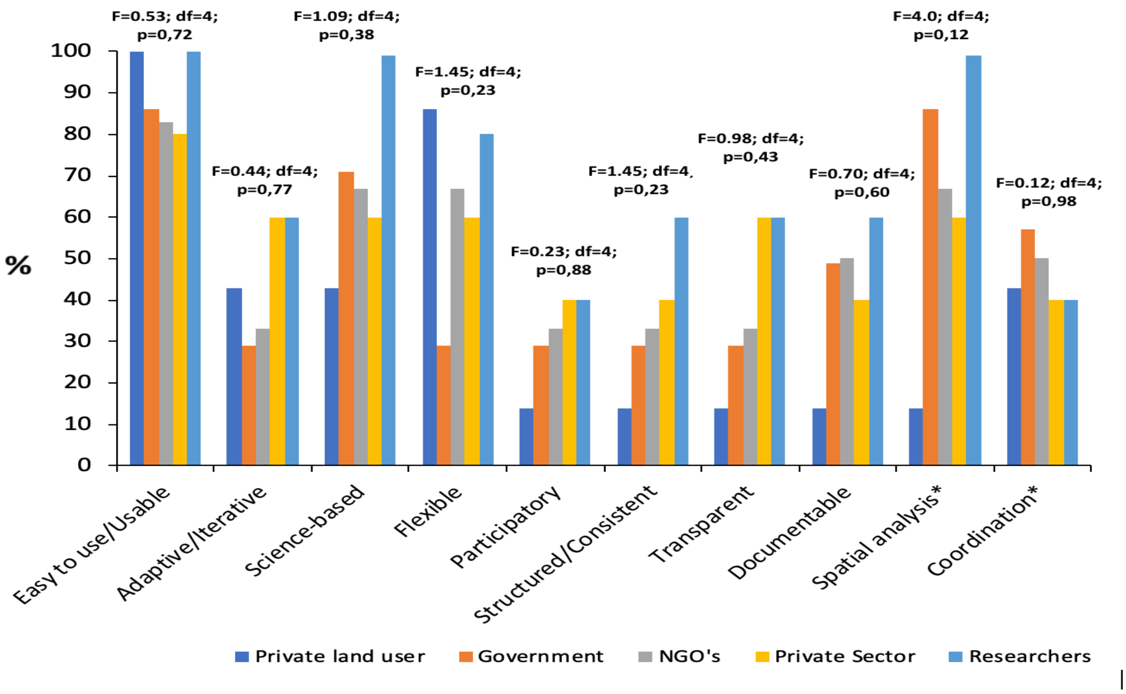


**Figure 4.2** Stakeholder responses regarding characteristics of their current IAP management decision-making process. *Other characteristics identified not described as robust decision-making characteristic

### 4.3.3 Practical considerations

Many respondents among the stakeholder groups, particularly those from the government, NGOs and the private sector, agree that a DST relevant to their IAP management decision-making needs would be useful and a welcome addition in their line of work. Regarding the 'wicked problem' challenge, the majority of the respondents across the stakeholder groups, emphasise that a DST could be especially helpful in framing difficult decisions, and raised three similar reasons, namely: the need to deal with uncertainty in the outcomes of management actions; conflicting management objectives; and the need to make up for the weaknesses in the current decision-making process.

However, respondents from the private landowner group have a different concern about the relevance of a DST. Three private landowners are open to the idea of a DST but questioned the ability of the DST to make a difference to the current IAP management decision-making process and challenges, and ultimate framing of IAP decisions. These three landowners are sceptical about the value of a DST and state that they did not envision how a DST could influence their current decision-making process. One other respondent's scepticism is based on concerns over the reliability, legitimacy and accuracy a DST could offer, given the challenges around the source, quality and availability of information feeding into it, especially with regards to long-term socio-ecological data. As one respondent states:

> *The quality of the output information or decisions is as good as the information that has been put in to generate the output [Private landowner, 11]*

With respect to giving suggestions for aspects, a DST should address to be useful and effective in framing woody IAP management decisions, all respondents across the five stakeholder groups responded differently (Table 4.3). The respondents had between one and seven suggestions, with a total of 87 different types of suggestions being mentioned. The results found that there is a widespread need for DST that addresses practical issues regarding prioritisation (97); decision-making guidance (97) and cost-benefit analysis (93). Various weaknesses of the current decision-making process are linked to this finding, including a lack structure, a lack of documented decisions and transparency.

Nearly every aspect of IAP management mentioned by the respondents as potentially benefiting from a DST, including: early detection, prioritising control operations measuring effectiveness; and efficiency of management actions. Similarly, aspects of the decision-making processes are also mentioned. Such aspects included risk assessment/analysis, the ability to predict the outcomes of different actions and the prioritisation of where to take actions and which actions to take.

In summary, the diverse responses to the question: 'What aspects should a DST address for it to be useful in your line of work?', highlight that DST is both useful and relevant in different aspects of woody IAP management and goes a long way in helping frame IAP management as a 'wicked problem'.

**Table 4.3** Respondent's perspectives of the aspects a DST should address for it to be useful in their decision-making processes

| Practical issues | % of respondents within categories | Examples and explanation |
|---|---|---|
| **Prioritisation** | **97 (n=29)** | Where to put limited and irregular resources such as funds and logistics across a landscape |
| Private landowner (7) | 86 | |
| Government (7) | 100 | |
| NGO (6) | 100 | |
| Private sector (5) | 100 | |
| Researchers (5) | 100 | |
| **Decision-making guidance** | **97 (n=29)** | Step-by-step guidance for stakeholders, which strategies to be used at which particular location; setting clear and achievable goals |
| Private landowner (7) | 86 | |
| Government (7) | 100 | |
| NGO (6) | 100 | |
| Private sector (5) | 100 | |
| Researchers (5) | 100 | |
| **Cost-benefit analysis** | **93 (n=28)** | Cost of implementing management actions vs. no action or maintaining secondary infestation; feasibility questions |
| Private landowner (7) | 100 | |
| Government (7) | 71 | |
| NGO (6) | 100 | |
| Private sector (5) | 100 | |
| Researchers (5) | 100 | |
| **Prediction** | **83 (n=25)** | Likelihood of damage resulting from woody IAP; densities of IAP as an indication of the degree of infestation; ranking new woody species for invasiveness |
| Private landowner (7) | 43 | |
| Government (7) | 86 | |
| NGO (6) | 100 | |
| Private sector (5) | 100 | |
| Researchers (5) | 100 | |
| **Information-hub** | **73 (n=22)** | Accurate record keeping; what are the available management options? |
| Private landowner (7) | 29 | |
| Government (7) | 100 | |
| NGO (6) | 50 | |
| Private sector (5) | 100 | |
| Researchers (5) | 100 | |
| **Risk analysis/ assessment** | **73 (n=22)** | Risk assessment/analysis based on the best accessible information; information required to control early invasions may be minimal and delaying control to acquire the information that could reduce likelihood of putting the invasion under control |
| Private landowner (7) | 29 | |
| Government (7) | 57 | |
| NGO (6) | 100 | |
| Private sector (5) | 100 | |
| Researchers (5) | 100 | |

## 4.4 Discussion

A lack of planning, inadequate guidance for effective and sustainable interventions have previously been identified as some of the factors reducing the effectiveness of control and management decisions (van Wilgen et al., 2012; Gaertner et al., 2017). This thesis presents a first targeted assessment, largely based on the engagement of diverse stakeholders, and the appropriateness of current decision-making process in IAP management. This thesis direction is critical given the fact that there is a diversity of stakeholders or interested parties involved in the management of IAP, each having unique perceptions regarding the issue and a specific viewpoint on the management action to take (Simberloff et al., 2011). Compliance of the current decision-making process was critically evaluated against the principles of robust decision-making (Table 4.1), which allows the current research to evaluate the effectiveness of the process and to make practical recommendations towards improving the decision-making process.

The assessment of the strengths and weaknesses of the current IAP decision-making process reveal a lack of *documentation*, *structure* and an *adaptive* approach as making the decision-making processes weaker. These findings are similar to other studies that show that despite previous research efforts to determine strategies for control operations, there is a lack of a *structure* for identifying priorities (Roura-Pascual et al., 2009). The results confirm that the principles of robust decisions from scientific literature resonate with on-the-ground stakeholder group making decisions. Given the need to improve decision-making in IAP management (McGeoch et al., 2016), the findings of this thesis certainly underscore the need to find and explore approaches to facilitate the application of these principles in IAP management. Incorporating the principles of robust decision-making can provide a structure for deriving common goals and a means of maintaining communication. This is also noted by Foxcroft (2004) in their development of a conceptual framework for exploring science and management links for IAS management.

Evaluation of the current decision-making process reveals how infrequently the principles of robust decision-making (described in Table 4.1) arise during the respondents' descriptions of their current decision-making processes. These findings are based on unprompted mention of those principles and, thus, might differ if interviewers had directly asked stakeholders about the importance of these characteristics in their decision-making processes. The findings are similar to those of Liu et al. (2011) and Estévez et al. (2015), who also show how land users or affected parties ascribe differing priorities and perceptions to the IAS management process. Diverse priorities and perceptions about the decision-making process can lead to management ineffectiveness (Estévez et al., 2015) as shown by the diverse weaknesses of the decision-making process identified in this thesis.

The infrequent mention of the principles of robust decision-making process descriptions resonates with respondents' identification of the strengths and weaknesses of their processes. These strengths and weaknesses discussed are closely aligned with either the presence or absence of principles robust decision-making (Figure 4.3). As also noted by Forsyth et al. (2012), the majority of respondents recognised that the inclusion of participation, flexibility and science-bases make their decisions stronger. Similar to this thesis findings, a study on researcher and land manager perspectives on IAP research needs, shows that both land user groups value working together on IAP issues as either of high or medium importance (Renz et al., 2009). In addition, the findings show that none of the land user groups rate their current level of cooperation or coordination as high, with over 90% describing current coordination as low or medium.

The correlation between the principles of robust decision-making and the strengths and weaknesses identified by the respondents continue in the respondents' descriptions of what they would like to see in a DST. The use of a DST could allow stakeholders to incorporate many of the principles they would like in the IAP decision-making process (for example, *documented* and *adaptive* decisions). Also, the use of a DST could allow different stakeholders to follow a documentable and consistent structure to reach IAP management decisions that for most of them, is currently lacking. Likewise, other studies show that incorporating,  the principle of *adaptability* for example, is an acknowledgement that the management of woody IAP occurs in an environment of uncertainty, unpredictability, and complexity (Lockwood et al., 2010).

A reliable DST that incorporates the principles can provide a *consistent structure* for decision-making and helps reach decisions about where to focus IAP management efforts. For some of the stakeholder groups (private landowners), it is lacking. In addition, using a DST could allow stakeholder groups to clearly explain how and why they reach a particular decision and are able to document the process. Consequently, all these characteristics of a DST could help address weaknesses in current decision-making processes identified among the different stakeholder groups and could be applicable regardless of the form of the DST used. Knowledge of how stakeholder groups perceive usefulness of DST provides some opportunities to improve the effectiveness of management decisions and to make best use of limited resources.

### 4.5 Conclusion

The results from this thesis highlight that stakeholder groups involved in IAP management are often confronted with several IAP management challenges and simultaneously with limited resources to deal with them. It is recommended that incorporating the principles of robust decision-making in the decision-making process and design of a DST emerged from the research as a potential way for improving the effectiveness of an IAP decision-making process. However, different stakeholder groups have substantially different priorities, perceptions about the current decision-making process which deserve special attention and should be considered in any decision-making process.

The findings highlight that most stakeholders would welcome a DST into the decision-making process for two reasons: firstly, to address various woody IAP management weaknesses in an integrated way; and secondly to assist stakeholders to make the decision-making process adhere closely to principles of robust decision-making thereby making the process appropriate for managing ‘wicked problems’. An appropriately designed DST, incorporating the principles of robust decision-making, is valuable in fostering collaboration in the decision-making process (Chun & Park, 1998) and can also be used as a learning tool that allows stakeholders to make informed decisions. It is clear that the majority of the stakeholder groups interviewed, possess specialised and unique knowledge regarding on-the-ground realities and experiences of IAP management. This thesis underscores the need to include their perspectives and experiences of the existing decision-making process to ensure effective and efficient attempts to improve it. The seven principles presented in Table 4.1 may present an opportunity to improve the current woody IAP management decision-making process, provided that they are applied in making decisions.

## CHAPTER FIVE

## A systems thinking approach for achieving a better understanding of invasive alien plant management and decision-making

This manuscript is intended for submission to a peer-reviewed journal (TBD)


### Abstract

Invasive alien plants (IAP) pose a significant threat to biodiversity and consequently to human well-being. Such invasions may have major economic costs in terms of the management measures taken at local and international levels. Managing IAP is particularly challenging given the complex interactions between economic, ecological, and social elements that exist in the IAP management system. The complex nature of IAP management and decision-making necessitates focus on less recognisable but potentially far more effective areas of intervention. This thesis applied systems thinking to examine the interconnectivity between social, ecological, and economic variables that create complexity in IAP management in the Garden Route Biosphere Reserve (GRBR). This was explored through the development of a Causal Loop Diagram (CLD) to identify the important feedbacks between variables in IAP management in the GRBR. A combination of a social-ecological inventory, key informant interviews, stakeholder workshop and expert opinion was used. Understanding the complexity of the system of IAP management provides a basis for determining what interventions might be needed with what stakeholders and organisations to improve the decision-making process. Results indicate that systems thinking helps to understand complexity, design improved policies, facilitate learning, and potentially achieve effective IAP management. A CLD was developed to explore and foresee the long-term consequences of IAP management actions and decisions, as well as to help avoid any unintended consequences of interventions, strategies and policies that may lead to policy resistance. To transcend policy resistance and fixes that fail, and improve IAP management, stakeholder groups need to consider deep leverage points that can be maintained over the long-term and trigger a fundamental change. The results reveal that more focus has rather been on shallow leverage points that are fairly easy to implement but do not result in significant systemic change.

Systems thinking should augment a conventional approach of dealing with IAP management.

**Key words:** causal loop diagram, levels of thinking, leverage points, management, system archetype

## 5.1 Introduction

Invasive alien plants (IAP) are increasingly acknowledged as a major component of global change, threatening the survival of native species (Shrestha et al., 2019) altering ecosystem processes (Shackleton et al., 2019b), and causing substantial economic losses in host regions (Pimentel, 2011). The impacts of invasive species are set to increase across all taxonomic groups (Seebens et al., 2017) in most biomes and in tropical ecosystems in particular, as the rates of species introductions and anthropogenic alteration of landscapes continue to increase (Millennium Ecosystem Assessment, 2005). Since Elton's volume, that first addressed the ecology of invasions by animals and plants (Elton, 1958), recognition of the global ecological and economic impacts of plant invaders has triggered an explosion in research attempting to understand the ecology and management of IAP (Ricciardi & MacIsaac, 2008).

In particular, the Garden Route Biosphere Reserve (GRBR) is one of the regions in South Africa that is most threatened by IAP (Kraaij et al., 2011), particularly woody species. New approaches are needed to improve the effectiveness of decision-making in the GRBR. Many land managers need to balance several socio-economic and ecosystem objectives at once, which may encompass reducing the spread of IAP, protecting native species, and sustaining ecosystem services (Büyüktahtakın & Haight, 2018). Management may also involve a broad range of stakeholders with diverse knowledge and values, and multiple jurisdictions with asymmetric objectives (not aligning with each other) and mandates for IAP management (Wittmann et al., 2015). The resultant multitude of conflicting perspectives, goals and objectives can make the problem practically impossible to define, let alone provide a solution, to the satisfaction of all stakeholder groups (Woodford et al., 2016). Additionally, stakeholder groups often have to decide on whether it is economically feasible to eradicate or contain an invasive alien species (IAS) based on limited budget and human resources (Epanchin-Niell & Hastings, 2010; Epanchin-Niell, 2017). This is particularly challenging when future damages that the species may cause, are largely uncertain (Wittmann et al., 2015) and conflicts of interest exist with regards to purposefully introduced IAP that offer economic and intrinsic benefits (Shackleton et al., 2016; Zengeya et al., 2017).

Considering the interconnectedness, interrelationships, uncertainty and multiple stakeholders involved (Chapter 4) in managing IAP, from a practitioners and policy perspective, their management is regarded as a complex system (Westgate et al., 2013; Vaz et al., 2017). The IAP management and decision-making process is a highly dynamic and complex problem, often characterised by a network of interactions between multiple dimensions of ecological, social, economic, cultural and political aspects, and between several stakeholder groups (McGeoch et al., 2016; Novoa et al., 2018). Conventional approaches to understanding IAP management have often tended to focus on particular parts of the IAP management system, for example, alien clearing to restore the conservation value of a particular landscape. In most cases, such approaches neglect the interconnectedness of the system. This results in a failure to attain a comprehensive understanding of the complexity of the system and its fundamental function.

These conventional or traditional approaches that view IAP management problem as tame (as opposed to 'wicked') have often focused on ecological and environmental aspects with little attention to social dimensions (Chapter 2, section 2.1.1; García-Llorente et al., 2008). These traditional solutions to problems in complex adaptive systems as in IAP management are static in nature, sectoral based and with much reliance on data and spreadsheets, often with limited transparency of assumptions (Chapman, 2004; Roura-Pascual et al., 2009; Forsyth & Le Maitre, 2011; Roundy et al., 2018). Although conventional approaches still play a pivotal role in IAP management, to effect significant changes in IAP management system it is essential to think differently and to avoid approaches that lead to quick fixes (Ehrenfeld, 2004). For example, great pressure from communities to quickly resolve the water hyacinth problem has been documented to have led to poor management decisions that wasted resources (Julien, 2008).

Despite mounting research in the invasion science field, the majority of research is still biologically driven and conducted, with only 3% of such studies integrating social-ecological systems holistically (Vaz et al., 2017). This indicates the need for greater transdisciplinary work (Chapter 1, section 1.3.1) in the field, which ensures the advancement of scientific understanding and making results more applicable to a range of stakeholder groups (Abrahams et al., 2019). Consequently, it is vital to incorporate new ways of thinking and novel methodologies to better understand IAP management and the decision-making process. In this research, systems thinking is adopted as a guiding approach for further examining the complexity and advancing understanding of IAP management and decision-making in GRBR. This approach incorporates the importance of connections, interactions and emergence in the system. The following research questions are answered:

1. What are the key variables that influence IAP management and decision-making?
2. How do these variables affect IAP management and decision-making?
3. What are the feedbacks or influencing factors between these variables?

A Causal Loop Diagram (CLD) to represent dynamic interrelationships and interconnectedness of IAP management in the GRBR is presented. This provides an understanding of complexities surrounding IAP management and identifies possible points of management or intervention to leverage change. Understanding the complexity of the system of IAP management provides a basis for: an in-depth understanding of challenges associated with IAP management/interventions; understanding strengths and weaknesses of the current solutions being implemented; and ultimately identifying gaps or windows of opportunities for improving outcomes. In the following sections, the systems thinking approach and the four levels of the thinking model framework are explained.

## 5.2 Systems thinking

A systems thinking approach is defined as a scientific methodology that allows for one to understand and manage complexity that addresses uncertainty, hidden assumptions, and the integration of mental models into system structures (Senge, 2006). Such an approach can help decision-makers to go beyond events, to look for patterns, understand and predict the long-term consequences of actions, decisions, strategies, and policies (Sterman, 2000). This helps to uncover the root causes of challenges, reduce risk, plan the future, anticipate delays and ultimately avert unintended consequences (Walters & Holling, 1990; Senge, 2006). A systems thinking approach to IAP management implies, for example, that the ecological and the socio-economic environments make up an integrated system that comprise individual elements which are interconnected and affect each other, consequently affecting the whole system (Benson et al., 2016). The use of systems thinking allows one to test the potential outcomes of different systemic interventions through observing what would happen to the system as a whole when a particular intervention or combination of interventions is applied (Benson et al., 2016; Nguyen et al., 2019). Systems thinking unravels complexity through four interrelated levels of thinking (Chapter 2; Maani & Cavana, 2007).

Using the analogy of 'the tip of an iceberg' adopted from Maani and Cavana (2007), the first level of thinking, that is 'events' level, represent the tip of the iceberg — how people understand things in the world through incomplete data or information from different sources. Most decisions take place at this level as woody IAP invasions are visible and may often draw attention and action. The information mostly used at this level offers answers to simple questions, for example, how, where, when, and who are involved in the management. Events are shallow and short-term, but they often spark management actions and can lead to new regulations and policies. The importance of this step is largely undervalued as stakeholder groups often assume they are well-informed about what the real problem is, while in reality they may be considering the symptom of the problem (Banson et al., 2018).

The second level of thinking is the one that involves interpreting and exploring patterns and their interconnectedness (Banson et al., 2018). Patterns represent a sequence or history of a larger set of events (or data points) over time connected to create a history. The collection of preliminary information, for example, historical and statistical records, policy documents, media reports, and stakeholder interviews, that rationalise the seriousness and clarity of the scope and magnitude of the problem/issue is identified (Banson et al., 2018). Therefore, the second level of thinking are rich in information and can provide a reliable base for making decisions and planning (Bosch et al., 2013).

The third level of thinking is systemic structures which depict causal relationships or feedbacks amongst variables operating in a system (Maani & Cavana, 2007). Systemic structures unravel the relationships in complex systems by representing interdependencies and interactions amongst variables within a system and can predict the system behaviour over time (Liu et al., 2011b; Banson et al., 2018). Significantly, this level of thinking provides an understanding of how different variables interact, and their resultant causal relationships (Meadows, 1997; Liu et al., 2011a).

Finally, the fourth level of thinking or mental models, represents the deepest and most important level of thinking, reflecting the beliefs, values, assumptions and culture of stakeholder groups (Maani & Cavana, 2007). Thus, mental models are the highest leverage for change as they allow stakeholder groups to understand the mental models that people have, which highlight the rationale for their behaviour and actions. Such a level of thinking describes emergent properties that arise from various, potentially conflicting, goals, sets of views and behaviours within a system of interest (Abson et al., 2017). The fourth level of thinking builds on the other three levels mentioned above and is crucial in identifying systemic and fundamental solutions. Change arising from this level of thinking has the ability to provide means of transformation for organisations and societies (Meadows, 1997; Abson et al., 2017).

A systems thinking approach involves five main interconnected steps (Maani & Cavana, 2007), namely: problem structuring; causal loop modelling; dynamic modelling; scenario planning and modelling; and implementation and organisation learning. This thesis only focuses on the first two steps for deriving and understanding complexity of IAP management in the GRBR. The remaining three steps are mostly used for computer modelling, which is not the focus of this current study. Thus, the application of systems thinking to understand and improve IAP management and decision-making in the GRBR would, have potential for local to national application considering the environmental or socioeconomic impacts of IAP, which is to augment the decision-making toolbox dominated by orthodox, linear thinking approaches.

### 5.2.1 Problem structuring

In systems thinking, problem structuring is the most fundamental step with its main aim to describe the major challenges of concern to management, to identify the scope and delineate the boundaries of the study (Van Mai & To, 2015) and ask the right questions. Problem structuring improves the informational content of a problem and is a prerequisite for designing solutions to a problem (Dunn, 2018; Ravetz et al., 2018). This process involves stakeholder consultations to identify a problem and describe its importance. Consequently, the first step in problem structuring is to identify the key stakeholder groups and involve them in the problem articulation process.

### 5.2.2 The Causal Loop Model (CLD) development

The overarching objective of this step is to develop a conceptual model of the problem under focus (in this case IAP management), known as the CLD. This step provides a practical approach to modelling and a simple way to understand the complex elements within a system structure (Banson et al., 2018). A CLD is a useful analytical tool for representing dynamic relationships among system variables linked by arrows that imply their causal relationships to produce dynamic feedback structure (Van Mai & To, 2015; Kotir et al., 2016). This level of analysis corresponds to both the third level and fourth level of thinking. It is the most widely used phase of the systems thinking approach (Richmond, 1993; Sterman, 1994) providing a visual representation that helps to communicate complex systems in a concise form (Maani & Maharaj, 2004; Lannon, 2012). The variables in a CLD can be drawn from key phrases or words identified through the problem structuring step explained earlier (Section 5.2.1). Each of the arrows in the CLD has either a positive '+' (variables moving in the same direction) or a negative '-' (variables moving in the opposite direction) polarity.

Furthermore, the arrows within the CLD connect pairs of variables, forming balancing (B) and reinforcing (R) feedback loops. These feedback loops are useful in identifying if intervention has the ability to generate a system-wide change or if there is need to improve or introduce a new solution (Sterman, 1994; Meadows, 1999). Reinforcing loops are positive feedback systems that accelerate change within systems, which can result in either rapid growth or decline. Balancing loops, on the other hand, seek to balance the system until self-equilibrium is achieved (Van Mai & To, 2015). A CLD may comprise several combinations of B and R loops, as well as time delays (denoted by '//'). A complex system is generated by the interplay between B and R over time, time delays, and shifts in loop dominance over time (Sušnik et al., 2012; Van Mai & To, 2015). The dominance of reinforcing loops in this system, for example, implies that there are more sources of erosion, growth, and failure which stakeholder groups need to address and minimise (Sahin et al., 2020).

### 5.2.3 System archetypes

A CLD can become quite complex. To counter this, it is important to identify the core system structures which can then be used to explain the general system behaviour (Van Mai & To, 2015). These fundamental system structures are known as system archetypes (Braun, 2002), and represent generic system models or templates representing a broad variety of situations (Sterman, 2000; Braun, 2002). For example, a system archetype that represents decision-makers identifying quick fixes to specific parts of a system in response to a problem, may lead to silo mentality in which a fix in one place, simply transfers the problem to another, resulting later in a much bigger problem (Bosch et al., 2013; Banson et al., 2018). Consequently, such a system archetype works in the short-term (balancing effect), and can also result in unintended and often detrimental consequences that amplify the original problem (reinforcing effect), and which can allow the system to revert back to its original or worse state after a delay (Senge, 2006). General management principles also exist in system archetypes which can be employed to influence the behaviour of systems in a favourable direction (Senge, 2006). System archetypes are part of a suite of tools that are valuable in identifying places in the system of leverage change and to develop intervention strategies (Banson et al., 2018). Conversely, it is important to note that system archetypes are not intuitive and thus difficult to identify, but once a CLD of a system is developed, its associated system archetypes become more apparent (Van Mai & To, 2015).

In this regard, the research aims to capture how variables in an IAP management system are interrelated and to identify possible points of management or intervention to leverage change. This is achieved by visualising the complexity in managing IAP through a systems thinking lens. The development of a CLD that identifies important feedback loops, should be useful for improving IAP management and decision-making in the GRBR, especially for practitioners and stakeholders grappling with the problem.

## 5.3 Study area

The study area, namely, the GRBR, which is largely located in the Western Cape Province and extends into the Eastern Cape Province of South Africa (Figure 5.1). Biosphere Reserves (BR) are designated by the UNESCO-MAB as “areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use” (UNESCO, 2016: page 175). In South Africa, there are nine designated BR as well as one currently under review, all covering 102 615 $km^2$ which is approximately 8.4% of South Africa’s land area (Pool-Stanvliet et al., 2018). The BR are being managed through non-profit organisations (Pool-Stanvliet et al., 2018).

The area of the GRBR is 698 363 ha, and was designated by UNESCO-MAB as a BR in 2017 (Pool-Stanvliet et al., 2018). The study area occurs within a biodiversity hotspot, namely, the Cape Floristic Region (CFR), and is characterised by rugged mountains, coastal plains and foothills (Baard & Kraaij, 2014). The mean annual rainfall ranges between 800 and 1100 mm with mild temperatures (18-25°C). As part of the CFR, the GRBR area is globally recognised for its important biodiversity and high endemism (Cowling & Richardson 1995; Vromans et al., 2010); best described by a mosaic of biomes including wetlands, fynbos shrublands and grasslands, southern Afro-temperate forests, thicket, riverine vegetation and smaller areas of coastal vegetation. Several sites with conservation value including the Garden Route National Park (for example, Tsitsikama Marine Protected Area and Wilderness Lake Ramsar Site) Nelson Bay Cave and the Langkloof Valley are found within the GRBR. As a result of a successful establishment of plantations in the Southern Cape in the 1900s which expanded rapidly after the second world war, the indigenous vegetation is now threatened by IAP mainly by *Pinus* and *Acacia* species (Baard & Kraaij, 2014).

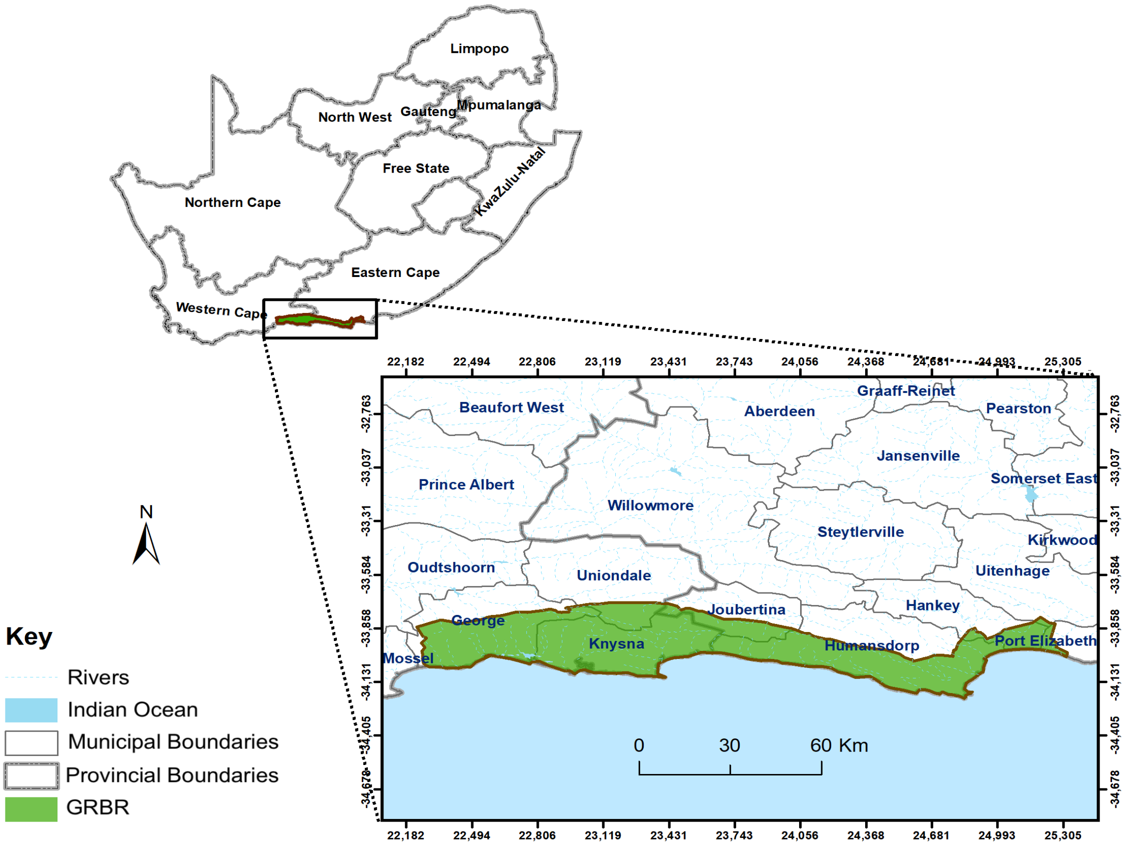


**Figure 5.1** The location and extent of the Garden Route Biosphere Reserve (GRBR)

In South Africa, IAP costs the economy an estimated R6.5 billion a year (Cape, 2019). In addition, invasion by IAP, particularly woody species and large shrub species, poses a significant threat to the water resources, flora, and other ecosystem services in the GRBR (van Wilgen, 2008). In the GRBR, dominant woody IAP include wattles (*Acacia* and *Paraserianthes* spp.), blue gums (*Eucalyptus* spp.), hakeas (*Hakea* spp.), and pines (*Pinus* spp.). Control of these IAP can prove challenging due to, for example, their copious seed production, rapid growth rates, large and long-lived soil seed banks, long-range dispersal, and adaptations to fire, in particular to post-fire flushes of seedlings (van Wilgen, 2008). It has also been shown that previously cleared areas have the potential to revert to heavily invaded areas if funds or capacity do not allow for timely follow-up control, particularly after events such as fire (Kraaij et al., 2011; Kraaij et al., 2017).

The problem of IAP in the Western Cape, and in particular GRBR, has a long history (van Wilgen, 2008). As early as the 19$^{th}$ Century, the South African Government embarked on extensive alien tree growing campaigns with a rationale of making South

Africa less dependent on international timber and wood markets. In this initiative, landowners were encouraged, through incentives, to cultivate alien trees (Urgenson et al., 2013). However, by the 1960s, a subset of alien species was acknowledged as problematic, and as a result, widespread campaigns to remove IAP were initiated in the early 1980s. The Conservation of Agricultural Resource Act of 1983 (Act 43 of 1983, amended in 2001) and the National Environmental Management Biodiversity Act of 2004 (Act 10 of 2004), amended in 2014, place restrictions on the propagation, growth and trade of designated IAP species on both private and public land.

## 5.4 Methods

### 5.4.1 Problem structuring

The research adopted three methods (Table 5.1), namely: social-ecological inventory, key informant interviews and a stakeholder workshop to allow knowledge co-production and triangulate data, to enhance a better understanding of the critical issues or variables constituting the IAP management system in the GRBR. These are expanded in this section.

**Table 5.1** The methods that were used to develop the CLD

| Research instrument | Purpose |
|---|---|
| **Problem Structuring:**<br>Social-ecological inventory<br>Key informant interviews<br>Stakeholder workshop | • Identification of the key variables/issues in regard to IAP management and decision-making<br>• Confirmation of system boundary: IAP management from a social, ecological economic, political and economic system |
| **Model conceptualisation:**<br>Stakeholder workshop | • Identification of interconnections and relationships among identified variables<br>• Development of a preliminary conceptual model represented as a CLD<br>• Identification of feedback loops<br>• Identification of interventions (such as, system archetypes; leverage points |
| Expert consultations | • Refinement of the initial CLD generated from the stakeholder workshop |

#### *5.4.1.1 Social-ecological inventory*

For the social-ecological inventory, existing local IAP management and decision-making processes were investigated. Stakeholder groups (Chapter 4) in the landscape

(GRBR), key individuals in these groups and their management practices were identified as were links between organisations, institutions, and stakeholders. Methods included participatory observations, extensive field visits and the review of other secondary information sources, including project reports, notes, websites, newspaper articles and correspondence, similar to  Schultz et al. (2007). The inventory focused on identifying stakeholder groups and individuals currently having a direct/indirect stake (either affected or involved in management actions) in IAP management activities in the GRBR. The social-ecological inventory baseline assessment also helps to generate insights into local IAP management practices and also delineates the system boundary.

*5.4.1.2 Key informant interviews*

Key informant interviews formed the basis for problem structuring, and is a common practice used to articulate problem identification and definition. These provide detailed information about stakeholders' IAP management experiences (Castillo-Montoya, 2016). Thirty key informant interviews (Chapter 4) were conducted until data reached a theoretical saturation level (Saunders et al., 2018), using an interview guide (Annexure C). This part of the interview guide (Section C) focuses on extracting variables influencing the current IAP management and decision-making in the GRBR, namely: effectiveness, cost, practicality, impact, acceptability which are important issues that could arise as result of disapproval/resistance from stakeholders. The key informant interviews facilitated the following: personal contact during the interviews which resulted in a high response rate; use of open-ended questions to evoke responses that are meaningful, culturally salient to the key informant, detailed, and explanatory in nature (Roberts et al., 2014); and probing and follow-up questions during the interviews to give participants the opportunity to respond in their own words. The interview guide was approved by Nelson Mandela University Ethics Committee (H18-SCI-SRU-003, Appendix A).

*5.4.1.3 Stakeholder workshop*

A stakeholder workshop was arranged with stakeholders identified in the social-ecological inventory. The stakeholders were identified in the inventory and also those contacted in the previous chapter (key informants). Efforts were made to canvas 'beyond the usual suspects' to bring different perspectives and experiences, including those that might be marginalised in conventional IAP management and planning process (Fischer et al., 2014; Shackleton et al., 2019b). The stakeholder workshop was facilitated by a facilitation team from Nelson Mandela University (NMU), which included four post-graduate students, and assisted by the Southern Cape Landowner Initiative (SCLI). The facilitation team led the co-development of the critical issues or variables constituting the IAP management. SCLI is an 'alliance of the willing', a public platform for landowners and land managers concerned about alien invasive plants in the Southern Cape to come together and share their stories, learn from each other's successes and failures, to find opportunities to work together and to share resources where possible.

The team used a structured social learning method of engagement (Schusler et al., 2003), through facilitated dialogues to encourage participants to discuss issues around alien plants and also limit cognitive bias (Hanea et al., 2017). Social learning has been noted as a method that can help society tackle the complex, messy and 'wicked problems' (Lee, 1993; Folke et al., 2005; Dryzek, 2013). The social learning method encourages the sharing of knowledge, stimulates innovative thinking, and explores possibilities around real-life questions and issues (Dryzek, 2013). The method assists participants to conduct an in-depth evaluation of key challenges and opportunities. Social learning also helps people who are meeting for the first time to engage and encourages the deepening of mutual ownership of outcomes and relationships. The stakeholder workshop participants were encouraged to share their knowledge and experiences with others, to actively listen to each other with understanding and empathy, to question assumptions, connect ideas, and identify links and trends.

Using a guide (Appendix D), the stakeholder workshop focused on understanding IAP management and decision-making by: identifying key variables; delineating the system boundary; identifying relationships among identified variables; development of a preliminary CLD; identification of feedback loops; and identification of system archetypes. During the stakeholder workshop, participants were divided into smaller breakout groups, by assigning each stakeholder a random number and those with a similar number would form one group (Figure 5.2). In these breakout groups, participants were encouraged to consider the GRBR IAP management system in its entirety and to reflect around key complex challenges and concerns of IAP to land management, water security, biodiversity, and fire and flood risk in the region.

After the breakout sessions, participants reported back on their discussions to the whole group. Stakeholders collectively reflected on: how IAP impacts their lives and the work they do; how they can work together to reduce the risks associated with IAP; and to consider what short- and long-term actions need to be taken for the management of IAP. A total of 32 participants attended the stakeholder workshop.

**Figure 5.2** Stakeholder workshop participants engaging in social learning small dialogues at the stakeholder workshop (Photo: Dr Bianca Currie)

The issues or variables related to IAP management in the GRBR considered by stakeholders are reflected in Table 5.2. An initial list of 61 variables was mentioned by the participants which was reduced to a total of 44 variables through consensus building. Each variable was clearly defined to avoid any overlap between the variables. Consensus building among stakeholders is increasingly becoming a common approach used to reach feasible strategies to deal with uncertain and complex problems (Innes, 2004). The facilitation team played an important role in assuring that consensus, rather than majority rule was sought, and that every stakeholder was heard and respected. In addition, discussions were based on stakeholder interests and not simply on arguments about predetermined positions (Fisher & Ury, 1981).

### 5.4.2 Causal Loop Diagram (CLD) of IAP Management in GRBR

A CLD was developed collaboratively by the researcher and the workshop participants as well as expert consultations through three sequential steps. Initially, a preliminary CLD was based on the variables identified by the stakeholder workshop participants (Table 5.2) through consensus building and during the key informant interviews (Chapter 4). Thereafter, the initial CLD was reviewed and validated through consensus building consultations with experts knowledgeable in IAP management and familiar with the GRBR. The experts looked for clarity, causality, and additional cause among the variables, based on their personal experience and beliefs pertaining to the directions of the causal links (Alasad et al., 2013; Mavhura, 2019). It was through these consultations, the stakeholder workshop and the literature review that the feedback loops within the CLD were outlined and participants were asked to give input on variable names and suggest modifications to variable links and their polarities, from which the final CLD of IAP management in GRBR was obtained (Figure 5.3).

The stakeholder workshop participants mapped the relationships among the variables in terms of interlinkages and causality of those variables. This CLD was used to identify a group of feedback loops that fitted the structure of common system archetypes. Thereafter, an identified archetype was used to assess IAP management processes currently being implemented within the GRBR and to suggest windows of opportunities for improvement. The systems dynamics modelling platform, STELLA, was used to draw the IAP management CLD. The study group lacked information to formulate prior mathematical relationships between variables. Thus graphical function, which is a feature of STELLA, fits the mathematical relationships based on any existing information, and this was used (Hossain et al., 2020).

## 5.5 Results

There are eight feedback loops in the final CLD (Figure 5.3), including eight reinforcing loops (R1-R8) and four balancing loops (B1- B4) derived from the 44 variables identified and defined by stakeholder workshop participants (Table 5.2). This reveals the causal relationships amongst a set of variables influencing IAP management and decision-making processes.

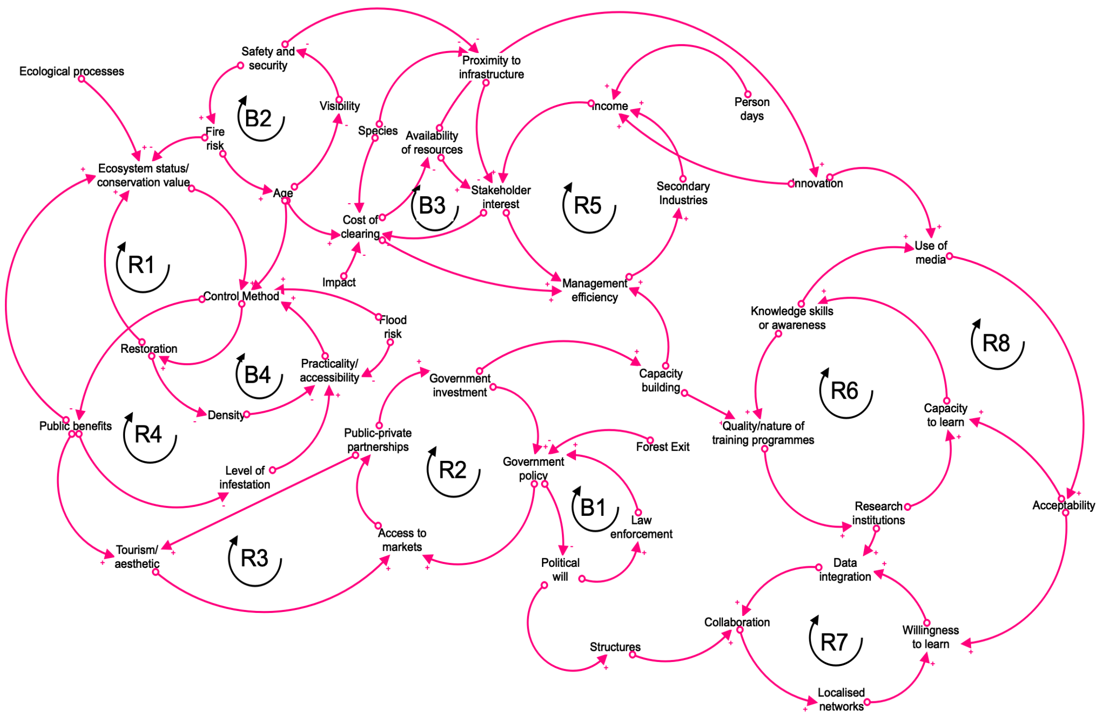


**Figure 5.3** A Causal loop diagram demonstrating the complexity of IAP management system based on stakeholder engagement in the Garden Route Biosphere Reserve (GRBR)

## 5.5.1 Reinforcing feedback loops

### *5.5.1.1 Control method loop (R1 and R4)*

Loops R1 and R4 describe the important role of control methods applied in determining the effectiveness of IAP management. Loop R1 links the variables of control method, restoration and ecosystem status/conservation value, while Loop R4 connects the variables of control method, public benefits, level of infestation and practicality/accessibility (Figure 5.4).

These reinforcing loops depict the importance of adopting a suitable control method in IAP management. According to the key informant interviewees, selecting the appropriate control method can ensure success in restoration and consequently restoration of the conservation value of a particular landscape. Furthermore, many stakeholders adopt control methods that are practical while effectively reducing the levels of infestation and at the same time accruing public benefits such as increased streamflow in the catchment. An example, is where the use of mechanical control methods can have a significant and immediate effect on reducing the level of infestation with potential long-term ecological consequences through increased soil erosion.

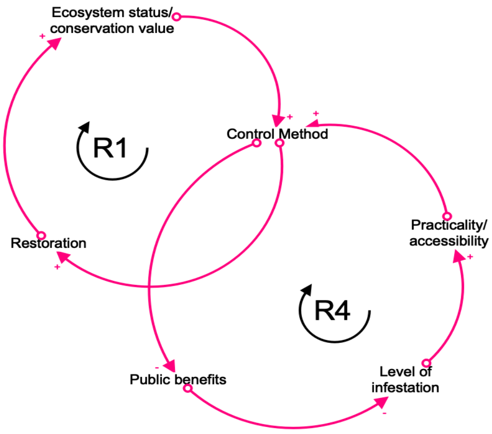


**Figure 5.4** Control methods loops

**Table 5.2** Variables constituting IAP management system in the GRBR identified through consensus building

| Cluster | Variable Name | Description |
|---|---|---|
| **Ecological** | 1. Density | The density of alien plants |
| | 2. Age | The age of alien plants |
| | 3. Species | Different types of invasive alien species |
| **Biodiversity** | 4. Ecosystem status/conservation value | Areas containing habitats that are conservation priorities; areas containing species of special concern |
| | 5. Ecological processes | Areas that are important for the continued functioning of important ecological process |
| | 6. Restoration | Assisting the recovery of an ecosystem that has been degraded/damaged |
| **Efficiency** | 7. Practicality/accessibility | The accessibility of areas for control |
| | 8. Visibility | Areas that are highly visible |
| | 9. Control method | Different types of control methods that can be applied |
| | 10. Level of infestation | The extent of coverage of IAP within a particular area |
| **Economic** | 11. Cost of clearing | Budget cuts; ineffective planning and budgeting |
| | 12. Income | Income generated through IAP management interventions |
| | 13. Access to markets | Availability of markets to sell IAP-related products such as firewood |
| | 14. Secondary industries | Availability of secondary industries for value addition |
| | 15. Management effectiveness | Achievement of goals; optimum allocation of management resources |
| | 16. Availability of resources | Access to the right resources |
| | 17. Person days | Number of people working per day times number of days worked |
| **Social** | 18. Safety and security | Proximity to human life |
| | 19. Proximity to infrastructure | Proximity to human settlement and infrastructure |
| | 20. Public benefits | Areas that can accrue benefits as a result of alien clearing |
| | 21. Tourism/aesthetic | Areas that are highly visible and where IAP can impact the scenic value |
| | 22. Flood risk | Areas that are prone or exposed to floods |
| | 23. Impact | Threats posed by IAP |
| | 24. Political will | Buy-in and support from political parties for particular interventions |

| | | |
|---|---|---|
| | 25. Capacity building | Capacity and skills to develop, implement, monitor and report on IAP management |
| | 26. Stakeholder interest | Buy-in and support for particular interventions from stakeholders |
| | 27. Willingness to learn | Desire and readiness to learn |
| | 28. Localised networks | Varying networks joining in managing |
| | 29. Fire risk | IAP Areas that are prone or exposed to fires |
| | 30. Acceptability | Considered being socially, ecologically and economically feasible |
| | 31. Capacity to learn | New skillset |
| | 32. Collaboration | Action of working together |
| **Government policy** | 33. Structures | Different functions or departments responsible for managing different parcels of land; mandates, |
| | 34. Forestry exit | Forestry companies handing back land to the authorities |
| | 35. Knowledge skills/ awareness | Awareness of IAP impacts, knowledge of the relevant legal requirements pertaining IAP |
| | 36. Use of media | Detailed and up-to-date data on distribution and impact of IAP, fire histories and other key environmental factors |
| | 37. Law enforcement | The enforcement of legislation |
| | 38. Data integration | Integration of existing plans and strategies |
| | 39. Research institutions | Varying expertise in influencing the managing IAP |
| | 40. Quality/nature of training programs | Budgets allocated to ‘higher priority’ issues e.g. service delivery |
| | 41. Public-private sector partnerships | Buy-in and support for particular interventions from both the private and private sector |
| | 42. Government investment | Access to resources and funding |
| | 43. Government policy | Political buy-in and support for particular interventions |
| | 44. Innovations | New ideas, methods and approaches |

*5.5.1.2 Public-private sector partnership loops (R2 and R3)*

The Loops R2 and R3 (Figure 5.5) revolve around an active partnership with citizen communities of practice and private sectors across the GRBR. The stakeholder workshop participants placed emphasis on the importance of identifying interventions with the potential to significantly strengthen the capacity of the pubic to manage the problem of IAP through public-private sector partnerships. The aim is to facilitate collective community-led partnerships with government investment and favourable policies to access markets. In addition, the stakeholder workshop participants agree on the importance of public-private sector partnerships in unlocking funding for IAP management. A close inspection of Figure 5.5 reveals that the current undesirable outcomes (poor stakeholder buy-in, poor collaboration) can be traced back to the lack of public-private sector partnerships in the GRBR leading to ineffective management of IAP. According to key informants (Chapter 5), a consequence of this is a heavy reliance on government investment and favourable government policies to fund IAP management operations. One key informant indicates that:

> *Heavy reliance on government funds has over the years been marred by slow procurement wheels, bureaucracy and corruption leading to budget cuts [Government ].*

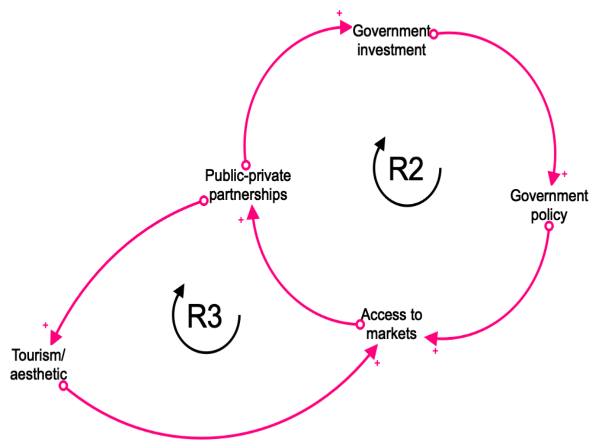


**Figure 5.5** Public-private sector partnership

*5.5.1.3 Management efficiency loop (R5)*

Secondary industries are directly related to income, which is directly and positively associated with stakeholder interest (Figure 5.6). There was a general consensus among workshop participants that the greater the potential income generated from IAP activities (for example, selling firewood, Eco-schools' furniture), the greater the interest from stakeholders becomes, which in turn, further increases the management efficiency of IAP. The major driver of stakeholder interest in IAP management is rooted in the income or incentives associated with clearing of IAP. For example, several small-medium businesses were mentioned that have established in the GRBR and are associated with IAP activities. Stakeholders proposed innovative ideas such as charcoal production, biochar production and techniques for achieving economies of scale in production in order boost IAP related secondary industries.

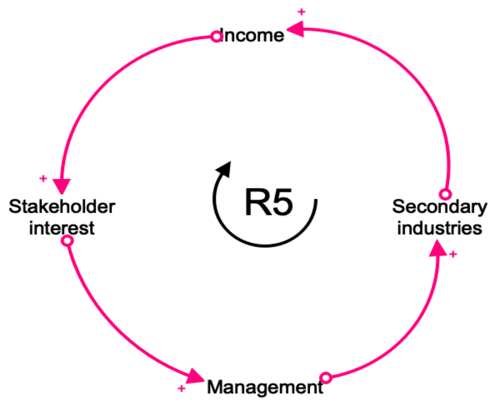


**Figure 5.6** Management efficiency

*5.5.1.4 Technical knowledge loop (R6)*

Loop R6 describes the important role of knowledge in improving IAP management. Loop R6 links the variables: research institutions; capacity to learn; knowledge skills or awareness; and quality/nature of training programmes (Figure 5.7). From a knowledge skills or awareness perspective, a high effectiveness in IAP management is determined by the quality and nature of training programmes, research institutions available and capacity to learn by the stakeholder groups (Chapter 4).

There was a consensus among the key informant interviewees and the stakeholder workshop participants that the ineffectiveness of IAP management approaches is one of the key factors frustrating most stakeholders involved in IAP management. According to key informants (Chapter 4), the decisions on managing IAP are often informal, in other words, decisions on managing IAP are primarily based on experience, ad hoc engagements with stakeholders, and/or short-term windows of opportunities or emergencies such as the Knysna Fires of 2018. The fires were regarded by the majority of the workshop participants as the "*worst*" on record in the Knysna region (burned approximately 15 000 hectares). However, the fires created business opportunities for small-scale alien clearing enterprises in the Knysna area.

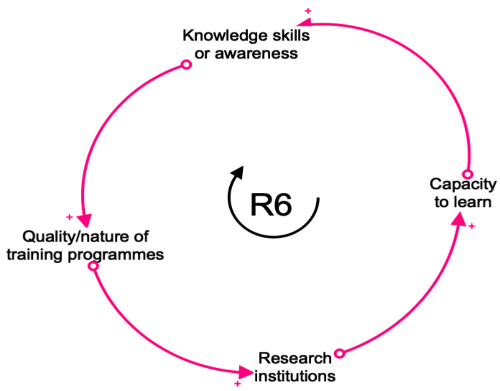


**Figure 5.7** Technical knowledge loop

With insufficient skillsets, especially for high altitude infested areas, there was a general consensus among workshop participants and experts that ineffectiveness of IAP management can be offset, in part, by improvements in technical knowledge generation and dissemination. For example, inaccurate IAP cover estimations is likely exacerbated by the lack of a clearly defined and technical method for determining cover or density. However, unwillingness by some stakeholders to learn can reduce uptake of new information and technologies that can improve IAP management effectiveness.

*5.5.1.5 Shared understanding loop (R7)*

Loop R7 describes the importance of creating a shared understanding, including data integration that affects collaboration in IAP management (Figure 5.8). Underpinning this loop was the acknowledgement that better relationships across and between institutions and between institutions and stakeholders, and a wider engagement to improve the willingness to learn, can only strengthen IAP management in the GRBR. Most stakeholder workshop participants and key informant interviewees have a shared understanding that most decisions on IAP are often cofounded, and in some cases disrupted by conflicting/diverging perspectives, goals or mental models. The conflicting perspectives, for example, are seen to often arise when ecosystem services and goods provided by IAP are weighed against their associated ecosystem disservices. For example, *Acacia dealbata* (Black wattle) is perceived differently among stakeholder groups (Chapter 4) depending on whether they occur within farms, near property or along water courses. One expert noted that: *“such conflicts typifies the extent to which IAP management should increasingly be viewed and managed as a ‘wicked problem’ in GRBR”*.

The Loop R7 also demonstrates how integrating data from all perspectives, reinforces the strength and/or effectiveness of collaboration that will cement localised networks and increase the willingness to learn leading to a shared understanding of IAP management. One key informant interviewee (researcher) emphasised that making these databases freely available, expanding coverage of IAP species and traits, and updating them regularly to include nascent invaders enhances their utility for improving management and decision-making.

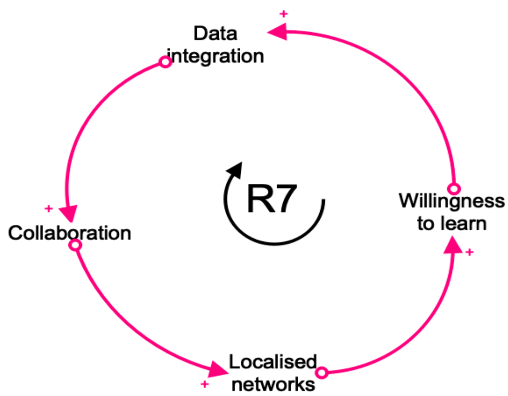


**Figure 5.8** Shared understanding loop

*5.5.1.6 Communication and information sharing loop (R8):*

Loop R8 highlights the role of knowledge skills through the use of media to improve the acceptability of IAP management interventions and the capacity to learn (Figure 5.9). Ineffectiveness of IAP management can be offset, in part, by improving communication and information sharing through greater efforts in education and awareness raising using various media. Information is the fuel for decisions that take place and is necessary for coordination.

The stakeholder workshop participants explained that management efforts may be disrupted, especially when applied in areas under multi-purpose management, due to asymmetric or misaligned management mandates. Hence, emphasis on the need to foster information sharing and communication initiates cohesion within the system.

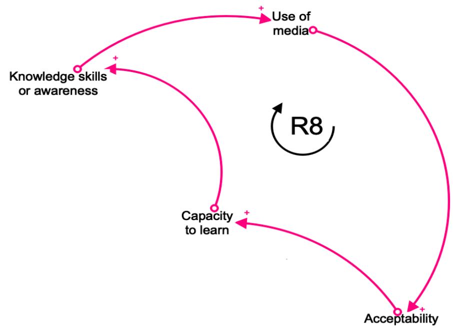


**Figure 5.9** Communication and information sharing loop

The goal of this loop is generating knowledge and skills that cross disciplinary boundaries, engaging multiple stakeholder groups, grappling with the unavoidable issues of values ethics and purpose, and leading to action and more acceptability. The stakeholder workshop participants agreed that such decisions need to be transparent and should consider opinions, perspectives and values of the wide range of stakeholders for them to be widely acceptable.

### 5.5.2 Balancing feedback loops

#### *5.5.2.1 Government policy loop (B1)*

The government policy loop (B1) is one of the four balancing loops in the GRBR invasive alien plant management system. This loop contains three variables: namely, government policy, political will, and law enforcement (Figure 5.10). Reshaping institutions through government policies that encourage political will and create an enabling environment for law enforcement can be a powerful strategy to improve IAP management decisions. Stakeholders propose that if government can support IAP management by putting in place stringent polices, such as, dealing with absentee land/property owners; or the issuing harsh penalties for not clearing properties if an adjacent neighbour has done so, will give them ‘hope and a chance of success in the fight against invasive plants’.

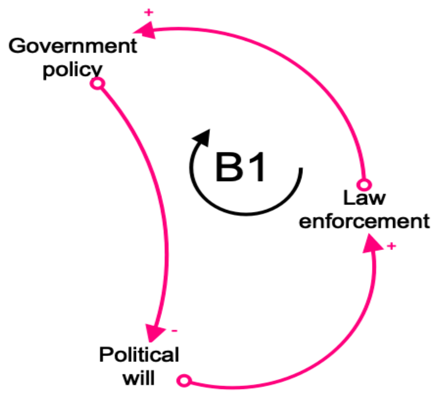


**Figure 5.10** Government policy loop

*5.5.2.2 Safety and security loop (B2)*

Loop B2 describes the influence of the safety and security variable in IAP management decision-making, countering the common notion of age of species in influencing management decisions (Figure 5.11). Key informant interviewees generally agree that managing IAP in GRBR often requires a deviation from the norm of prioritising less dense areas (cost-effective) to dense stands of IAP. This is because dense stands of IAP pose an immediate risk in the form of fire, and safety and security, and must be managed first. However, such considerations offer a short-term solution and draw management decisions away from areas of high conservation values, ultimately reducing the overall efficiency of management actions.

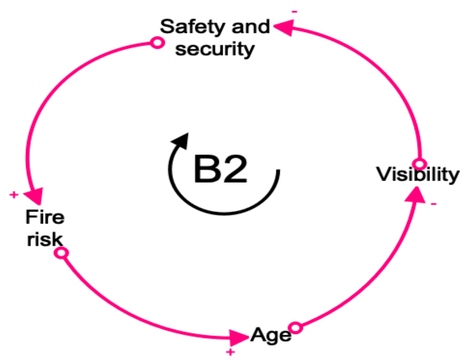


**Figure 5.11** Safety and security loop

*5.5.2.3 Availability of resources loop (B3)*

Loop B3 describes how the availability of resources influence stakeholder interest and the cost of clearing. The loop links three variables, namely: availability of resources, cost of clearing and stakeholder interest (Figure 5.12). As previously mentioned, stakeholder interest plays a crucial role in IAP management, however, the more the cost of clearing, the less the availability of resources, which leads to reduced stakeholder interest. Stakeholder workshop participants generally agree that by recognising when this disjunction exists, stakeholders may be able to devise solutions to IAP that are more effective, more sustainable and less liable to unintended consequences, whether it be push-back from negatively affected stakeholders or undesirable ecological interactions. Stakeholders ascertain that stakeholder interest plays an important role in facilitating system efficiency. For example, stakeholder groups operating in the Kouga river catchments mention that it would take considerably longer, and cost substantially more, to effectively manage IAP. This would be the case if they are to rely on the current available resources, current costs of clearing, and current stakeholder interest with no additional spread of IAP.

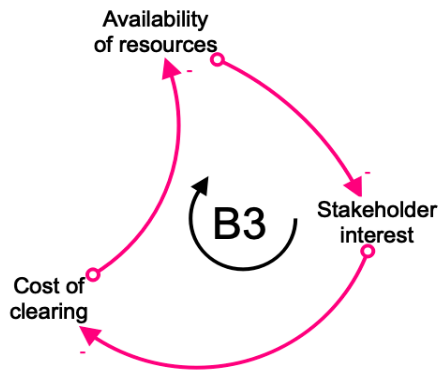


**Figure 5.12** Availability of resources loop

*5.5.2.4 Practical or accessibility loop (B4)*

This loop connects the four variables of control method, restoration, density and practicality/accessibility (Figure 5.13). Although the type of control method adopted influences the restoration measures adopted, the total density of IAP is likely to decrease irrespective of the method used and consequently the areas infested become more accessible. Furthermore, an increase in accessibility influences the choice of control method adopted. This is a delicate balancing act; the wrong choice of control method and treatments not being applied to standard will substantially reduce the effectiveness of restoration efforts.

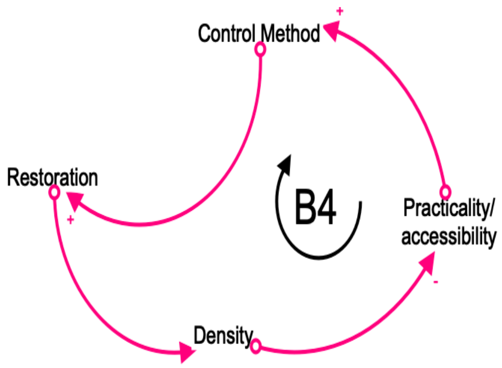


**Figure 5.13** Practical or accessibility loop

### 5.5.3 System archetype

The archetype observed in the CLD of the GRBR invasive alien species management system is policy resistance. This is described as the tendency for interventions to be defeated by the system's response to the intervention itself. It arises from a mismatch between the characteristics of a complex system and the shallow leverage points used to make decisions. For example, the provision of income through Working for Water's person days improves stakeholder interest in the short-term (Loop R5). Conversely, as a consequence of the initial success, the need for income builds while with budget cuts (Chapter 4) the management effectiveness is severely reduced. As noted by stakeholders, many of the projects aimed at reducing the extent of invasive populations are secured on the basis that these control projects could generate local employment opportunities. These projects have now been affected by government budget cuts, for example in the Krom and Kouga catchments of the Eastern Cape.

Establishing partial policies and solutions over time that address short-term problems of affected stakeholders, has given rise to new problems, which cycle has led to a situation that meets every criterion of policy resistance. For example, researchers during the key informant interviews (Chapter 4) indicated that there is evidence for widespread ineffectiveness in the treatment of IAP in the field, with most of the work done by contractors being sub-standard.

The policy addition of job creation to the stated goals of management also reveals another system archetype, namely: the fixes that fail archetype in the IAP management system in GRBR. There was a general consensus among workshop participants that this policy imperative led to a loss of focus on the control of IAP, consequently making control interventions ineffective, and further fuelling on-going, intractable conflict. Other unintended consequences include regular overestimation of cover estimates prior to the awarding of contracts and wrong choices of treatment methods. The ‘fixes that fail’ characterises quick-fix (short-sighted) solutions, stemming from linear thinking, which concentrates on treating the symptoms rather than the root causes of the problem. Another example seen in the CLD is the management of the spread of IAP through fire prevention and suppression (Loop B2). While this works in the short-term as the fuel loads builds, there is an increase in the incidence and severity of the fires. Much reference was given to the 2018 Knysna fires.

### 5.6 Discussion

Various studies have emphasised the need for comprehensive stakeholder engagement for effective invasive alien species management (Crowley et al., 2017; Novoa et al., 2018; Shackleton et al., 2019b). Although not using all the steps in systems dynamics modelling, this thesis builds and applies systems thinking to develop a CLD, which is a powerful tool for dealing with complex problems that has the ability to uncover feedback structures and leverage points in a system (Agnew et al., 2018). Specifically, the CLD highlights the feedback mechanisms within the system and that all its parts are interconnected to each other directly or indirectly (Gray et al., 2018). The various interconnected factors including the ecology, government policies, costs, and social and cultural are revealed. In addition, the CLD helps to capture the main driving forces that determine the current and future trends of IAP management. The CLD therefore serves as a platform for dialogue, communication, collaboration, and decision analysis among relevant stakeholders involved in IAP management. Having such information can enable the development of interventions to engage and inform stakeholders (Shackleton et al., 2019b). For instance, this can be used to reach consensus among opposing groups and develop management practices that are acceptable to all stakeholders (Novoa et al., 2018; Shackleton et al., 2019b).

The results of this study show the dominance of reinforcing loops in the IAP management system, which indicate that there are several sources of growth, erosion, and failure which stakeholders need to address and minimise. Many of the interventions in IAP management have failed to realise and address these reinforcing loops, thus causing ineffectiveness that is exhibited by considerable increase in the extent of invasions (van Wilgen et al., 2012). To address this, several guidelines for the planning and prioritisation of control operations have been developed, but to date there has been a failure to implement these plans (Kraaij et al., 2017). The guidelines designed to improve management have primarily focused on addressing separate parts of the system while neglecting the interconnectedness of the system's components. An example is focusing only on treatment of IAP in the Krom and Kouga catchments of the Eastern Cape (McConnachie et al., 2012), while disregarding other variables like ignorance, inappropriate equipment, inadequate skills and training (Kraaij et al., 2017). This thesis, using systems thinking, expands the awareness of possible interventions and variables by building an understanding of the many interconnections between variables influencing IAP management.

While causal loop modelling has been widely applied in, for example, health systems (Lembani et al., 2018; Rees et al., 2018), the GRBR presents a useful system to explore the unique complexities of IAP management. An approach, such as the one presented in this thesis, can be tailored to address different IAP management feedbacks, interconnections, design better policies, and facilitate stakeholder learning around the world. However, developing qualitative models, in the case of this thesis's CLD, may not be more than enough to provide a complete analysis of the problem (Mirchi et al., 2012). Critics of qualitative modelling argue that numerical simulations nearly always add value, even under inherent uncertainties about data and qualitative information utilised (Dhawan et al., 2011). For example, Jafari et al. (2018), developed an integer programming model that incorporates uncertainty in the available budget and the invasive spread rate as discrete scenarios to determine a robust, cost-effective management plan. Although extensive computer simulations such as those of Jafari et al. (2018), should only be followed after a clear picture of the system has been established through reasonably simplified conceptual models (Mirchi et al., 2012), as was done for this thesis in the development of a CLD of IAP management in the GRBR.

In summary, as demonstrated by the results, many of the variables affecting IAP management in the GRBR system are intrinsically interlinked, similar to Banson et al. (2015); Van Mai & To (2015); and Banson et al. (2019). By visually representing IAP management and decision-making from a causal perspective (Figure 5.3) one can become more aware of the structural forces that produce system behaviour (Mirchi et al., 2012). For example, as highlighted in Chapters 1, 2 and 4, it is important to acknowledge local knowledge and the nuances of stakeholders. Results show that stakeholders have different understandings of the system, and exploring it together using a systems thinking approach can provide insights into these perspectives, such as weaknesses of the current decision-making process (Chapter 4). Acknowledging local differences as part of the process of identifying places in the system to leverage change, can help create shared commitment to the plans (Loop R7). Furthermore, results emphasise the essential role of engaging the stakeholders in identifying interconnected stakeholder issues via the lived experiences of stakeholder groups (Eversole, 2012). However, from experience, this takes time, and stakeholder understanding continues to evolve and emerge over time.

Similar to other studies, such as those by Gaertner et al. (2016) and Potgieter et al. (2018), this thesis's results show that IAP management seldom gives full consideration of the whole system with most decisions being based on experience and short-term opportunities or emergencies. This approach to decision-making potentially wastes limited resources and fails to address the threats associated with IAP (Gaertner et al., 2016). However, the whole system can be challenging with the wide range of stakeholders often having diverse interests and knowledge (Chapter 4), resolving conflicts and seeking a common ground (Leenhardt et al., 2017). The study found that similar challenges such as disagreements were experienced in the stakeholder workshops. However, through breaking out into small groups and giving a group presentation at the end of the group session, the finalisation of the CLD based on the interactive discussion and feedback in the GRBR helped to resolve conflicts and seek a common ground in the workshop.

Similarly, it is acknowledged that new forms of collaboration through localised networks are required to foster effective relationships, strategies, and roles in an IAP management system in the GRBR. Public-private sector partnerships in the management of IAP were identified as having a crucial role as facilitating institutions, potentially ensuring reliable advice and information for government agencies, and leading and facilitating local on-the-ground action. This is similar to the strategies of Martin et al. (2019) where the activities, engagement strategies, scale and scope that were proposed for different partnerships, varied widely. This supports the view that a one-size-fits all approach is not a reliable leverage to widely differing local conditions and perceptions.

The CLD also serves as a platform for identifying system archetypes that contain underlying key leverage points in the system. These can potentially assist stakeholders in addressing the root causes of inefficiencies in IAP management rather than focusing on the symptoms, detecting current problematic trends and anticipating future problems (Mirchi et al., 2012). Consequently, system archetype enables decision-makers to devise appropriate intervention strategies that can improve the management and decision-making process of IAP in GRBR (Van Mai & To, 2015). The policy resistance archetype identified in this case study shows that the current decision-making processes are narrow, short-sighted and risk long-term failure. For example, the practice of issuing short-term IAP clearing does not allow for capacity building, and when funding is cut or channelled elsewhere (Chapter 4) stakeholders are left without embedded capacity and experience to manage invasions (Kraaij et al., 2018). Such policy resistance arises because systems are constantly changing; they are governed by feedbacks, self-organising, adaptive, and non-linear (Sterman, 2011).

Finally, 'fixes that fail archetype' were also identified revealing that the current IAP management and decision-making are short-sighted. One of the main challenges related to unintended consequences of the current IAP management is a mismatch between the characteristics of wicked problems and the simplistic mental models which inform the decisions (Chapter 4). The consequences of management actions spill out across space and time, yet decisions tend to focus on the local and short term and risk long-term failure. For example, the current approach that uses poverty-relief funds for IAP control is politically attractive. But, in the long-term, the 'poverty-relief' model over-estimates requirements (for example, person-days) and demands to allow employment to be maximised (Kraaij et al., 2018), at the expense of effective ecological goals (van Wilgen & Wannenburgh, 2016).

## 5.7 Conclusions

Humans live in an interconnected world where social, economic, and environmental challenges intersect to produce complex challenges. Systems thinking approaches offer a potential avenue to deal with these complex issues and help to catalyse effective decisions. While traditional linear thinking is valuable, it may lead to policy resistance and quick-fix solutions that fail to address the underlying drivers of IAP management problems. For example, the inefficiencies in IAP management and decision-making in the GRBR continue to prevail despite interventions aimed at reducing them. This shows a lack of comprehensive understanding of the complexity of IAP management. Our case study has shown that IAP management system comprises numerous interdependent component elements that are interwoven into a complex system and that changes in one part affect other parts, ultimately impacting the whole system.

The thesis makes the case that the application of a systems thinking approach potentially helps to provide a comprehensive understanding of the complexity of IAP management systems through the development of a CLD that visualises the underlying system structural elements and explains the dominant feedback loops currently influencing IAP management in the GRBR. Also, sub-dominant feedback loops that are most likely to influence IAP management in the future are visualised. The process of systems mapping provides a framework in which stakeholders can share experiences and understand systemic interventions and their dependency relationships. Such a framework creates a co-learning environment that facilitates collaboration and communication among land managers, researchers, government departments, non-governmental organisations, and the general public, and identifies diverse interventions that affect planning, implementation, and monitoring of IAP management objectives

Overall, the methodological approach used in this thesis can be adapted and applied to address complex challenges facing the management of biological invasions, not only in the GRBR, but also in other provinces of South Africa, subject to verification. The CLD is a first, systemic step which benefits research, management and decision-making through enabling a more system understanding of what influences IAP management and how this might influence future management. It is clear, that there is need to focus on deep leverage points to guide decision and policy makers to solutions in this challenging complex world.

# CHAPTER SIX

## Towards achieving a better understanding of invasive alien plant management and decision-making process

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*"Remember, always, that everything you know, and everything everyone knows, is only a model. Get your model out there where it can be viewed. Invite others to challenge your assumptions and add their own."*

-Donella H. Meadows

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**Overview**

This chapter positions the research findings of this thesis in the broader invasive alien plant (IAP) management context and considers transformative policy implications for IAP management and decision-making. Here, the research question is reintroduced, the research design and methodology used to answer the research question, is reflect ed on and the research findings in relation to the research problem are discussed. The chapter further offers policy recommendations to improve the effectiveness of IAP management and decision-making.

## 6.1 Introduction

The increasing number, widening distribution and increasing density of invasive species and their socio-economic and environmental impacts (Seebens et al., 2017) in the Garden Route Biosphere Reserve (GRBR), coupled with inadequate resources to manage the threat, stresses the importance of improving the efficiency of management actions and decision-making processes (McGeoch et al., 2016). Considerable effort has gone towards the management and regulation of invasive species in South Africa (Richardson et al., 2011). Globally, South Africa is one of the leading countries in terms of research on biological invasions, contributing over half of the research on the topic in Africa (Pyšek et al., 2008; van Wilgen et al., 2020). Despite substantial achievements in managing biological invasions, the sheer number of species and the wide range of possible management interventions means that decision-making is complex (Woodford et al., 2016). Decisions about invasive alien species (IAS) management typically involves uncertain outcomes, multiple and conflicting objectives, and many interested stakeholder groups with diverse views (Maguire, 2004). This complicates decision making.

This research, using a mixed method approach, set out to contribute to the growing body of knowledge on biological invasions by analysing and providing an improved understanding of the decision-making process on invasive alien plant (IAP) management. Overall, this thesis explored stakeholder perspectives, interactions between invasive alien plants (IAP) management and decision-making processes variables in the GRBR within the lens of systems thinking. Accordingly, the overarching research question of this thesis seeks to address: How do we make effective decisions about IAP management and how do IAP management and decision-making interact? In order to answer this research question, the study considered three specific research objectives (Table 6.2). Although the three empirical chapters (Chapter 3, 4 and 5) presented in this thesis more or less correspond to each of the three objectives, respectively, the third objective is achieved by drawing from all the previous three empirical chapters.

**Table 6.2** Research objectives in relation to the thesis chapters

| Research objectives | Chapter | | |
|---|---|---|---|
| | III | IV | V |
| 1. To review the available and/or existing decision support tools for IAS management and assess whether they apply the principles of robust decision-making. | ■ | | |
| 2. To examine the perspectives on current IAP decision-making process for woody IAP management in the GRBR. | | ■ | |
| 3. To examine the feedbacks and interactions in IAP management and decision-making process in the GRBR. | ■ | ■ | ■ |

This thesis provides, for the first time, the application of principles of robust decision making (Chapter 3 and 4) and systems thinking (Chapter 5) to examine the complexity of IAP management, using the GRBR as a living laboratory. The outcomes demonstrate an increased understanding of IAP management and decision-making in the study area and in general. This increased understanding can serve as a useful platform for engagement, communication and collaboration, and decision-making among stakeholders working to improve IAP management and decision-making using the GRBR as a case study.

## 6.2 Methodology significance, reflections and limitations

The study used both qualitative and quantitative data, collected using social-ecological inventories, key informant interviews, a stakeholder workshop and expert consultations. The following sections provide a reflective account of the methodology used in this thesis and gives insights, reflections and lessons learnt for future researchers who embark on a similar pathway.

### 6.2.1 Justification of the case study approach

A case study approach was taken in this research, with GRBR being selected for data collection. Case study research approaches are typically employed to explore real life events over which the researcher has little control, and where the boundaries between context and the events are not readily evident (Yin, 2011). Multiple sources of evidence were used to explore IAP management and decision-making, but in such a way that the holistic and meaningful attributes are preserved and can be easily understood by the researcher (Stake, 1995). This case study approach was appropriate as one of the objectives was to examine the perspectives of stakeholders in the current IAP decision-making process, and this required a rich understanding of the related context. By using this approach, a detailed understanding of the selected– GRBR, was provided in this thesis, both for its own sake and in order to add to broader theoretical understanding and generation of theories about the underlying issue (Newing, 2010), that is, IAP management and decision-making. The case study approach allowed engagement with diverse stakeholder groups (Chapter 4 and 5) in a meaningful way with this thesis contributing to bridging the gap between science and society (Chapter 2). However, it was explained (when getting consent to participate) that the research was only for academic purposes and that there will be no further engagement after the completion of the degree.

Through the application of the case study approach, the thesis created an enabling space to "establish generalisations that hold in diverse situations" (Stake, 1995: page 39), for example, identifying system archetypes for IAP management systems (Chapter 5). This provided insights into challenges or theory beyond the immediate research context, which can be extended to other cases of collective interest (Yin, 2011). Furthermore, the case study also provided an opportunity to develop and assess theoretical principles (principle of robust decision-making) that later can be developed to construct generalisations about a wider population to which the case study belongs (de Vaus, 1996). This thesis provides the basis for improving IAP management in similar situations (Stake, 1995). Of particular interest is the development of a Causal Loop Diagram (CLD) that visualises the underlying system's structural components and explains the dominant feedback loops currently influencing IAP management decisions in GRBR.

#### *6.2.1.1 Selecting a particular 'case' to study*

Case study research in conservation has often originated from a request for advice from managers of a particular site, and thus a pre-selected case is specified (Newing, 2010). If a specified case study is not, however, provided then it is recommended that theoretical and practical concerns be taken into account when choosing. For choosing the case study for this thesis the following was considered: Firstly, and on the scientific side, IAP are regarded as the single biggest threat to biodiversity, water scarcity, fire risks, negative impacts of climate change as well as a loss of agricultural productivity and tourism opportunities in the Garden Route district (Cousins et al., 2018; Kraaij et al., 2018). Secondly, and on the practical side, IAP management in the GRBR is particularly challenging due to a lack of effective management frameworks and paradigms for dealing with IAPs (van Wilgen et al., 2016; Kraaij et al., 2017). In addition, the availability of existing contacts through the Sustainability Research Unit's database made it practically easy to reach out to interviewees, experts and stakeholder workshop participants.

### 6.2.2 Sampling techniques

Non-probability sampling strategies (Chapter 4) were applied in this thesis, that is, purposive and chain referral strategies for selection of key informant interviewees as well as selection of stakeholder workshop participants (Chapter 5). The study specifically employed these two strategies since they aimed to target individuals who are most relevant to IAP management rather than the whole population (Newing, 2010). Purposive sampling implies that participants or subjects are selected based on defining characteristics that make them the holders of the data needed for the study or they possess experience on the central phenomenon (Creswell & Clark, 2007). It is important to note that purposive sampling decisions are not only restricted to the selection of participants, but also entail the incidents, settings, events and activities included for data collection (Maree, 2007). Purposive sampling allowed for the gathering of a significant amount of data in a limited time and cost by focusing on knowledgeable and interested stakeholders (Chalmers & Fabricius, 2007).

Chain referral was also used for purposive sampling, especially in cases where the targets were difficult to find. The key principle in determining the sample size for this thesis was the principle of saturation (explained in the following sections). In addition, the sampling decisions were made for the explicit purpose of obtaining the richest possible source of information to address the research questions.

### 6.2.3 Mixed methods approach

Research studies that use a social-ecological systems lens often encounter methodological and analytic challenges that are difficult to solve using familiar scientific procedures (Schroter et al., 2009). Drawing on this perspective, using only one data source would be inadequate and would provide an incomplete understanding of the research problem, especially when there is a need to generalise exploratory findings (Creswell & Clark 2007). Subsequently, this thesis uses a combination of methods and approaches to gain an in-depth understanding of the multitude of factors interacting across the complex social-ecological system in the GRBR (O'Brien, 2012), an approach known as mixed methods. Mixed methods approaches are becoming increasingly important given the complexity of global change and the limited knowledge culminating in uncertainty (Creswell & Clark, 2007).

Mixed methods research is "[…] an approach to knowledge (theory and practice) that attempts to consider multiple viewpoints, perspectives, positions, and standpoints […]" (Johnson et al., 2007: page 114). The expectation was that this thesis would draw on two main mixed methods concise purposes: firstly, to enhance the validity of methods and findings, and secondly, to gain a fuller illustration or better understanding of the phenomena under investigation through relating complementary findings (Williams, 2011). According to Creswell (2013), the origins of mixed methods are nested within the social and behavioural sciences which found strengths in both quantitative and qualitative viewpoints.

A combination of qualitative and quantitative methods was applied in this thesis and provided an invaluable space to integrate, triangulate and complement research findings that captures the full range of experiences and knowledge in IAP management. Quantitative approaches provide statistical rigor through the use of descriptive and inferential statistics, and a basis for prediction and control (Neuman, 1997; Newing, 2010). Conversely, qualitative approaches are rich in detail, move away from the search of generality and consistency of the scientific method, provide critical analysis and construct a narrative account (Newing, 2010). Qualitative research approaches emphasise the validity of multiple meanings, holistic analysis and recognised the importance of subjective, experiential perception of the world (Stake, 1995). This is fundamental in understanding complexity of IAP management and decision-making processes. The research was based on the central assumption that a mixed methods approach results in a more comprehensive understanding of the research problem than either approach alone (Creswell & Clark, 2007). Mixed methods approach was applied in the form of a social-ecological inventory, secondary sources of information. In addition, stakeholder workshops, key informant interviews and expert consultations with groups comprising the widest possible cross-section of participants as well as wide institutional representation were conducted (Roura-Pascual et al., 2009).

## 6.3 Summary of key findings

While the number and impact of IAP in South Africa is increasing (Chapter 1, Chapter 4 and Chapter 5), their management often is expensive, limiting the areas that can be prioritised within the limited resources (Chapter 1-5; Kumschick et al., 2015; McGeoch et al., 2016). It is important to examine the complexity of IAP management decision-making to ensure cost-effective resource allocation and reduce ineffective expense (Cassey et al., 2018; Courtois et al., 2018). As indicated in Aichi Biodiversity Target 9, prioritisation is a critical path for parties to make progress in the management of the invasive species and their negative impacts on biodiversity. However, the sheer size of invaded areas, the number of species involved, and the wide range of possible management interventions coupled with diverse stakeholder base means that identifying priorities is complex (Woodford et al., 2016). Support is therefore required to guide decision-making processes and the subsequent allocation of resources (McGeoch et al., 2016).

The three research chapters (Chapter 3-5) each yielded a number of insights in terms of the research question and objectives outlined in Chapter 1. This section summarises these findings, before reflecting on the overall insights across the study.

Chapter 3 provides a global overview of the state of knowledge on the availability and use of decision support tools for managing invasive alien species. Although studies in scientific literature have increased over the past decade (as shown by the publication trends in Chapter 3) showing the need to improve management of IAS, more effort is required to develop integrated tools that apply the principles of robust decision-making. Immediate results from the lack of such tools include potential imbalances in selection of management actions, lower applicability of decision tools and principles of robust decision-making. Also, despite the increasing trends in articles reporting decision tools in IAS management, the practical use of existing decision tools has often been limited: they typically ignore economic, social, and political factors as well as the principles of robust decision-making. To this end, there is need for more attention to these factors when developing decision tools for IAS management. There has been much focus on the use of risk and impact assessment (for example, Essl et al., 2011; Roy et al, 2014; Hawkins et al., 2015; Bacher et al., 2017); however, practical methods that relate specifically to management actions are largely lacking (Hulme, 2009; Heikkilä, 2011; Van derhoeven et al., 2017).

Chapter 4 examined stakeholder perspectives of the current decision-making process of IAP management in the GRBR. In particular, the perspectives on the current decision-making process for woody IAP management was characterised and the compliance of the process with the principles of robust decision-making as outlined in Table 4.1 was evaluated. The main highlights were that stakeholder groups involved in IAP management are confronted with several IAP management challenges which often weaken their decision-making process. The strengths and weaknesses in the current decision-making process for IAP management are an interaction between ecological, economic and social factors. The results showed that availability of a plethora of management plans, science-based decisions, the creation of jobs, flexible process, and coordination were frequently identified as strengths. Much more diversity was shown in the identification of weaknesses (12 factors identified) including: lack of structure and consistency, lack of stakeholder buy-in, social and political pressure, bureaucracy and lack of capacity and knowledge.

The management and decision-making of IAP is a 'wicked problem' and is difficult to define with different stakeholder groups (private landowner, government departments, non-governmental organisations, private sector and researchers) perceiving versions of the problem based on their differing values and ideologies. Stakeholders need to still make decisions within a landscape that is inherently complex. Relatively few respondents among the five stakeholder groups referred to how the inclusion of *documentable*, *transparent*, *participatory* and *structured/consistent* decision principles are part of their current decision-making process. This chapter provides two key insights highlighting that most stakeholders would welcome a DST into the decision-making process for two reasons. Firstly, to address various woody IAP management weaknesses in an integrated way; and secondly to assist stakeholders to make the decision-making process adhere closely to principles of robust decision-making thereby making the process appropriate for managing 'wicked problems'.

Chapter 5 brought together all the findings from the previous chapter and applied systems thinking to understand the emergent properties that arise from the interactions between different components of a particular problem (Newell, 2012), as in IAP management. The value of system-oriented approaches is evident in this chapter, especially with its emphasis on the interrelationships between components rather than the components themselves. It helped to better understand the big picture of IAP management and decision-making through identifying the multi-faceted consequences of stakeholder decision-making processes. This provided valuable insights on how to better weigh options and design the most effective strategies to manage the impacts of unintended IAP management consequences. However, with a few notable exceptions (Hill et al., 2015), one of the most important facets of systems thinking that has largely been ignored is: Which system archetypes contain leverage areas that would enable interventions to change the overall behaviour of the system? By answering this question, it was possible to identify the core system structures that can explain general IAP management system behaviour.

In collaboration with stakeholders, a re-orientation of IAP management around the systems thinking notion of deep leverage points or mental models was proposed (Chapter 5). The study, for the first time, applied a systems thinking approach to help understand comprehensively the interrelationships between factors in IAP management system through the development of a CLD (Figure 5.3). This focussed on addressing the systemic aspects, that is, identifying dominant feedback loops currently influencing IAP management and decision-making, as well as sub-dominant or latent feedback loops that are likely to influence decisions in the future. I found that the systems thinking approach is advantageous when compared with the reductionist/linear approaches adopted in many natural resource management studies. For instance, it highlighted the multi-faceted consequences of decision-making and it allowed stakeholder groups to understand that the actions of individuals and their resulting consequences are deeply entwined within the social, economic, environmental and political systems. The comparative advantages of systems thinking as a powerful tool in dealing with complex problems are summarised in Table 6.2:

**Table 6.2** Comparative advantages of systems thinking vs. linear thinking (Source: Ollhoff & Walcheski, 2002)

| LINEAR VS. SYSTEMS THINKING | |
|---|---|
| **Linear Thinkers** | **Systems Thinkers** |
| Break things into component pieces | Are concerned with the whole |
| Are concerned with content | Are concerned with process |
| Try to fix symptoms | Are concerned with the underlying dynamics |
| Are concerned with assigning blame | Try to identify patterns |
| Try to control chaos to create order | Try to find patterns amid the chaos |
| Care only about the content of communication | Care about content but are more attentive to interactions and patterns of communication |
| Believe organizations are predictable and orderly | Believe organizations are unpredictable in a chaotic environment |

This chapter further demonstrates that failure to account for the interrelationships and interconnections can result in unintended consequences of policy decisions identified in Chapter 5. For example, policy addition that emphasises job creation to stated goals of IAP management is noted by stakeholder groups to result in regular overestimation of costs prior to awarding of contracts and wrong choices of treatment methods to create more jobs. Consequently, the CLD presented in Chapter 5 could serve as useful platform for engagement, communication and collaboration, and decision-making among stakeholders working to improve IAP management and decision-making in the GRBR.

Most importantly, results show the need to trigger transformational change in woody IAP management has relevance to decisions made at local scales. Through the CLD, the emergence of champions in the system would be valuable in triggering transformation in the decision-making process. These champions are dedicated individuals in various leadership positions who assume the initiative to lead in the coordination of IAP management activities. This has an impact on the national (in South Africa) and local scale (GRBR) and the champions are useful in identifying where in a system one should intervene to change its overall behaviour.

The use of the analogy of an iceberg to illustrate the conceptual model, the Four Levels of Thinking (Maani & Cavana, 2007; Chapter 2, section 2.2.2), as a framework for systemic interventions demonstrates that stakeholders need to focus on the deeper (fourth) level of thinking. These are mental models of individuals and organisations that influence why things work the way they do. While the fourth level of thinking is important, the results of this thesis show that most decisions and interventions in IAP management are currently taking place at the events or symptoms (issues that are easily identifiable)– tip of the iceberg above waterline. The quick fixes currently taking place appear to be the easiest way out, although they do not provide long-term solutions. For example, the current approach that uses poverty-relief funds for IAP control is politically attractive, however in the long-term, the model overestimates requirements and demands that employment must be maximised. This highlights the importance of employing the fourth level of thinking to avoid quick fixes that fail.

## 6.4 Implications and recommendations for conservation, management, and policies

### 6.4.1 Decision-making under uncertainty

Dealing with uncertainty is a recurrent theme in this thesis and many other studies relating to invasive alien species (IAS) as uncertainty occurs across the invasion process (McGeoch et al., 2016; Essl et al., 2017). As shown in this thesis, it arises for various reasons, including: lack of information; asymmetric knowledge about the problem; conflicting evidence; context-specific; and imprecise definitions and guidance (Van derhoeven et al., 2017) and can be reducible (for example, engaging stakeholders, consensus building and gathering more information (Chapter 4 and 5) or irreducible (for example, natural variation that results in a probabilistic outcome (Leung et al., 2012). It is evident in this thesis that even where uncertainty is reducible, the sheer size of invaded areas makes it unlikely that sufficient engagement with stakeholders and gathering of evidence could be possible to provide high confidence in the decision-making process (Chapter 4; McGeoch et al., 2016). However, IAP management decisions must still be made despite uncertainty and complexity (Sutherland & Burgman, 2015). A key aim of this thesis is therefore to apply the principles of robust decision-making and develop a Causal Loop Diagram (CLD) that could be used to improve management and decision-making even where data are lacking or insufficient (Chapter 5).

A CLD visualises the underpinning system structural components of IAP decision-making process, highlighting the multi-faceted consequences of decision-making process. By identifying the interconnectivity between social, political, economic, and environmental contexts of IAP management, CLD is a powerful tool for dealing with complex problems which have the ability to uncover the underlying feedback structures and leverage points in a system. This helps decision-making under uncertain conditions. However, it is important to note that the CLD is not intended to provide a full panacea for decision-making under uncertain conditions but rather to provide an example of how visualising the complexity of a system can help us to identify leverage points and the key important trade-offs that exist in the system. Future research should aim to develop a CLD that is able to quantify this system, through for example, computer modelling. Such a model assists stakeholders in enacting effective IAP management strategies that take into account uncertainty by revealing the complexity, dynamic behaviour and trade-offs between different management objectives.

### 6.4.2 Using stakeholder judgement to overcome data limitations and guide research

Stakeholder judgement through workshops and key informant interviews, coupled with consensus building, was used throughout this thesis to help overcome the limitations of insufficient data (Chapter 4 and 5). Beside the practical reasons for stakeholder engagement in the decision-making process, this thesis also highlights the moral reasons to justify this process. From a practical perspective, stakeholder engagement provides a means of eliciting the issues or variables constituting the IAP management system in GRBR; which would not be practically achieved using conventional methods. There are also benefits in the knowledge exchange created by bringing together a large and diverse group of stakeholders that work in different areas and do not engage with each other on a regular basis similar to Roy et al. (2014), during stakeholder workshop (Chapter 5). From a moral perspective, the process of engaging stakeholders also helps to build trust, which is critical for gaining an all-inclusive understanding of the problem and its possible solutions (Kueffer, 2010).

Stakeholder and expert knowledge are useful in supporting decision-making in conservation biology in general (Martin et al., 2012) and frequently used in IAS management (Baker et al., 2008; Essl et al., 2011; Van derhoeven et al., 2017).

However, these sources of knowledge are prone to various cognitive biases (Morgan, 2014) and can also be less accurate in comparison to empirical evidence (Dorlet et al., 2015). Thus, it is important to reduce cognitive biases by using structured techniques (Sutherland & Burgman, 2015). This thesis follows the social learning method for Stakeholder Workshops, where participants are encouraged to share their knowledge and experiences with others (Chapter 5). Stakeholders are prompted to collectively reflect on how IAP impacts their lives and the work they do, how they can work together to reduce the risks associated with IAP and to consider what short- and long-term actions need to be taken for the management of IAP. This approach, together with consensus building reduces the risk of cognitive bias.

It is also essential that stakeholder workshop participants define their justification and uncertainty of issues or variables in IAP management, which not only allow uncertainty to be reflected in the final results but also allow participants to provide judgements even where data was limited. Other techniques used to structure and elicit stakeholder judgement in this thesis include allowing workshop participants to present their list of variables that came out of break-out groups. This also provides participants the opportunity to discuss and provide feedback, and the use of facilitator-led discussions encourages engagement and open discussion. The use of smaller breakout sessions to provide smaller and more informal space in which to express views (Chapter 5; also Forsyth et al. 2011) proves invaluable in assuring that consensus is sought rather than majority rule, and that every stakeholder is heard and respected. While these approaches are useful to minimise bias in stakeholder knowledge, good practice in this field is developing rapidly and so further evaluation (to suite the stakeholders involved) and adaption (context-based) is recommended (for example, following the recommendations of Forsyth et al. 2011; Vanderhoeven et al. 2017; Dìaz et al. 2018).

### 6.4.3 Using consensus building to cope with uncertainty

Consensus building was used in the stakeholder workshops to identify and define the 44 variables constituting IAP management in the GRBR (Table 5.2). This form of collaborative planning has grown in popularity, not just because it is a way to reach agreement and action by connecting with others, but it also provides a way to cope with uncertainty (Innes, 2004). The workshop participants found the process personally and professionally useful, from feedback provided by the participants. One participant found the process: *"a break from traditional workshop style where I am subject to listening and following slide show…. I will definitely try this within our organisation".* This highlights that the process has potentially enhanced the stakeholders' capability to learn, and gain a new shared understanding, break through mental and emotional barriers, build trust, and create increasingly sophisticated CLD. While uncertainty was recurrent in this thesis, this approach has potential to bring about transformational change in the context of IAP management and decision-making process.

In addition, the social learning method of engagement adopted during the stakeholder workshop also ensured consensus building and was a break from the typical presentation format and encouraged participants to identify and formulate actionable strategies. It anticipated that by participating in management focused workshops, there is potential for the discussions coming out the stakeholder workshop to lead to fruitful collaborations among stakeholder groups (Rohal et al., 2018), however, further research needs to be done to ascertain this. In addition, due to the complex nature of IAP management and recognising that there is still a lot of uncertainty, the strategy development needs to be an iterative process, characterised by experimentation, monitoring, collective learning and adaptation.

#### 6.4.4 Adopting the principles of robust decision-making

One of the key highlights of this thesis is to underscore the need to adopt the principles of robust decision-making (Chapter 2, 3 and 4). Together these principles led to a more robust decision-making process, which is defined as a process that supports decision-making under conditions of high complexity and uncertainty and that allows decision makers to learn from and explain the reasoning behind their decisions even if decisions do not lead to the intended results. For example, a large number of the stakeholders, particularly private landowners– Chapter 4, previously relied on their own experiences and information rather than science-based research. However, by incorporating the principles of robust decision-making, stakeholders are more likely to, for example, adopt *science-based* and *structured* decision processes. This in turn could improve the effectiveness of their management strategies (Walsh et al., 2015). This was based on the evaluation of how infrequently the principles of robust decision-making arose during the respondents' descriptions of their current decision-making processes. This was also echoed by the infrequent mention of these principles in the respondents' identification of the strengths, but rather frequent mention was made in the identification of their weaknesses in decision-making processes. The study demonstrated that although it is important to acknowledge that, for example, scientific-based decisions are rarely used, it is because in some cases the scientific research output is only partially relevant to the management challenge being faced by stakeholders (Laurance et al., 2012).

### 6.4.5 Insights from systems thinking approach employed

The complexity of IAP management and decision-making process is understood by revealing how the CLD variables interact together to influence how decisions are made and their effectiveness. The decisions of stakeholder groups involved in IAP management are deeply entwined within the social, economic, and environmental systems (Chapter 5). Some of the key insights gained include:

i. The application of systems thinking has demonstrated the potential to reveal the origins behind events and their associated behaviours, for example, the multi-faceted consequences of decision-making. Applying this approach in this thesis can help stakeholders involved in IAP management to make informed decision and consequently avoid unintended results (Kahneman & Egan, 2011; Banson et al., 2018) and also help to augment conventional approaches.
ii. The unintended consequences that often result from a sole dependence on linear or traditional approach (Chapter 4) to addressing IAP management challenges has led to ineffective management of IAP and poor sustainability of decisions, creating a vicious cycle (van Wilgen & Richardson, 2014; Gaertner et al., 2017). For example, the emphasis of job creation in the Working for Water (WfW) programme is lamented to have resulted in, for example, regular overestimation of cover estimates prior to awarding of contracts and wrong choices of treatment methods in order to create more jobs. This is likely to improve by following recommendations by Kraaij et al. (2017) that the funding be made available directly to conservation agencies to reduce these unintended consequences.
iii. The CLD reveal that the ability of IAP management systems to achieve and sustain its effectiveness is subject to many interacting variables (Table 5.2),

representing two-way relationships between actions and consequences. The study demonstrats that the variables are not only limited to economic, ecological, and social factors, but include diverse stakeholders with varied asymmetric values, beliefs, objectives, and agendas adapted for managing IAP (Gaertner et al., 2017; Potgieter et al., 2018b).

iv. Challenges and trade-offs in solving problems often stem from the fact that problems do not occur in isolation, but in relation to each other (van Wilgen and Richardson, 2014). For instance, the current model used in the WfW programme does not allow for capacity to be built within the conservation authorities and in the event that funds are channelled elsewhere would leave the conservation agencies without embedded capacity and experience to manage IAP invasions (Kraaij et al., 2017).

v. The process of systems mapping provides a framework in which stakeholders can share their understanding of systemic interventions and their interrelationships. This creates a co-learning environment that facilitates communication among different stakeholders, that is, managers, scientists, private landowners, general public and policymakers, and it identifies a diverse range of interventions that affect planning, implementation, monitoring and reviewing of IAP management and decision-making (Gaertner et al., 2016).

vi. Overall, the research approaches used in this thesis are adaptable and can be applied to address complex challenges facing decision-makers in IAP management - not only in South Africa, but also in other parts of the world (Nguyen et al., 2019). The systems thinking tools, and the insights they provide, make this approach accessible to a wide range of decision-makers and stakeholder groups (Mirchi et al., 2012).

## 6.5 Future research direction

Despite the advances and contributions made through this research, much remains to be done to improve IAP management and decision-making. For example, there remains a need to develop a systems dynamics model (a methodology and mathematical modelling technique to frame, understand and discuss complex dynamic systems or issues) that is able to quantify this GRBR IAP management system. Such a model could assist decision-makers in enacting effective strategies for managing current and future IAP by revealing the complexity, dynamic behaviour and trade-offs between different objectives. Future research can build upon this work by further exploring the suggested avenues to deeply understand the complexity of the different factors influencing the effectiveness of IAP management. This has implications on how to better advance and improve understanding of IAP management and decision-making process and include:

- Stakeholder involvement in the decision-making process: Future research should look into approaches to increase the roles of different stakeholders in IAP decision-making. This could be particularly helpful in developing management frameworks in which stakeholders are not consulted about their needs by decision/policy makers, but rather the stakeholders themselves drive the process for deciding 'how', 'when' and 'where' their conservation needs, and interests are best addressed.
- Representativeness and accountability of stakeholders: The representativeness (the involvement of the 'unusual participants' in the GRBR) and accountability (how stakeholders accounts for their actions, for example, the case of absentee land owners in the GRBR) of the stakeholder merits further research, including ways to identify which system archetypes best assess those issues in practice. It is also necessary to develop explicit and rapid mechanisms to understand the perceptions of how stakeholders make their decisions, for example. Perceptions of the effects of IAS have been reported to vary among different stakeholder groups (Shackleton et al., 2019b).
- The results also show the need to recognise that IAP management is a complex social-ecological system (Chapter 2) which affects and is affected by social, economic, political, and environmental factors at different scales (Estevez et al., 2015). The management and understanding of IAP management should shift from the traditional way of thinking and through the CLD this thesis highlights different factors influencing effectiveness of IAP management (Chapter 5). However, the reality is that there are other factors, interacting at multiple scales not considered in this thesis that influence the effectiveness of IAP management. For example, factors including the attributes of individuals facing IAS, IAS traits, social-cultural context and institutional, governance and policy context (Shackleton et al., 2019b) were not considered. Future studies should thus build upon this work and aim to deeply understand the complexity of the different factors influencing the

effectiveness of IAP management, which should have important implications on how they can be better managed to ensure long-term sustainable biodiversity conservation.

- While the CLD presented in this thesis is useful in highlighting the reciprocal connections and relationships of IAP management and decision-making variables (Table 5.2), it is not intended to provide a full explanation of this issue. But rather provide an example of how visualising the complexity of a system can help to identify leverage points and the key important system archetypes that exist in the system. It has not been tested and there remains a need to develop a system dynamics model, through, for example, computer modelling, that is able to quantify interconnectivity in the IAP management system. Such a model could assist stakeholders in making effective decisions by revealing the complexity, dynamic behaviour and trade-offs between different management objectives in a quantifiable manner.

## 6.6 Limitations

A limitation of the approach used in this thesis is that results are as good as the quality of data (Forsyth et al., 2011), particularly in the development of a CLD in Chapter 5. The composition of the stakeholder workshop participants is important for reaching consensus since individuals within the group could have conflicting understanding of feedback loops or may be unwilling to deliberate and potentially change their views on contentious issues. This potentially makes it impossible to reach an agreement unanimously. Including diverse stakeholders and applying consensus building in the stakeholder workshop strengthens the CLD outcome, allowing for more defendable and effective decision-making process.

Although the use of consensus building among stakeholders is increasingly used as a common approach to reach feasible strategies to deal with uncertain and complex problems (Innes, 2004), its application in this thesis to identify the 44 variables (Table 5.2) was constrained by the lack of clear selection criteria. Thus future studies can for example, apply a multi-criteria approach using analytical hierarchical process (AHP) methods (Saaty & Vargas, 2001). In this case, AHP is used to determine the relative importance of the variables in relation to the specific goal (Saaty, 1977). Pair-wise comparisons of variables can be made to derive accurate ratio-scale priorities, as opposed to the conventional approach of assigning single weights (Saaty, 1977). This approach has been successfully applied to prioritise species and quaternary catchments for IAP control (van Wilgen, 2008; Forsyth et al., 2011).

### 6.7 Conclusion

Biological invasions are, and are likely to remain, a major component of an increasingly human-dominated world, with substantial threats to biodiversity, economies, and livelihoods of communities in many ways (Hulme, 2009). The study of the management of IAS is not only of considerable academic interest but is also important to combat the impacts and continual spread of invasive species worldwide. There is therefore significant benefit to be accrued from building close partnerships between the research community, interested and affected stakeholder groups and those making or implementing management decisions. A focal point for these parties is identifying deep leverage points such as where to intervene, and where to trigger transformational change and transitions (Chapter 2). In IAP management and decision-making processes, however, considerably more efforts and closer links are needed. Alignment of personal values (Liu et al., 2011b), and the establishment of common norms and trust (McAllister et al., 2017) are essential in achieving agreement on common goals (Graham & Rogers, 2017; Graham, 2019) and then subsequent collaboration and coordination of management efforts (McAllister et al., 2017).

This thesis provides an excellent and potentially unique foundation through presenting the principles of robust decision-making (Chapter 3 and 4) and the development of a CLD (Chapter 5), from which to develop and test further methods and tools to engage, communicate and collaborate with stakeholder groups working to improve IAP management. The study has expanded the application of systems thinking in IAP management and decision-making. It also offers stakeholder groups involved in IAP management a valuable opportunity to share experiences and knowledge on feedback loops involved in managing IAP in a transparent way, while simultaneously identifying leverage points for improving the decision-making process. Such approaches are urgently required at local, national and global scales if we are to successfully slow the challenges posed by IAS and the catastrophic impacts they are having on global diversity and consequently human well-being. Although, use of stakeholder workshop at the global could be not feasible.

It is my hope that this work advances invasions science and encourages further collaboration and learning among diverse stakeholders, as well as new perspectives that are yet to emerge. It is through this continual process of broadening research perspectives and considering more and different facets of stakeholder knowledge – and how they interact to influence decision-making– that we are able to build and expand upon the fundamental work laid by Charles S. Elton all those years ago in his book (Charles S Elton, 1958), and continue to advance the research frontier into the future.

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# APPENDICES

## Appendix A. Ethics approval confirmation letter

NELSON MANDELA
UNIVERSITY

**FACULTY OF SCIENCE RTI COMMITTEE**

| | |
|---|---|
| To: | Prof Fabricius/ Mr Masunungure |
| From: | Debbie du Preez |
| Date: | 27 July 2018 |
| Ref: | **H18-SCI-SRU-003** |

Dear Prof Fabricius/ Mr Masunungure

**TITLE OF PROJECT: Decision analysis to inform to invasive alien plant management in the Garden Route Biosphere Reserve**

Your above-entitled application was considered and approved by the Sub-Committee for Ethics in the Faculty of Science on 24 July 2018.

The ethics clearance reference number is H18-SCI-SRU-003 and is valid for three years. Please inform the Committee, via your faculty officer, if any changes (particularly in the methodology) occur during this time.

*An annual affirmation to the effect that the protocols in use are still those, for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.*

We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

**Debbie du Preez**
**Research Assistant: Science Management**
**Faculty of Science**

## Appendix B: Information and informed consent form

| RESEARCHER'S DETAILS | |
|---|---|
| Title of the research project | Decision analysis to inform invasive alien plant management in the Garden Route Biosphere Reserve |
| Human Ethics Reference number | H18-SCI-SRU-003 |
| Principal investigator | Current Masunungure |
| Address | Nelson Mandela University, George Campus |
| Postal Code | 6530 |
| Contact telephone number (private numbers not advisable) | 0817979834 |

| DECLARATION BY PARTICIPANT | | *Initial* |
|---|---|---|
| I, the participant and the undersigned | (full names) | |

| **A.1 HEREBY CONFIRM AS FOLLOWS:** | | **Initial** |
|---|---|---|
| **I, the participant, was invited to participate in the above-mentioned research project** | | |
| **that is being undertaken by** | Current Masunungure | |
| **from** | Sustainability Research Unit, Nelson Mandela University | |

| **THE FOLLOWING ASPECTS HAVE BEEN EXPLAINED TO ME, THE PARTICIPANT:** | | | **Initial** |
|---|---|---|---|
| 2.1 | **Aim:** | The investigators are studying the current decision-making environment in invasive alien plant management in order to identify its strength and weakness and ultimately understand the interrelationships between variables to improve decision-making.<br><br>The information will be used for academic purposes. | |
| 2.2 | **Procedures:** | I understand that I have been approached to participate as a key informant and to take part in the expert workshops. | |

| | | | |
|---|---|---|---|
| 2.3 | **Risks:** | There is no risk of harm, embarrassment or offence in being involved | |
| 2.4 | **Possible benefits:** | No benefits will be accrued as the study is purely for academic purposes. | |
| 2.5 | **Confidentiality:** | My identity will not be revealed in any discussion, description or scientific publications by the investigators. | |
| 2.6 | **Data reuse:** | The data can be reused for academic purposes only, in future:<br>• Longitudinal studies<br>• Comparative studies | |
| 2.7 | **Permissions:** | Permissions has been granted to:<br>• Voice record the interview<br>• Take photos relevant to the study | |
| 2.8 | **Access to findings:** | The findings of this thesis will be communicated as follows:<br>• Electronic copy of final thesis<br>• Simple communication pamphlet with key findings | |
| 2.9 | **Voluntary participation / refusal / discontinuation:** | My participation is voluntary — YES / NO | |

| **3. THE INFORMATION ABOVE WAS EXPLAINED TO THE PARTICIPANT BY:** | | | | | | | | | **Initial** |
|---|---|---|---|---|---|---|---|---|---|
| (name of relevant person) | | | | | | | | | |
| in | **Afrikaans** | | **English** | | **Xhosa** | | **Other** | | |
| and I am in command of this language, **or** it was satisfactorily translated to me by | | | | | | | | | |
| (name of translator) | | | | | | | | | |
| I was given the opportunity to ask questions and all these questions were answered satisfactorily. | | | | | | | | | |

| | | |
|---|---|---|
| **4.** | No pressure was exerted on me to participate and I understand that I may withdraw at any stage without penalisation. | |

| | | |
|---|---|---|
| **5.** | Participation in this study will not result in any additional cost to myself. | |

| **A.2 I HEREBY VOLUNTARILY CONSENT TO PARTICIPATE IN THE ABOVE-MENTIONED PROJECT**: |
|---|
| Signed/confirmed at on 20 |

| | |
|---|---|
| Signature of participant: | |

| STATEMENT BY INVESTIGATOR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **I,** | Current Masunungure | | | | | **declare that:** | | | |
| | **I have explained the information given in this document to** | | | | | **Participant: Code Number** | | | |
| **2.** | **He / she was encouraged and given ample time to ask me any questions;** | | | | | | | | |
| **3.** | **This conversation was conducted in** | **Afrikaans** | | **English** | | **Xhosa** | | **Othe r** | |
| | **And no translator was used OR this conversation was translated into** | | | | | | | | |
| | **(language)** | **by** | (name of translator) | | | | | | |
| **4.** | **I have detached Section D and handed it to the participant** | YES | | NO | | | | | |
| Signed/confirmed at | | | o n | | | 20 | | | |
| Signature of interviewer | | | | | | | | | |

| DECLARATION BY TRANSLATOR (WHEN APPLICABLE) | | |
|---|---|---|
| I, | (full names) | |
| **confirm that I:** | | |
| **1.** | **Translated the contents of this document from English into** | (language) |
| **3.** | **Conveyed a factually correct version of what was related to me.** | |

**Appendix C. Key informant interview guide**

| | | | | |
|---|---|---|---|---|
| **Principal Investigators:** | **Prof. C. Fabricius; Dr. T. Kraaij and Current Masunungure** | | | |
| **Affiliation :** | **Nelson Mandela University, SRU** | | | |
| **Role in IAP Management: (Tick where Applicable)** | Private Land owner | | Municipality | |
| | Researcher | | SAN Parks | |
| | CapeNature | | Private Consultancy | |
| | Conservation Agency | | Forestry Companies | |
| | WfW | | Government Depart. | |
| | Private Companies | | Other…….. | |
| **Contact (if willing):** | | | | |

**Section A: Issues influencing management decisions**

1. What are the current biggest challenges in invasive alien plant (IAP) management that you are experiencing?
2. Are there some IAP species (woody) that are of greater concern than others? \if so, Which and Why?
3. What are your greatest risks or concerns for the landscapes in your management areas? Could you list the top 3 and why?
4. What are your top priorities in manging the risks or concerns mentioned above?
5. What are your strategies for reaching these? Can you be specific/elaborate?

**Section B: Concerns and priorities**

6. What are your top concerns (economic, ecological, social) in IAP management?
7. What ecosystem services/values/goods within your catchment/area are you most concerned with protecting? Could you list the top 5 and why?
8. Does protecting these services/goods drive your management decisions? Why or why not?

9. Do you agree that IAP (woody) threatens these services/goods? (If so, which values do they threaten?)

**Section C: Decision-making process**

10. What are the key variables affecting IAP management and decision-making process and outcomes?
11. Who is responsible for making the decision to control or not to control IAP?
12. What is the procedure/process that is followed to reach the decisions?
13. What are the weaknesses and strengths of the current decision-making process/procedures?
14. How do you decide when an IAP population should be controlled?
15. What elements are considered when deciding whether to control an IAP population?
16. Which factors do you consider when deciding which control option is best?
17. Are there any other factors that are considered in management decisions that have not been mentioned previously?
18. Are there any decisions that you have made/know of that illustrate particularly successful (or flawed) decision-making?

**Section D: Opportunities**

19. To what extent are other agencies included in your management actions?
20. How can you work together with other agencies to reduce the impacts of IAP, mentioned earlier?
21. Earlier we spoke about challenges in IAP management? Do you see these challenges changing in the future? (If yes, in what ways; if no, why not?)
22. What issues should a decision support system address to be useful to you or in your line of work?
23. The purpose of our discussion today was to determine how IAP management decisions are made and how they could be improved. Do you think I have missed anything

**Appendix D. Stakeholder workshop guide**

<table>
<tr><td>Principal Investigators:</td><td colspan="4">Prof. C. Fabricius; Dr. T. Kraaij and Current Masunungure</td></tr>
<tr><td>Affiliation :</td><td colspan="4">Nelson Mandela University, SRU</td></tr>
<tr><td rowspan="6">Role in IAP Management:<br>(Tick where Applicable)</td><td>Private Land owner</td><td></td><td>Municipality</td><td></td></tr>
<tr><td>Researcher</td><td></td><td>SAN Parks</td><td></td></tr>
<tr><td>CapeNature</td><td></td><td>Private Consultancy</td><td></td></tr>
<tr><td>Conservation Agency</td><td></td><td>Forestry Companies</td><td></td></tr>
<tr><td>WfW</td><td></td><td>Government Depart.</td><td></td></tr>
<tr><td>Private Companies</td><td></td><td>Other……..</td><td></td></tr>
<tr><td>Contact (if willing):</td><td colspan="4"></td></tr>
</table>

**Phase 1**- Problem Structuring

1. Identification of the key variables in regard to IAP management and decision-making. Example of questions include:
    - What are the factors or variables involved/important in IAP management and decision-making?
    - Who is involved?
    - Are they collective efforts? Who is leading them?
2. Confirmation of system boundary
    - Define each of the variables/factor identified.
    - How do variables affect the other?
    - Each group to present variables/factors.

**Phase 2**- : Relationship between variables

1. Identification of relationships among identified variables
    - Causal linkages between variables
2. Construction of a preliminary conceptual model represented as a CLD
    - Create the causal 'story'- causal loops linked through common variables.

- If possible, draw/determine the expected behaviour of the system over time.

**Phase 3**- Model Confirmation:

1. Refinement of the initial CLD generated from the previous modelling workshop.
    - Determine what type of behaviour the loops produce: reinforcing and balancing loops
2. Identification of feedback loops
    - Reinforcing loop- change in one direction is compounded by more change.
    - Balancing loop- counter change in one direction with change in the opposite direction; attempts to bring things to the desired state.
3. Identification of interventions (i.e., leverage points and system archetypes).
    - Try walk through the loops and 'tell the story' to ensure that the loops capture the behaviour being described.
    - Deduce and discuss points of leverage and identify system archetypes.

**P/S:** Please kindly provide any feedback with regards to the methodology or approach taken in this workshop: