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An Interactive Decision Support Tool for Participatory Pest Management Planning

Combining Local, Regional and Scientific Knowledge Through Immersive, Collaborative and Interactive Technologies

By

Dylan Mitchell Mathiesen B.IT (Hons I)

Thesis submitted by Dylan Mitchell Mathiesen in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Information Technology under the College of Business, Law, Governance and IT at James Cook University.

College of Business, Law, Governance and IT,

James Cook University.

23 December 2016

Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given.

Dylan Mitchell Mathiesen

23 December 2016

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The researcher was supported under the Australian Postgraduate Award scholarship. Budget for publication, travel and tools were provided by the College of Business, Law and Governance and the JCU eResearch Centre. Expertise and mentorship were provided by Travis Sydes and Helen Murphy who assisted in identifying participants and organising sessions with them, ensuring the study was suitably designed and providing expert opinion on the function of the software. CSIRO provided accommodation and facilities when working remotely with stakeholders. This thesis was professionally copy edited by "The Expert Editor" following the IPEd guidelines. All of the work within this thesis is solely the Authors, with the exception of the items noted under this Statement of Contributions or additional materials within this thesis that have been clearly cited. No work within this thesis has been intentionally taken without permission.

Abstract

Decisions about resource allocation for invasive species management are usually made by multiple land managers who lack full knowledge of, or access to, information about the landscape beyond their area of interest. Although a vast number of modelling tools exist to aid pest management they are often too difficult for the majority of pest managers or are too time consuming to run. Advances in interactive technologies have opened new opportunities for the development of engaging decision support tools. The combination of these technologies with pest management planning will allow multiple stakeholders to engage and assess interactions simultaneously, so management decisions can be based on a larger ecological and financial vision. This thesis explores the value interactive technologies have for improving the pest management decision making process.

To investigate the potential of interactive technologies applied to pest management planning an interactive tool was designed, developed and evaluated. Far North Queensland (FNQ) was selected as the study location due to its rich biodiversity and ideal climate for pest weeds. The research was divided into three phases: 1) Understanding the existing pest management process, both from relevant literature and from the perspectives of individual pest managers as well as identifying areas where interactive technologies could be applied; 2) Implementation of the tool; 3) Refinement of the tool with end users and evaluation with real pest managers.

Phase One explored the existing pest management process, expanding on the literature and methodologies used for pest management in FNQ. Analysis of the existing pest management process was conducted using Activity Theory (AT) and the Activity-Oriented-Design Methodology (AODM). Contradictions and limitations in the existing process were identified along with a series of pertinent research questions, the answers for which would help develop a deeper understanding of pest management. These questions were answered using a series of interviews with six pest management planners from different backgrounds. An observational study was also conducted with a group of expert ecologists using an interactive tool with a new type of distribution model to collect feedback on its potential in pest management.

Phase Two developed an implementation based on the findings of the first phase. A new type of interactive pest management decision support tool was built around the MigClim dispersal model. A number of optimisations were made to improve its runtime. A web service was developed that could run the MigClim model and render dispersal outputs. An interactive user interface was built around the web service that allows users to add pest populations and define management objectives to interact with the model. The user could press the run button at any time to see a visualisation of the impact their objectives had on the pest species over time along with the cost and amount of work required.

Phase Three incorporated potential end users to refine the interaction process and conceptual design of the tool. Two usability testing sessions were run with groups of three participants. A number of issues were found where the tool did not provide the information the participants needed or behaved unexpectedly. These concerns were addressed in new iterations of the prototype tool. A final case study was conducted with six experienced pest managers. They were trained in using the tool and asked to develop a plan around a quasi-real pest species. An evaluation was conducted after the focus group to explore how this interactive tool compared to traditional pest management planning.

There were a number of key findings about interactive technologies and pest management. Both experienced planners and first time planners, with limited training, ran the MigClim dispersal model to inform their decision making processes. The tool allowed them to refine their plans over a period of time using the model to evaluate different strategies. The planners highlighted the ability for interactive tools like this to be used in other applications such as: educating communities, engaging uninterested stakeholders, preparing budgets, and building consensus with other planners.

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Publications

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Glossary

ACD Activity-Centred Design

AODM Activity-Oriented Design Methodology

API Application Programming Interface

AR Augmented Reality

AT Activity Theory

AWPM Areawide Pest Management

CAVE CAVE Automatic Virtual Environment

FNQROC Far North Queensland Regional Organisation of Councils

HCI Human-Computer Interaction

HCD Human-Centred Design

IPM Integrated Pest Management

JCU James Cook University

PNG Portable Network Graphic

QLD Queensland

QPWS Queensland Parks and Wildlife Service

RPC Remote Procedure Call

UCD User Centred Design

WFS Web Feature Service

WMS Web Map Service

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Chapter 1

Introduction

The world is in the midst of an invasion. Invasive alien species are causing widespread damage to food production and the environment. Although not a stereotypical alien invasion, pest animals, plants and disease are expanding their range at an increasing rate. As the world becomes more connected by air, sea and road the potential for invasive pest dispersal increases and the threat posed intensifies. Pest species disrupt environmental systems and human activity incurring a huge cost to society along the way. The prevention of their spread and cost effective management of these species is paramount and presents a challenging problem for those tasked with the job.

Pest management is a complex process involving numerous stakeholders including landowners and a large number of organisations, each with unique objectives and interests. Modelling and decision-making tools that target pest species management are already commonplace in the scientific community but often, the skills to use these technologies is lacking at the local land management level. Decision makers often have to rely solely on their own expertise and knowledge to make resourcing decisions. Existing and emerging interactive tools have the ability to change this and make scientifically validated decision support tools available to the everyday pest manager. Moreover, these new technologies have the potential to encourage collaboration of additional stakeholders.

This research project develops a new type of collaborative and interactive pest management decision support tool. This tool is designed to assist planners in building robust pest management plans and targeting resources where they will be most effective. It allows management objectives to be drawn onto a map on a desktop computer, touchscreen device, or large touch-sensitive table. The tool uses a modified version of the MigClim (Engler et al., 2012) dispersal model to simulate user defined pest management strategies 30 years into the future. The simulations are computed and presented as an interactive animation in combination with the estimated amount of work, management costs and infested hectares. Playback can be stopped at any point and the management strategy can be redefined from that time forward. This thesis describes the interaction design and development of an interactive visualisation tool applied to conduct pest management planning.

1.1 The Invaders

The term invasive alien species, invasive species, or more commonly pests, are typically introduced plants and animals that cause damage to biodiversity, the environment, human health or the productivity of the land. “Invasive species” is often only used for species with a mechanism for dispersal that cause or have the potential to cause significant damage. They have been estimated to cost the Australian economy $13.7 billion annually through loss of agricultural productivity and environmental damage (Hoffmann and Broadhurst, 2016). Invasive plants, animals and disease are also considered to be the greatest biological threat currently facing global food production. Furthermore, anthropogenic changes to the climate and environment are enabling pest species to cover vast expanses of land rapidly. Effective management of invasive pests is urgently required to reduce the damage they cause to human activity and the environment.

The prickly pear (*Opuntia*), first introduced to Australia in 1788, is a great example of the damage invasive species can cause. The invasion ultimately caused the abandonment of millions of hectares of farming land. The British hoped to use the newly formed Australian colony to farm Cochineal (*Dactylopius coccus*), an insect, used to make red dye for military uniforms, that survived off the prickly pear (Biosecurity Queensland, 2015). Cochineal was successfully cultivated on the introduced prickly pear that thrived in the dry conditions.

During the 1840s the prickly pear began to spread from plantations. Mechanical control mechanisms and chemical control proved expensive and ineffective at preventing its spread. Properties and farms over run by prickly pear often had to be abandoned. By 1900 it had infested 4 million hectares and by 1920, 24 million hectares (Freeman, 1992). The Cactoblastis (*Cactoblastis cactorum*) moth was identified in the 1920s as a potential control mechanism and introduced to the prickly pear sites (Dodd, 1936). By 1932 an estimated 7 million hectares of infested land had been reclaimed by the Cactoblastis moth and was used for new settlements. To date, the Cactoblastis moth has successfully suppressed the prickly pear populations to a fraction of its peak range.

Although the management of prickly pear was highly effective, many invasive pests are not so easy to control. The cane toad (*Rhinella marina*) was introduced in 1935 as a control mechanism for the cane beetle (*Dermolepida albohirtum*). , the cane toad quickly spread out from the cane farms, thriving in Northern Australia. Having no natural predators its population exploded, causing significant damage to many ecosystems and native species (Shine, 2010). Management of the cane toad has proved almost impossible and they have continued increasing their range (Nyquist, 2016). There are many other examples of large scale pest management programs in Australia struggling, such as Siam (*Chromolaena odorata*) and Lantana (*Lantana camara*) (Heap, 2014; Bhagwat et al., 2012; Herron et al., 2001).

These pests are managed at a variety of levels (see Figure 1.1), from federal organisations running national eradication programs, through to state organisations, local councils and individual landowners. Each level holds a stake in the pest management process. These stakeholders have responsibilities to manage particular types of pests. For instance, landowners are required to keep their properties free of declared pest species while organisations like Biosecurity Queensland are tasked with averting emerging threats across the state. Farmers must control pests on their properties to ensure their farms remain productive and their crops have adequate drainage.

The funding available to pest managers is substantially lower than what is needed to manage pests in Australia, making resource prioritisation essential. Decisions regarding the targeting of pest management resources are often made without a full understanding of the relevant invasive pest. However, collecting data on the current range of pest species is a difficult and expensive process, involving crews and often helicopters to survey remote and hard to access locations. Furthermore uncooperative or uninformed

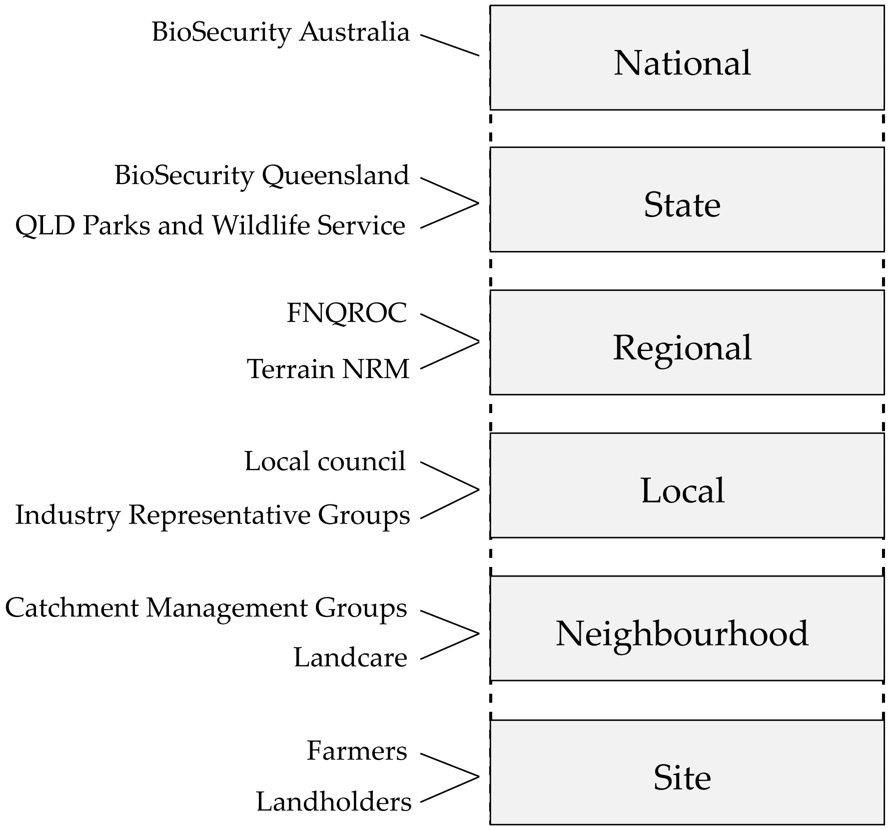

Figure 1.1: Layers of pest managers, stakeholders and organisations in Far North Queensland. Based on Peterson et al. (2007).

landholders may not adequately manage or report pest species on their properties. These factors make pest management challenging. Current management approaches attempt to engage large groups of stakeholders to assist in managing species.

Determining the possible future range of a pest and potential for it to hinder agricultural activities and damage the environment is important when prioritising the allocation of resources. Understanding the future of an invasive pest in the environment can help to plan early targeting where it will be most effective. Several tools are already used for uncovering the future potential range of each species: Maxent (Phillips and Dudík, 2008) - for determining species distributions; MigClim (Engler et al., 2012) and SDMtoolbox (Brown, 2014) - for modelling future ranges; and Circuitscape (Shah and McRae, 2008) - for understanding species population connectivity. However, these tools are difficult to use and are not designed for stakeholders who are not research scientists with expertise in ecological modelling. Stakeholders without access to these tools will often resort to making resources allocation decisions based on their intuition or more simplistic analyses. Providing these tools to stakeholders could enable more informed decisions to be made about the allocation of these resources. However, newer, more user-friendly tools must be designed that allow use by the non-expert to support their decision-making process.

1.2 Interactive Technologies

Many existing, and emerging technologies are changing the way scientists, citizens and decision makers go about solving problems. Personal smart-phones and computers have increased in abundance over the past decade, and high-speed internet provides easy access to information and rich interactive multimedia. Collaborative touch surfaces, such as the Diamond Touch (Dietz and Leigh, 2003), have been around since the early 2000s, allowing multiple users to interact with a large single device. Advances in emerging technology such as Augmented Reality (AR) and Virtual Reality (VR) is also bringing a lot of promise and providing new ways for people to interact with computers.

Touch-sensitive table tops have started to become common in libraries, museums, galleries (Geller, 2006) and conference rooms. They are essentially larger versions of touchscreen tablets, allowing multiple users to gather around them and collaborate on projects (refer to Figure 1.2). The larger display size of these devices also allows for a greater amount of detail to be presented and for more precise input when compared to a smaller device. Touch-tables deployed into these public environments often have few instructions or support, leaving people to work out how to operate them themselves. Interfaces must be developed to mimic natural processes and be intuitive and easy to learn. These types of large touch screens have also been used in professional planning settings, for encouraging collaboration, expressing ideas and communicating ideas (Arciniegas and Janssen, 2012).

AR and VR headsets offer the potential for immersing people into 3D worlds and have been used for assisting in problem solving tasks. AR applications have already shown their utility in education scenarios (Carmigniani et al., 2011), medical processes

Figure 1.2: Interactive Touch Table at the National Arboretum, Canberra Australia. Users can select locations on the map to view additional information and rich media.

(Marescaux et al., 2004; Kang et al., 2014) and completing complex tasks (Savioja et al., 2007; Henderson and Feiner, 2009). AR works by supplementing the real world with additional information, allowing users to see through objects (Mathiesen et al., 2012), or providing navigation directions from the users current perspective (Reitmayr and Schmalstieg, 2004). VR allows users to immerse themselves in virtual worlds, experiencing it from a perspective previously not achievable. Both AR and VR offer huge potential for educational purposes and specifically with explaining complex concepts. However, using these systems typically requires expensive hardware that becomes more costly as more participants are added.

1.3 A Collaborative Tool for Engagement Around Management Decisions

Interactive and immersive interfaces applied to decision-making in pest management have the potential to improve the communication and engagement with and between the general public and decision makers. Teaching using interactive technology has been shown to increase cognitive engagement compared to traditional teaching methods (Vogel et al., 2006). With the availability of low-cost computers and high-speed internet, interactive visualisations can be distributed to a large portion of the population very easily. The application of conservation planning to interactive visualisations could create a large population of citizen scientists learning by practice and adding value by feeding new data into the pest management planning process.

The merging of conventional pest management decision support tools with interactive user interfaces could enable a more accessible and open planning process. Improving the "public image" of pest management by involving and educating stakeholders is crucial to developing long term sustainable plans (Richards et al., 2004; Reed, 2008). By making the pest management planning process more interactive and open the opportunity for the general public to be engaged and feedback new information is greatly improved. The increased involvement of the public will also improve trust between ecologists, stakeholders and the public at large.

There are, however, several gaps in the knowledge base required for implementing a pest management planning tool. A number of models and decision support tools are available to help planners build spatial management strategies. However, these tools often require specialised training and domain knowledge. Even fewer tools support collaboration between stakeholders making spatial decisions. There are only a few known projects that have explored collaborative pest management planning (Pert et al., 2013; Pressey et al., 1995; Pressey, 1998). Developing new tools requires a more detailed understanding of the areas interactive tools can be applied to and the requirements of decision makers.

1.4 Research Overview

1.4.1 Research Aims

This project aimed to develop a collaborative and interactive tool that supports pest managers in making decisions involving the targeting of resources. An analysis of the pest management process was conducted, which focussed on the collection of distribution data, data analysis and targeting of resources to identify the specific areas new interactive tools could assist. A tool was developed that integrates the existing data collected by organisations involved in pest management with the aim of supporting the decision-making process. The user experience was designed in a manner which could minimise the training required and integrate it into the existing planning processes. The benefits and limitations of this type of tool were assessed using the prototype developed here in a close to real world scenario with pest managers.

The research question this thesis explored can thus be stated as:

> *What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?*

This hypothesis can be further broken down into the following research objectives:

- To investigate the needs of land holders, management staff and operational staff in order to design pragmatic invasive species management plans. These findings would allow the effective design of a workflow for the invasive species management platform to best address the research question.
- To investigate methods for capturing and evaluating local knowledge from stakeholders in an intuitive manner.
- To design and develop a software framework that can be re-used for more general land management problems.
- To investigate the impact of simplifying the scientific modelling process on users with different backgrounds from land owners to decision makers to researchers.
- To investigate the changes to the process of pest management workshops when real-time modelling is introduced into the decision-making process.

1.4.2 Research Contributions

This research presents a new and novel tool to support pest managers in their decision-making process. The methodology, tools and findings from the studies conducted under this project could be used beyond the scope of pest management. Further, this research also presents insights into the process of training users in the utilisation of new interactive tools and minimising learning time.

Other types of spatial land management decision making, such as disaster planning or environmental reserve design present similar problems to pest management. In reserve design, planners must balance the optimal plan from a model with the complex social and economic issues concerning the communities they affect. Furthermore, the planner and community both need to be involved in the process to achieve long term success. Interactive, easy to use planning tools, like the one developed in this project, have the potential to engage the community in more of the process. Conventional models appear to be black boxes to non-experts so making them easier to use could bolster community engagement. The methodology, findings and design of the software from this research project are already being used to develop a new generation of interactive pest management tools.

1.4.3 Constraints and Assumptions

This research looked at the design of an easy to use interactive decision support tool for pest management planning. Although literature and expertise was be drawn from a broad area, the project focussed on pest management in the Far North Queensland region. There are several constraints and assumptions that were considered:

- Pest management is conducted over large areas and not centrally managed, as such the research needs to be conducted over a small area to ensure adequate detail in pest management planning is incorporated.
- This research makes the assumption that although species may differ the fundamental issues and inefficiencies facing each region are common across Australia.
- Different regions collaborate and share their processes and some of the larger government organisations work across multiple regions. This research assumes that their techniques are consistent across their organisations.

- The smaller landholders (farmers, and 'lifestyle' property owners) were contacted to take part in the study, but none were available to participate. Although a significant group of lanholders aren't included, the larger stakeholders involved in the study generally have more influence over weed networks. This research is therfore focussed (but not exclusively) on the stakeholders that can have the most impact.

1.4.4 Personal Pronoun

Traditionally personal pronouns were not considered acceptable in academic writing. However modern researchers have begun using them in Information Technology, Computer Science and Human-Computer Interaction (HCI). This thesis uses Activity Theory to ground the exploration of the user needs and the practice of pest management planning. Software design is not an entirely objective process and relies on the expertise, knowledge and observations of the practitioner undertaking it. In this thesis my thought process and journey is an essential part of the methodology and should not be diluted. I used the personal pronoun "I" to clearly distinguish my thoughts and observations from objective findings.

1.4.5 Research Approach

This research project used an Activity-Centred Design (ACD) process to understand contradictions and shortcomings in current pest management planning methods, to design and develop a prototype interactive tool, and to compare the tool to the existing process.

Developing an Understanding of the Problem

At the commencement of this research I began attending public pest management forums and working groups and also reading local pest management plans and weed strategies, to develop a practical understanding of the problems experienced in pest management. I modelled my understanding of the pest management process using the Activity-Oriented Design Methodology (AODM) as an Activity System. AODM facilitated the identification of contradictions in the current pest planning process and gaps in my knowledge. A series of research questions were developed to assist in building a more complete understanding of the relationships between different stakeholders in the pest management process.

Engaging with Pest Managers, Operators and Community Groups

To answer these research questions a series of qualitative interviews with six people, from Far North Queensland, experienced in the pest management process were conducted, each from different organisations and representative groups. Participants were asked about their experiences in the pest management process including limitations, successes, collaboration and community engagement. The interview transcripts were analysed using thematic analysis (Boyatzis, 1998) to group related concepts and identify problems that existed across the different levels of management. The findings identified that prioritisation and collaboration amongst different stakeholders were the areas with the most potential for improvement with interactive technology.

Understanding the Influence of Interactive Tools

An observational study was conducted with experts using a table-mounted touch screen projector. The researcher observed participants learning to use the interactive tool to gain an understanding of the learning process that participants go through when first using these types of interactive tools. The findings of these studies were summarised and presented as a set of user requirements for the development of the tool in Chapter 4.

Implementing a Tool

An implementation of the decision support tool was developed around the MigClim dispersal simulation model. The collaborative tool was developed using Python as a web-based application targeted at large table-mounted touch screen displays. MigClim was optimised to reduce the wait time and modified to use management objectives familiar to the planners from the previous interviews.

Iterative Development with Usability Analysis

An iterative process through five iterations was used to refine the tool. Two usability analysis sessions were held with participants that were unfamiliar with the pest management process. Findings from these were used to shape the development of the pest management tool.

Evaluation with Pest Managers

An evaluation with experienced pest planners was conducted that asked them to develop a plan around a quasi-real species. At the conclusion of the scenario, participants were involved in a focus group and guided through a discussion around the value of the pest management tool. An analysis of this session with the focus group was conducted to answer the research question and objectives.

1.4.6 Thesis Structure

This thesis is laid out in a chronological order with discussion and summaries integrated into the end of each research component. Each chapter develops its work into a conclusion which is used in the following chapter. Figure 1.3 gives a pictorial representation of the thesis structure. A general discussion of the findings and conclusions are provided at the end of the thesis.

Chapter 2 contains the literature review exploring the current pest management process, interactive tools, community engagement and decision support tools. Chapter 3 details the methodology used throughout this research projects. Chapter 4 explores the pest management process, using ACD, AODM, qualitative interviews and an observational study. Chapter 5 describes the implementation of the decision support tool from the finding in the previous chapter. An iterative process was used to refine the pest management tool and an evaluation of the tool is described in Chapter 6. A summary of findings and discussion of the implications of this research is provided in Chapter 7. The future work that was identified and a thesis conclusion are provided in Chapter 8.

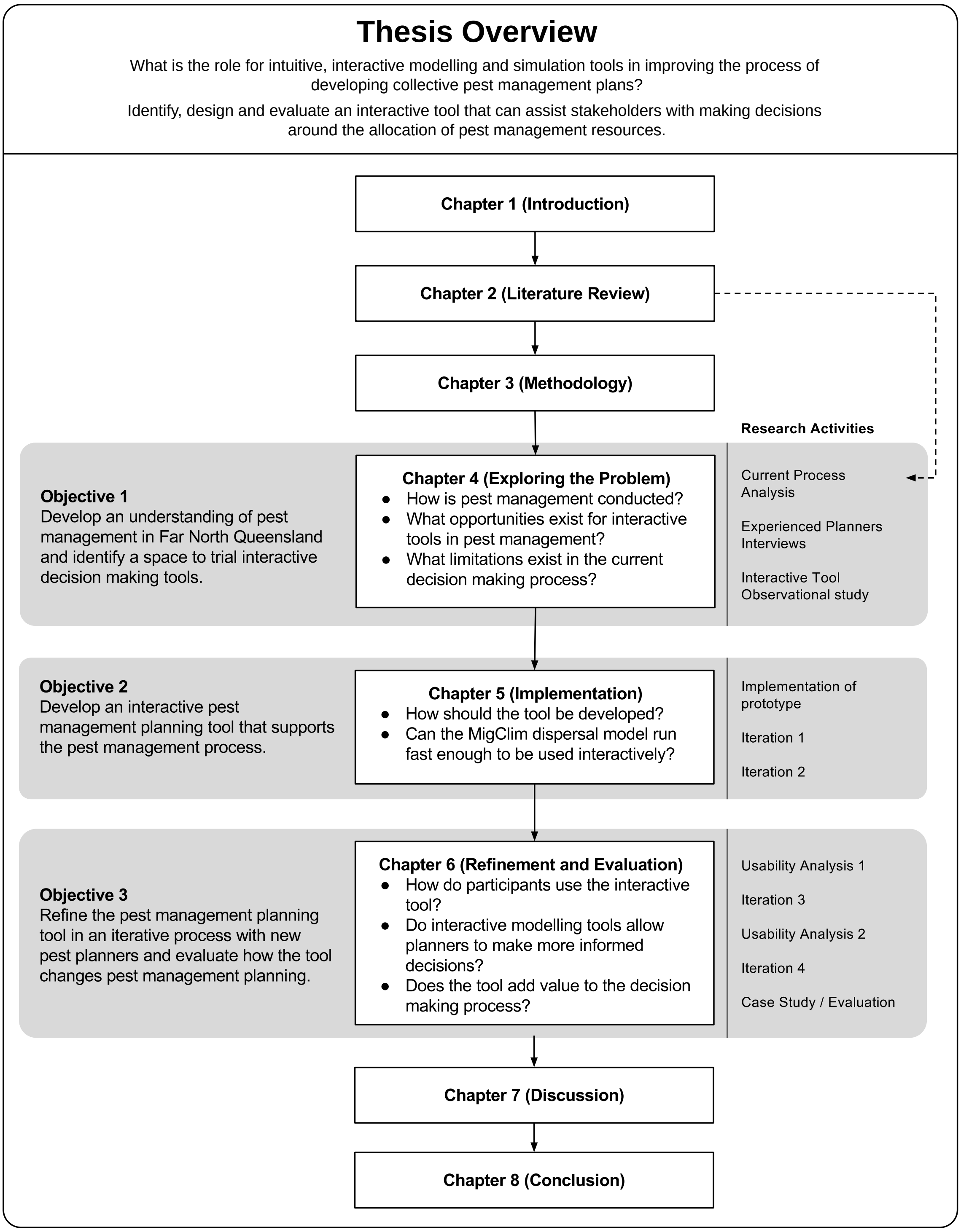

Figure 1.3: Overview of the thesis structure

This chapter concludes by restating the research question explored in this thesis.

Research Question

What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?

Chapter 2

Literature Review

Chapter Overview

This chapter explores the current literature on pest management and decision-making tools. The chapter begins by establishing the broader context and reasons for pest management and explores a number of pest management techniques that emerged in the 19th and 20th centuries and shaped contemporary pest management methodologies. An overview is provided of the tools and techniques used in modern pest management and followed by a review of interactive technology and decision support tools. The emerging themes from the two reviews are combined to create a new concept for pest management. From the research gap identified in this literature, the research question addressed in this thesis is elucidated. A review of the methods and techniques used to conduct this research is provided in the Methodology (Chapter 3).

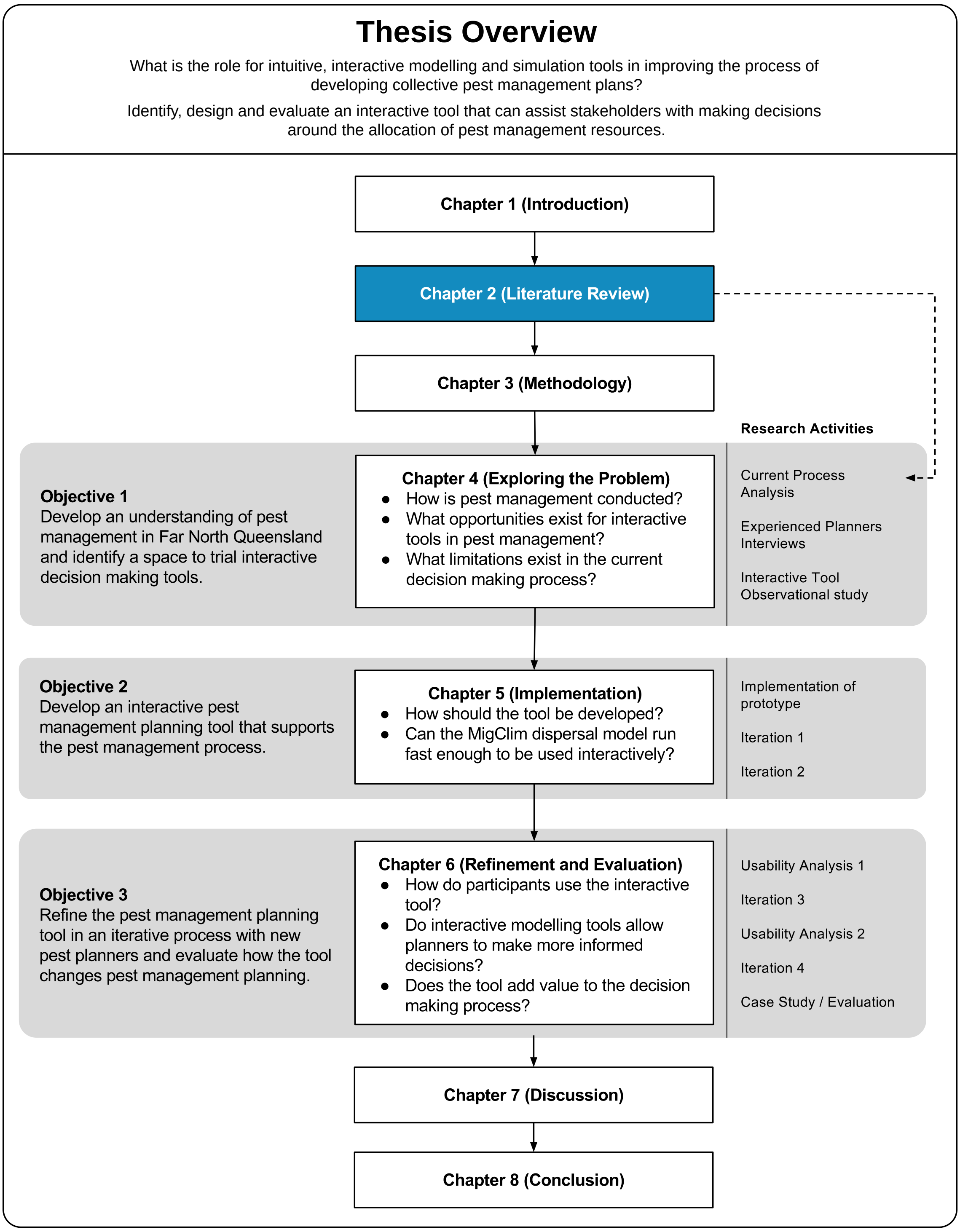

Figure 2.1: Diagram showing the order of research activities presented in this thesis. The blue highlight illustrates the current position in the thesis.

2.1 Introduction

The incursion of new foreign species is a constantly increasing threat globally, and finding ways to manage these invaders is a growing problem (Leung et al., 2002; Mack and Simberloff, 2000; Pimentel et al., 2005). The management of the natural resource assets across a wide region is a complex and challenging task involving large numbers of stakeholders and decision makers, often with competing interests. Engaging all parties across a region to achieve the best possible optimisation of both stakeholder interests and conservation outcomes is a complex and time-consuming task. The volume of data and information available can often exceed the capacity of an individual stakeholder to effectively comprehend the extent of the problem let alone appreciate the perspectives of all stakeholders.

This review explores the existing management and planning techniques and investigates the application of emerging technologies and tools used in other fields to improve the effectiveness of the planning process. Specific focus is given to the current generation of readily available and affordable (consumer grade) technologies that have limited deployment costs. New technology could help in a number of ways: to compile wider bodies of user knowledge, engage the public, build more cost-effective management strategies, and help to further inform the decision-making process. The ultimate goal of applying these technologies is to produce management strategies with land managers, industry, farmers and the local community that are based on well-reasoned information.

2.2 Terminology

Invasive species are typically non-native animal or plant species that have been introduced from elsewhere and pose some threat to the biodiversity or natural assets of a region. The term invasive species is fairly general and is sometimes used with multiple meanings in the literature. Additional terms, such as feral animals, pests and invasive alien species are often used to highlight specific characteristics of the species. These terms are described below.

Invasive refers to the ability of a species to increase its range or over-run its existing range.

Often invasive species have no natural predators or competition to control their population numbers and thus limit their dispersal.

Pest in the dictionary refers to an annoying thing or a nuisance. In environmental science, pest refers to a species that can cause damage to environmental systems or disrupt human activity. Pests are often invasive and have high reproductive rates, making them difficult to control with conventional methods.

Feral refers to animals that have previously been used for domestic purposes or working purposes. The Cane Toad (*Rhinella marina*) is an excellent example of a feral species. Originally introduced in 1935 to control the Cane beetle (*Dermolepida albohirtum*), the Cane Toad has become a feral pest causing widespread damage to native species and is rapidly spreading across Northern Australia.

For this thesis, the term "pest" is used to refer to invasive species that impact ecosystems, biodiversity and human activity and are typically difficult to control. Although the focus of the planning tool developed in this thesis is on pest weeds, the findings can easily be applied to the management of pest animals.

2.3 The Pest Management Problem

Advances in transportation over the past century have connected cities and countries on a scale never previously achievable. Faster and more affordable travel in cars, trains, boats and planes have opened new markets and economic opportunities across the globe. Along with this expansion came an increased rate of dispersal of invasive alien species within countries and across the world (Westphal et al., 2008; McNeely, 2001). Efforts by the agencies tasked with protecting borders are often overwhelmed by the continuous and increasing stream of goods entering countries. Invasive alien species inevitably slip through border protections, some with the potential to cause widespread damage to local ecosystems, biodiversity and human activities.

When invasive pests break through quarantine mechanisms and establish themselves in the environment, they can cause significant damage to flora, fauna, agricultural activities, forestry and waterways (Clavero and García-Berthou, 2005). While some pests may only cause harm to a small segment of the biota making up an ecosystem, their impact can cause a ripple effect to the rest of the ecosystem and in some cases cause major disruptions and potential ecosystem collapse. Ecosystems are dynamic organisations, and small changes can have far-reaching consequences such as potentially pushing endangered native species to extinction or causing damage to entire assemblages of plant species within forests. Problem pests can also complicate agricultural activities across entire regions. Therefore, in order to protect native ecosystems from damage, it is vital that Natural Resource Management (NRM) and land management groups control invasive pests.

Managing these pests is a difficult task. In the introductory chapter, Prickly Pear (*Opuntia sp.*) was described as a fairly well known example of a damaging invasive species. Although Prickly Pear is successfully managed today, at its peak it had infested around 24 million hectares (Freeman, 1992). Early control mechanisms, such as physical removal and burning techniques were ineffective due to the deep root structure of the plant which would simply regrow from the remaining roots. Chemical control using arsenic pentoxide was effective but was highly toxic and expensive to use (Biosecurity Queensland, 2015). The high cost and difficulty in management caused many landowners to simply abandon their property and move elsewhere. In the early 1930s a biological control was trialled and the Cactoblastis Moth (*Cactoblastis cactorum*), whose larvae feed on the leaves of the pear, was introduced to Australia and rapidly reclaimed the lost land.

Today, management strategies, quarantine and treatment methods have improved substantially. Highly threatening pest species are often recognised before they are introduced into Australia and quarantine strategies adapt to help prevent their naturalisation. Although these strategies have improved, Australia's ecosystems and agricultural industry are still threatened by pests that manage to slip through the quarantines. A timely example of an emerging threat is the Panama disease (race 4), a highly threatening disease which could cause significant damage to the banana industry in Australia. Much like the early days of Prickly Pear, there is currently no highly effective control mechanism for areas infected with the disease. An infected property would likely need to be abandoned and quarantined to prevent the further spread of the disease.

Invasive plants, animals and disease cause substantial disruption to farming activities and environmental systems. Sinden et al. (2004) conducted an analysis of the cost of pest weeds on productive agricultural land. The study found in the 2001-2002 financial year pest weeds had an economic impact in excess of $4bn on the Australian economy. An estimated $1.3-1.5bn was spent on management of weeds and a further $2.2bn in lost agricultural productivity. A more recent study conducted by Hoffmann and Broadhurst (2016) expanded on the findings of Sinden et al., calculating the economic costs for all pests in 2011-2012. Hoffmann and Broadhurst found that Australia collectively spends an estimated $3.7bn annually on management activities with an additional economic loss in excess of $9.83bn. The total combined annual cost to the Australian economy was $13.7bn. Both Sinden et al. and Hoffmann and Broadhurst conceded that their estimates only incorporated data that was available at the time and that the true cost was likely to be much greater.

In Australia, there are an estimated 3207 introduced plant species that have been naturalised (Invasive Plants and Animals Committee, 2016). About 500 of these weeds have been declared as noxious and are managed through a variety of levels of governance. The number and range of these species makes eradication and management extremely tough. Management programs range from those undertaken by an individual landholder managing pests on their property to national programs targeting specific pest species across the entire country.

2.3.1 Integrated Pest Management

Ideally, we would eradicate all of the invasive plants, animals and diseases from Australia. However, in most cases, widespread eradication is just not possible. Pests have high reproductive rates and can quickly reinfest areas they had already been removed from. Successful eradication requires management activities to be implemented faster than the pest can increase its range.

Even after the successful elimination of plants from an area, seeds from the plants may be viable for extended periods of time. For example, seeds from Miconia (*Miconia calvescens*) have been observed germinating after five years of dormancy (Csurhes, 1997) and Branched Boomrape (*Orobanche ramosa L.*) after 12 years (Biosecurity Queensland, 2003). The long viability of some seeds means eradication requires a sustained effort, revisiting and confirming the absence of mature plants, until no viable seeds could possibly remain. Each mature plant that is found in that period would require the viability period to be restarted. Eradication is a long and complex process and is an insurmountable challenge to tackle all pest species simultaneously.

Although we cannot simply eradicate all of the invasive pests in Australia, we can use a systematic methodology to reduce their impact on agriculture and the environment. This systematic approach is often known as Integrated Pest Management (IPM). Unlike conventional control methods, IPM focusses on the whole system of pest management, ensuring control is undertaken in a sustainable manner (Flint and van den Bosch, 2012). Control mechanisms are targeted to reduce the costs and to ensure the sustainability of managing the species. Pesticides are used in a manner that limits their harm to unintended targets and ensures usage is effectively timed. Similarly, high priority species are treated first, to ensure the impact of those invasive pests are minimised.

The initial concepts of IPM emerged from the struggles with pesticide resistance of pests in the early 1900s (Hoskins et al., 1939). Hoskins et al. recounted the failures of many imported parasites and predators to control their host pests causing a return to chemical control mechanisms. Over the following 30 years, a number of pests developed resistance to those chemicals. Hoskins et al. reported on other trials in the 1930s that attempted to target pest control mechanisms based on predictions of weather and solar cycles. These IPM control methods were intended to pay careful consideration to the impact chemicals had on their surrounding ecosystems.

The seminal paper by Michelbacher and Bacon (1952) described the need for control mechanisms to take into account the entire entomological lifecycle and food web. They described that the timing and dosage control of their treatments against Codling Moth (*Cydia pomonella*) was a large part of their success in managing the pest. Bartlett (1956) highlighted the benefits that integrated control could provide in retaining natural predators while still managing pest insects on crops. This integrated control approach selectively targeted the chemical applications to work alongside natural predators of pests. While the phrase “Integrated control” first appeared in Michelbacher and Bacon’s paper from 1952, it is difficult to determine when it became commonly used by practitioners, as it did not start appearing in the literature until the late 1950s (Stern et al., 1959; Smith and Hagen, 1959; Getzin, 1960). These wholistic integrated control methods grew in popularity over the following years as more examples of their success were published in the literature (Getzin, 1960; Van Den Bosch and Stern, 1962; Rabb, 1962; Smith, 1978).

The term "Integrated Pest Management" was not coined until 30 years after the initial concepts of integrated control had been introduced. Although it is unknown who coined the term, it is attributed to being popularised in a presidential address by President Richard Nixon to the US Congress in the 1970s (Kogan, 1998). There is currently no concrete definition of IPM in the literature as emerging concerns have brought more attention to pesticide residues left on food and debates still continue as to the extent of IPM (Baker et al., 2002; Orr, 2003). However, there is consensus that IPM is undertaken in an informed and integrated whole of landscape approach to minimise harm both economically and to surrounding ecosystems (Kogan, 1998; Orr, 2003). Management methods are crafted in a sustainable manner to ensure the control mechanisms do not promote pesticide resistance. Modern IPM has incorporated the need to reduce damaging agricultural run-off and pesticide residues left on food crops.

The management methods used under an IPM strategy generally evolve over time. Long term goals are established, but goals vary to adjust for seasonal variation, weather and the engagement of stakeholders. Generally, IPM approaches require the collection of a significant amount of data to make effective management decisions (Ehi-Eromosele et al., 2013). Selective targeting requires knowledge of existing populations of a pest species and collection of this data is often an intensive process requiring staff to explore remote and difficult to access areas to confirm the absence of a pest. Search operations are conducted in an informed manner, using modelling and buffers around known populations to help reduce the search area. The selective treatment of pests in an IPM approach can contribute to reducing costs, collateral damage and ensure the sustainability of control mechanisms.

A focus on early intervention and eradication of emerging pest species is essential to effective pest management. Managing pests before they establish large populations can reduce their damage and associated management costs. As pest plants increase in both range or density, their potential for dispersal increases. Populations of emerging infestations typically follow an exponential curve as the plants multiply. Early intervention programs using IPM can help avert future impacts from specific highly threatening species. An example of this is the Four Tropical Weeds program run by Biosecurity Queensland (Erbacher et al., 2008) which targets five weeds occurring in North Queensland.

Managing existing and established weed populations is also an important part of pest management. An example of a program managing significant species is the federal management program called Weeds of National Significance (WoNS) (Hennecke, 2012). The WoNS program was established to focus on managing weeds with the highest potential to cause damage. Naturalised plants were prioritised based on their potential for spread, environmental and social impacts, and their ability to be managed. The 32 highest priority weeds were listed as Weeds of National Significance and strategic plans have been prepared for each species to coordinate management at all levels of government. All landholders, including residential and NRM groups, are required to manage these registered weeds on their properties.

2.3.2 Areawide Pest Management

Areawide Pest Management (AWPM) is an approach that has emerged and developed since the 1800s (Klassen, 2005). The approach of the AWPM's is the coordinated management of pests over a large area as opposed to management at the property level (Knipling, 1980). To be effective, this approach often requires the cooperation of large groups of stakeholders and landholders. AWPM was formulated into a methodology by Knipling and Rohwer and proposed to the North American Plant Protection Organisation (as described by Kogan, 1998). Their approach focussed on IPM over large areas seeking to suppress pest species to a manageable level (Knipling, 1980). Their argument was structured around four key criteria:

1. Planning should be conducted over a large spatial extent.
2. The program should be coordinated by organisations that represent all interests.
3. Priorities should be established to selectively maintain the most significant pests at acceptable densities.

4. Some management activities should be required of participants in the region.

The AWPM approach is often used when the sole effort of individual landholders is not adequate to manage or eradicate a pest species (Klassen, 2005). These principles of AWPM have been successfully applied in large-scale programs over the years and have been extensively reviewed in the literature by Chandler and Faust (1998). Some of the successful programs using AWPM include the eradication of Cattle ticks (*Boophilus annulatus*) and Screwworm (*Cochliomyia hominivorax*) from the USA, the successful eradication of fruit flies in a number of countries, and successful trials against *Ae. aegypti* mosquito in various countries.

A cooperative program between the federal and state government beginning in 1906 was run to eradicate the cattle ticks in the USA. The program worked in cooperation with cattle owners aiming to eradicate the ticks across the country. A cattle dipping program was conducted across fifteen states to treat the ticks, and by the 1950s the cattle ticks had been eradicated from the majority of the USA (Allen, 2008).

One of the major eradication successes of the AWPM has been the introduction of sterile males of a species released into the pest population. Knipling first proposed the use of sterile males to control the populations of Screwworm in 1937 (Lindquist, 1955). The program used radiation to sterilise the male Screwworm in an attempt to reduce the viability of the Screwworm populations. These sterilised males would compete with the wild males to mate with females but would be incapable of producing offspring. After the release of the sterilised males, infestations of Screwworm quickly declined before being declared eradicated (Knipling, 1980). Although the approach of using sterilised males did not require large-scale co-operation of property owners as did the cattle dipping program, it was beneficial to the entire US livestock industry.

2.4 Contemporary Pest Management

The evolution of pest management from a simple method of chemical control to an IPM strategy has driven the need to engage large groups of stakeholders in the management process. Pest species are not constrained by property boundaries or land ownership. Unmanaged pests on a property often become the problem of their neighbours over a period of time. Management strategies need to address pests across multitudes of land tenure and involve the coordination of neighbours and communities to effectively reduce the rate of re-incursion and for control methods to be successful (Allen et al., 2001). Every person who owns or manages land has a stake in pest management. Therefore, involving all stakeholders within a community in the pest management decision-making process is essential for management objectives to be effective over the long term.

Ideally, pest management plans would take into account the entire state of a pest in an area and define the most effective management activities that could take place. However, the extent of a pest is likely to occur across land owned by multiple stakeholders with varying interest in the process. Even landowners who are interested in pest management may only have knowledge of, or interests in, species that impact their activities. Pest management plans must take into account the varying levels of interest and co-operation in managing invasive pests.

2.4.1 Organised Pest Management

Currently, pest management in Queensland is overseen by a variety of organisations, government departments and individual landholders. Planning for species are conducted at a variety of scales. High priority species are managed on a national level by Biosecurity Australia, such as the WONS or Four Tropical Weed Program discussed earlier. Regional management groups such as the [Central Queensland, Whitsunday or Far North Queensland] Regional Organisation of Councils (CQROC, Whitsunday ROC, FNQROC) manage pests at the regional scale, assisting local councils to develop complementary plans with neighbouring councils (Far North Queensland Regional Organisation Of Councils, 2010). Each local council also conducts their own pest management planning activities for pest species in their local government area. In addition NRM groups, organisations and landowners all conduct their own planning and management on their individual properties.

The majority of organised pest management above the individual landholder level in the state of Queensland, Australia, use concepts developed from AWPM. Groups of organisations and landholders collaborate to address pests over large spatial extents. In Queensland (Australia) the Land Protection (Pest and Stock Route Management)

Act 2002 (QLD) requires all local councils to have pest management plans that define strategies and objectives across all land in their local government area. Each of these pest management plans uses an areawide approach to promote an effective and collaborative pest control methodology. These objectives are laid out by working groups and community forums. Some control activities are conducted by the local council but others are the responsibility of local landholders.

These contemporary areawide pest management approaches do, however, have their drawbacks. Burnett (2006) used a "weaker link" public good model to assess underinvestment in invasive pest management. They found that the promotion of large scale pest management activities often removes the incentives for individual regions to manage pests themselves, and leads to them relying on investment of others to manage pests to a sufficient level. In these cases, an effective strategy may be for external organisation to encourage individuals to support systematic areawide approaches. Florec et al. (2013) discusses Burnett's work in the context of the Qfly (Queensland Fruit Fly, *Bactrocera tryoni*) program run in Australia. Weak links in the Qfly management program, such as a single ineffective inspection station, can render the work performed by the effective inspection stations irrelevant. Funding must be applied in a manner to ensure weak links in programs do not render the whole program ineffective.

Further limitations exist at the local level. Objectives are developed by local councils for pest management across their local government area. However, individual landholders are not given incentives to manage pests that do not have a direct impact on their land (Epanchin-Niell and Wilen, 2015; Fenichel et al., 2014). Councils have enforcement powers to ensure compliance of individual property owners but this authority is limited by the staff knowledge of pest populations in the first place. This is a double-edged sword, with councils needing pest distribution data to make quality decisions, but their enforcement powers have the effect of making landholders reluctant to report pests. These local pest management plans and areawide plans need to be developed in a careful manner to ensure individuals are invested in the process and incentives promote action on their part.

2.4.2 Modelling and Forecasting to Direct Resources

Pre-emptive action is a core principal of pest management practices. Land managers have always used and sought new methods for improving their control methods. Work in the 1930s, around the time integrated control started to emerge, used weather forecasting and solar cycles to predict pest population surges (Hoskins et al., 1939). The advent of computers and satellites in the 1970s brought new opportunities to enhance predictive capabilities with vegetation assessment and rainfall monitoring (Hielkema et al., 1990). As computers became faster, modelling became more ambitious and optimisation algorithms emerged to support decision making in agricultural pest management (Shoemaker, 1973; Hartstack and Hollingsworth, 1974).

A number of different computer-based modelling approaches have emerged over the last 50 years to support pest management planning. This section will provide an overview of some of the widely used modelling tools and concepts. This is in no way an exhaustive comparison between the different tools, but also serves to provide a picture of the techniques available for conducting pest management planning. Species distribution models, dispersal models, habitat connectivity analysis and tools for developing pest management strategies are described below.

2.4.2.1 Species Distribution Models

Species distribution models combine species presence/absence data with environmental predictors to determine their potential habitat (Guisan and Zimmermann, 2000). These models are designed to provide predictive capability when current occurrence records are sparse. They typically work by finding patterns in collected data, describing environmental attributes and where the species currently occurs, and using this as a representation of the required abiotic conditions for the species. The potential habitat is then estimated by finding locations that are similar to these conditions. This suitable habitat of a species can be used by pest managers to target delimitation and control exercises or define future potential ranges for pre-emptive work (Peterson and Vieglais, 2001).

Maxent (Phillips et al., 2006) is one of the most well-known and highly regarded species distribution models (Hernandez et al., 2006; Elith et al., 2006) and has been widely used in ecology and pest management (Cini et al., 2012; Kumar et al., 2014). Maxent uses a statistical maximum entropy algorithm to determine the potential geographic distribution of a species. Other examples of widely used species distribution models include: Bioclim, which uses an envelope estimation algorithm (Busby, 1991); and GARP[1], which uses a genetic algorithm (Scachetti-Pereira, 2002). They are often used in conjunction with other modelling tools to help direct the pest management planning process.

2.4.2.2 Dispersal Models

Dispersal models combine species distribution data with the habitat suitability model and a dispersal function to create a simulation of a species spreading over time. Pest plant species disperse through a variety of different biotic or abiotic mechanisms. Some of these mechanisms include the wind, water, animals and humans. Different mechanisms influence the dispersal distance of a pest plant. For example, plants with seeds that are not dispersed by external vectors have very limited dispersal range, whereas a plant dispersed by birds or humans can disperse hundreds of kilometres. The dispersal mechanism, the productivity of the pest plant, its suitability to the environment and its current distribution and density can be used to predict how it will spread through the landscape.

Another major predictor of the dispersal of pest plants is propagule pressure (also known as introduction effort). It is based on the number of individuals involved in a release event (propagule size) and the frequency of the release events (propagule number). Propagule pressure is considered to be able to explain why some invasive species are successful when others are not (Lockwood et al., 2005). As the frequency or size of release events increases the probability of seeds establishing in surrounding suitable areas subsequently increases.

Dispersal models are often used in pest management and conservation to predict how species will move over time. Many different approaches to dispersal modelling have been described in the literature (Nehrbass et al., 2007; Will and Tackenberg, 2008). Fennell et al. (2012) developed a tool using a mechanistic model that simulated the dispersal of

[1] http://www.nhm.ku.edu/desktopgarp/ (accessed 18/07/16)

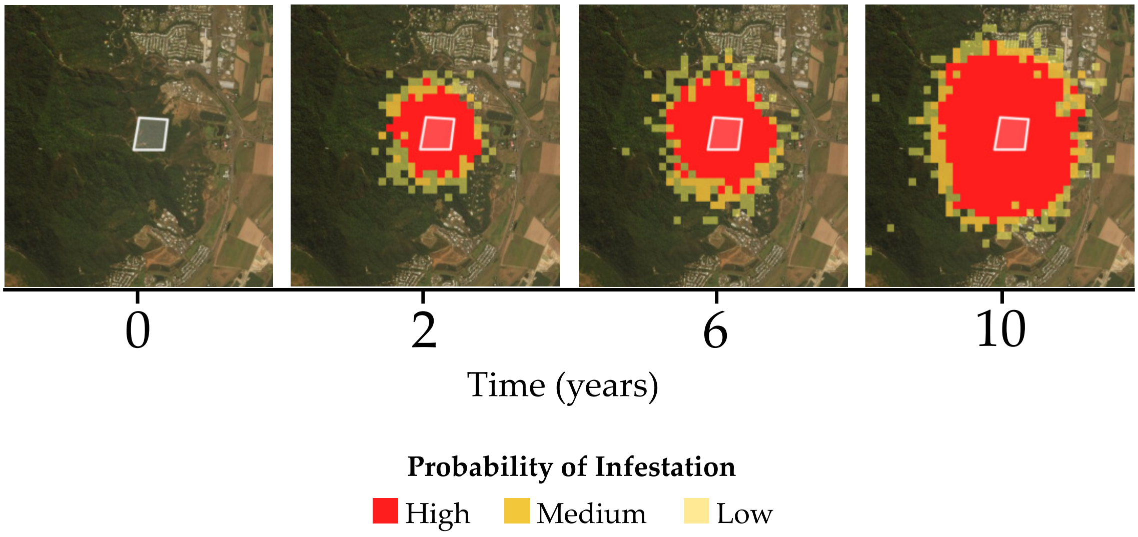

Figure 2.2: Visualisation of the MigClim dispersal model, captured from the software developed in this thesis.

invasive plants via dispersal corridors. Higgins et al. (2000) devised a decision support tool that modelled the dispersal of invasive weeds that disperse after fires. Their tool integrated multiple modelling approaches to allow decision makers to understand the interlinked nature of fires and pest dispersal.

Often, dispersal models are built using a specific statistical methodology and few generic examples or frameworks are known. One of the few generic widely used dispersal simulation tools is MigClim (Engler and Guisan, 2009) (see Figure 2.2). This is a stochastic cellular automaton using dispersal potential and habitat suitability to determine the probability of a planning unit becoming infested in each dispersal step. MigClim has been used on a variety of projects, including species response to climate change (Alarcón and Cavieres, 2015; Godefroid et al., 2016) and pest management (Sydes and Murphy, 2014). Sydes and Murphy highlighted the opportunity dispersal simulation tools, like MigClim, offer to inform decisions and engage new audiences around pest management.

2.4.2.3 Habitat Connectivity Analysis

Habitat connectivity is a measure of the landscapes ability to provide opportunities for species to move around. In some areas, suitable habitat for a species may be connected by thin strips of suitable habitat known as corridors. In conservation management, ensuring suitable habitat is adequately connected is important to maintaining biological diversity (Krauss et al., 2010). Invasive species, however, can also make use of these landscape corridors to spread (Procheş et al., 2005). In pest management, the connectivity of a pest species habitat can be exploited to limit their dispersal potential at a bottleneck in the network (Minor and Urban, 2008). If a pest species requires corridors to spread between patches, it can be contained to a patch by focussing delimitation and removal efforts on the corridors.

A number of habitat connectivity analysis tools exist to support managers in making decisions around conservation and pest management. Some examples of popular tools include: UNICOR (Landguth et al., 2012); the Connectivity Analysis Toolkit (Carroll et al., 2012); and Circuitscape (Shah and McRae, 2008). All of these tools use a shortest path algorithm to determine the connectivity of different patches of suitable habitat. They have been used to investigate species movement in climate scenarios (Nuñez et al., 2013), placement of habitat bridges (Stoner et al., 2015), reintroductions of species (Jarchow et al., 2016) and pest management (Alvarado-Serrano et al., 2016).

2.4.2.4 Strategic Decision-Making Tools

Many new tools have emerged that incorporate large amounts of spatial data to allow managers to make better decisions. Januchowski-Hartley et al. (2011) postulated that pest resource prioritisation using non-systematic methods is too complex. They presented a methodology that identifies the optimal spatial locations for applying management actions for invasive species while minimising the costs. New tools are starting to emerge that allow managers to use a systematic process to optimise their strategies based on costs and benefits. Coinciding with the final stages of this research project, Brotankova et al. (2015) presented a model that allows managers to interact with an optimisation algorithm using a budget, different actions and changing management objectives.

2.4.3 Conservation Planning - A Closely Related Field

Systematic conservation planning is an approach which aims to design effective reserves to protect biodiversity. Pest management is often a major consideration of conservation planning and conservation plans often involve strategies for the management of invasive pests species to prevent damage to biodiversity and the environment. The two fields are closely interrelated and often reserves and mechanisms designed to support biodiversity can often promote the proliferation of invasive pests. A brief overview of conservation planning and decision support tools is provided below.

Conservation decision support tools have been utilised in real world conservation planning scenarios for several decades. The decision support tools help process large species and land datasets to produce meaningful conservation outcomes. An important part of the conservation planning process is ensuring the long term sustainability of conservation plans by minimising the costs. Similarly, engaging the community can help ensure conservation is managed in an effective and affordable manner.

An ideal conservation plan will take into account not only protection of the environment but the costs associated with implementing the plan in the long term (Margules and Pressey, 2000). Costs have often been disregarded as part of the conservation planning process, however are vital to ensuring the long term affordability of the plan (Naidoo et al., 2006; Moore et al., 2004). The ability of a government to afford the conservation plan's recommendations into the future is one of the most important factors to be considered in designing the plan in the first place (Younge and Fowkes, 2003; Cowling et al., 2003) Reducing the costs of conservation plans provides the ability for broader and more comprehensive conservation to take place.

Conservation planning tools are used widely to assist in the planning process of environmental conservation. From 2006-2011 Queensland, Australia ran a "NatureAssist" program[2] to protect the biodiversity of the state. Hajkowicz et al. (2008) built conservation plans covering 81, 046 hectares to a value of A$1.9 million using systematic conservation planning tools. To minimise the costs and maximise the protection of the environ-

[2] The NatureAssist program co-operates with landholders on specific properties, based on their conservation value, to reduce the impact of stock and pest animals on the environment. https://www.ehp.qld.gov.au/ecosystems/nature-refuges/natureassist/

ment Hajkowicz et al. implemented a custom combinatorial optimisation, similar to the Marxan reserve design algorithm.

Marxan is a systematic reserve design tool that supports the decision-making process by designing and implementing plans to conserve animals and land types (Ball et al., 2009). Marxan is currently one of the most widely accepted and frequently used conservation planning and reserve design tools. Marxan is designed to process large datasets of species distributions, land types, costs and requirements. The data is processed to provide decision support to conservation problems by processing the data with a technique commonly referred to as the Knapsack problem.

The current conservation decision support tools provide much-needed analysis of large datasets needed by planners. However, they do not assist in the engagement of the general public. This engagement in the conservation planning process significantly aids plans to become more politically and financially sustainable (Rands et al., 2010). Ideally, these tools could help engage the public and further their understanding of the conservation planning process.

2.4.3.1 Summary of Available Tools

These modelling tools applied to pest management allow planners to develop an understanding of pests at larger scales than would have otherwise been possible. Dispersal simulations and connectivity analyses give a glimpse of the future and support strategic decision making. Meanwhile new tools implement optimisation algorithms that work co-operatively with planners to guide their decision-making process.

2.4.4 Participation in Planning

Participation in environmental management has evolved through several distinct phases over the years. During the 1960s awareness raising campaigns around environmental issues were the dominant form of local engagement (Lynam et al., 2007). During the 1970s planners started to take note of local knowledge discovering communities had a wealth of collective knowledge far more diverse than the planners could collect themselves. The 1980s saw the surge of Rapid and Participatory Rural Appraisal (RRA / PRA) techniques establishing local participation as the norm (Chambers, 2006). Participation in environmental decision making continued to progress into the 21st century and is described by Reed as *'increasingly becoming regarded as a democratic right'* (2008, p. 2418).

The term PRA describes the group of approaches and methods that enable local people to collaboratively build plans and to act on their implementation. These emerged during the late 20th century with the aim of empowering local residents in their decision-making process. Chambers (2006) describes his own experiences around the emergence of participatory techniques in the 1970s with a project mapping local wells in a South Indian village. Chambers spent two days mapping wells but failed to develop an adequate map due to his lack of familiarity with the area. On his second visit during the 1980s, he invited local farmers to make their own map. *'They did the plotting in just 25 minutes!'* (Chambers, 2006, p. 3). Other experiences with similar findings emerged around the same time (Conway, 1985).

In the past, pest management was most often viewed as an issue for the individual landholder. With the emergence of AWPM approaches and IPM as methods for effectively controlling widespread pests, modern approaches have become more collaborative. There is a push from both landholders and organisations to form co-operative pest control groups. In Australia, there are a mix of public (local, state, national organisations) and private pest control groups that conduct pest management. The public pest control groups often develop requirements for landholders to manage pests. Local groups form to collectively control pests across their properties where there may be benefits to collaboration (an example of this is described in the Interviews conducted in Chapter 4). However, landholders do not often want to participate in voluntary private groups unless given incentives to do so (Rook and Carlson, 1985).

Earlier in the review, the difficulties experienced stimulating investment in areawide pest management were discussed. Similarly, in conservation planning the involvement of the community and stakeholders is a significant part of ensuring the long term adherence to plans. Areawide pest management plans often impact on, and require effort from, participants that may not have any immediate stake in the problem. For large scale planning to be effective, communities must be engaged and actively working to manage their pest problems.

These human factors in relation to conservation and reserve design have been fairly extensively explored in the conservation planning literature. Participation in conservation decision making is seen both as a democratic right (Reed, 2008) and a necessity to promote adherence to plans (Knight et al., 2008). Conservation plans have a need for detailed local knowledge that is often only maintained by the locals who have experienced the situation firsthand (Berkes and Folke, 1998). Beyond the need for local knowledge and long term adherence to conservation plans, engagement of communities often ensures local values are captured and incorporated into the plan. When conducted correctly, these processes can empower individuals that may not have previously had a voice (Chambers, 2006). Furthermore, the incorporation of local knowledge and values increases the sense of ownership and reduces the potential for conflicts arising during the plan's implementation (Pressey and Bottrill, 2009; Rands et al., 2010).

2.4.5 Looking Forward

As described through the review so far, pest management planning has been moving towards larger scale participatory planning approaches. Practitioners and researchers have recognised the value and knowledge local participants can bring to the pest management planning process. Furthermore, managing pests in a collaborative method helps improve the effectiveness of planning and reduce the costs. However, there is still a disconnect between the planning tools and the non-expert participants involved in pest management planning.

The development of modelling and forecasting tools (described in Section 2.4.3.1 on page 32) has increased the ability of planners to make decisions that more accurately represent real world scenarios. However, these decision support tools have mostly been designed to be used solely by experienced planners and researchers. To truly realise the benefits of participation in pest management planning, the decision support tools should support those with limited experience in using GIS applications. As has been described in the PRA and conservation planning literature, engagement of local people can increase the knowledge available for decision making, ensure the plans represent local values and improve the probability of long term adherence and success (see Section 2.4.4).

Future pest management decision support tools must be designed to work in community forums and facilitate the involvement of non-expert community members. New tools could unlock a new wealth of information an analysis for stakeholders who do not currently have the budget to hire experienced planners or skills to conduct their own in-depth analysis. To find methods and techniques for developing these tools a review of engagement and interactive technologies will now be conducted.

2.5 Engagement Through Interactive Technologies

The land management process has been moving towards more in-depth and comprehensive visualisations over the past few years (Schroth et al., 2006; Pettit et al., 2011). However, the progression towards interactive visualisations in land management (particularly pest management) has been left behind when compared to other fields such as medicine (Pedreira da Fonseca et al., 2016; O'Connor et al., 2001), science (Donalek et al., 2014; Mathiesen et al., 2012), and education (Lee, 2012). The use of interactive technologies in these fields has been shown to aid learning of complex ideas through the use of pictorial representations, variability and improved spatial awareness (Posner and Keele, 1968; Lindgren and Schwartz, 2009; Finke, 1990). Applications of interactive technologies to computational modelling, known as computational steering, have improved user understanding of cause and effect processes (Parker and Johnson, 1995). These improvements in interpretative skills from these technologies show their potential application to land use management.

Touch-based computing, Virtual Reality (VR) and Augmented Reality (AR) have great potential for intuitive display and interaction as they give users the ability to interact directly with complex visualisations. When applied to land use management these new methods allow users to make changes and adjustments to the model inputs without the need to understand the mathematical model or the specifics of the science. The lowered skill level required for interacting with planning models will open up new opportunities for involving non-experts in the complex decision-making processes.

A more diverse and specialised knowledge base can be incorporated into the system by having a wider array of users to co-operate with the decision support algorithms.

Knowledge can directly flow into the planning scenario to change outcomes of the mathematical model without a planner needing to facilitate as a middle man. The direct input of new information will allow decision support algorithms to be run immediately without the requirement for the researcher to compile data. If the processing of the input is fast enough, users will be able to experiment and see how the environment reacts to different management plans. This solution refinement process between the user and computer is commonly referred to as Human-Computer Cooperation (HCC) (Terveen, 1995). HCC balances the non-linear creative thinking of individuals and the raw computational power of computers.

2.5.1 Interactive Technologies

Interactive computing is a broad topic that encompasses all software capable of responding to user input. Interactive software ranges from word processors to scientific visualisations and immersive video games. This review, however, confines itself to scientific visualisation and real-time interactive interfaces. Scientific visualisation has aimed to help scientists further understand complex data. Early scientific visualisation focussed on bringing new tools to scientists to make new discoveries in how natural processes work (McCormick et al., 1987). However, more recently, scientific visualisation has been applied to the teaching of scientific principles to students (Mintz et al., 2001; Pea et al., 1994).

Interactive technologies have been shown to aid learning of complex ideas through the use of pictorial representations, variability and spatial reasoning, (Posner and Keele, 1968; Finke, 1990; Lindgren and Schwartz, 2009). The application of these learning tools when made widely available can help to simplify the understanding of complex processes. Applications of interactive technologies to computational modelling, known as computational steering, have improved user understanding of cause and effect processes (Parker and Johnson, 1995). The introduction of interactive interfaces to conservation planning are sure to enable users to further understand conservation planning decisions without knowing the specifics of the science.

2.5.1.1 Virtual Reality

VR is a broad field that encompasses a number of technologies that create virtual environments with realistic imagery and sound. These virtual worlds simulates a user's physical presence in that and can reflect reality or construct artificial environments and experiences. VR seeks to exploit the users presence in the virtual world and allow them to experience that world from a unique perspective. Further, interaction with these environments can take place in a manner that may not be achievable in the real world. Some examples include, the user changing scale, seeing new perspectives, traversing environments quickly, or creating illusions (Normand et al., 2011). VR has been shown to have a number of advantages in motivation (O'Connor et al., 2001) and education (Lee, 2012).

One of the first proponents of VR was Sutherland (1965) with their seminal paper *The Ultimate Display*. Sutherland proposed that the system should stimulate as many of the senses as possible. He further described the need for haptic feedback where the virtual inputs could provide physical feedback and resistance to the user. Later works expanded on Sutherland's ideas developing head mounted displays (Mazuryk and Gervautz, 1996), haptic feedback systems and eventually video games, immersive rooms Cruz-Neira et al. (1992), and augmented reality.

Today VR has become ubiquitous, with a number of mainstream VR products available on the market. Video games are one of the most widespread examples. More recently a resurgence in VR headsets, originally conceived in the 1980s, has occurred with the release of the Oculus Rift[3] , PlayStation VR[4] and HTC Vive[5]. Google Cardboard[6] and the Samsung Gear VR[7] (shown in Figure 2.3), are a new type of low-cost VR headset that work with mobile phones. The cardboard makes VR headsets affordable for anyone who owns a modern smartphone.

VR tools have been shown to be effective at motivating users. Although VR is still in its infancy, many applications have been studied within medicine. Pedreira da Fonseca

[3]https://www.oculus.com/ (accessed 10/10/16)
[4]https://www.playstation.com/en-au/explore/playstation-vr/ (accessed 10/10/16)
[5]http://www.vive.com/ (accessed 10/10/16)
[6]https://vr.google.com/cardboard/ (accessed 10/10/16)
[7]http://www.samsung.com/global/galaxy/gear-vr/ (accessed 10/10/16)

Figure 2.3: Samsung Gear VR headset. *Image by Nan Palmero (Palmero, 2015).*

et al. (2016) conducted a clinical trial looking at the advantages of VR games when applied to reducing falls in post-stroke patients. The games were shown to improve the therapy process and reduce the number of falls. O'Connor et al. (2001) reported similar observations of games improving patient motivation in reaching their exercise goals. Participants at the conclusion of the study reported that the game helped motivate them throughout the trial. Staiano et al. (2013) also found an increase in weight loss when a game was compared to traditional methods. Many other medical studies looking at VR based motivation have shown promising results (Fox and Bailenson, 2009; Riva et al., 2000).

2.5.1.2 Augmented Reality

AR is the term given to the enhancement of the real world with additional information (Azuma, 1997). In essence, AR creates a hybrid view of the real and virtual world. This hybrid view can be used to bring new understanding to the real world by the addition of new information or the revealing of otherwise obscured information. Augmented reality extends the ability of visualisation technology to provide location specific information. Information can be placed into the environment as though it were real, to enhance the user's perception of reality (Livingston and Rosenblum, 2011).

The ability to provide additional information to users in the real world has been used in many scenarios, such as geological visualisation Mathiesen et al. (2012), performing maintenance (Henderson and Feiner, 2009) and navigation (Kroeker, 2010). In the armoured personnel carrier maintenance scenario, presented by Henderson and Feiner (2009), instructions were laid over the user's view. Components of the personnel carrier were highlighted and annotated to guide the participant through the maintenance process. The augmented reality tool helped the mechanic identify parts and repair problems without the need to refer to a physical manual. Users with limited mechanical experience could also utilise this technology to augment their knowledge and perform challenging tasks. Many other AR devices have been shown to offer significant improvements to non-expert users in performing complex tasks and understanding complex systems (Schall et al., 2009; Henderson and Feiner, 2009).

AR provides the ability to supplement the real world with additional information that can enhance the user experience. For instance, the addition of extra information to real scenes is fairly common in sports broadcasting. Televised ice hockey matches often add a glowing border to the puck to help viewers clearly identify and keep track of the puck as it moves across the ice (Azuma, 1997). Similarly, in live broadcasts of American football the first down line is commonly augmented over the football field, which allows viewers to see the line without needing to see the field markers in the televised shot (Azuma, 2004). This additional information in the user's view of reality enables them to quickly reference information to a specific point that may not be visible.

AR could enable planners to quickly view information in the context of the real world and VR could enable planners to remotely immerse themselves in different environments. Both of these technologies present an opportunity for decision makers to extend their understanding of pests and the landscapes they manage them in. However, AR and VR don't currently have mature collaborative frameworks, toolkits or best practices which would require development before this research question could be answered. As the technologies mature the opportunities for their application to pest management planning will only grow.

2.5.1.3 Immersive Rooms

Immersive rooms were first popularised in the 1990s beginning with the development of the 'CAVE' (CAVE Automatic Virtual Environment) (Cruz-Neira et al., 1992). The CAVE is a virtual reality device that immerses users into a virtual world by projecting images onto the walls of a small room. This was essentially a smaller version of the IMAX dome theatres, popular at the time. Unlike IMAX though, the CAVE uses a computer system to render the virtual environments in real-time. Participants could interact with and move around the virtual world. Further advances applied the concepts of the CAVE system to offices (Raskar et al., 1998), gaming (Jones et al., 2013), design (Seron et al., 2004) and scientific visualisation (Akkiraju et al., 1996; Ohno and Kageyama, 2007).

Immersive rooms like the CAVE allow participants to collaborate with other people while immersed in the 3D environment (Mortensen et al., 2002). Al-Khalifah et al. (2006) conducted a study with medical professionals using a CAVE system to study anatomy and practice procedures. They had promising results with the medical professionals requesting VR tools to become more common in medicine, citing the VR display allowed for easy identification of diseases. However, in the work of Swindells et al. (2004), comparing wayfinding using CAVE, wall and desktop displays, concluded that providing structure in the visualisations and interaction techniques improved performance more than the display characteristics.

Immersive rooms would enable groups participants to interact with a pest management planning tool in a shared space. Unlike AR and VR the immersive rooms have mature collaborative tools and approaches. A room configured with touch screen devices could enable large groups to interact with the system concurrently or as a team. Despite the advantages over AR and VR, immersive rooms are currently very expensive and are not easily transported to local pest management meetings.

2.5.1.4 Touch Screen Devices

Touch screens have become commonplace across mobile computing. They appear on the majority of smartphones and are slowly making their way into the monitors used on laptops, advertising screens and kiosks. Technologies have also been developed that

Figure 2.4: Participants collaborating around an interactive projector during the observational study conducted in Section 4.3 on page 106.

allow generic projectors to be turned into touch displays enabling much larger touch capable devices to be produced at a lower cost.

Collaborative multi-touch systems gained massive popularity in research with the launch of the DiamondTouch (Dietz and Leigh, 2001). The DiamondTouch was a large projection based table that tracked multiple participants and enabled them to interact with the touch screen concurrently. Although multi-touch systems had existed for a while (Fallis, 1985), the DiamondTouch was the first major consumer-ready device that was easy to setup and use. This spurred a surge in research around multi-touch devices and interaction techniques.

Since the DiamondTouch, touch screen devices have become ubiquitous, in smartphones, tablets and computers. Touch screen displays even include wall-sized interactive displays. Modern touch input projectors are common, affordable and often used in education settings. Touch screens have become a part of life for a large section of the Australian population. An example of a modern multi-user interactive projector is shown in Figure 2.4.

Touchscreens have many advantages over the more traditional keyboard and mouse interaction methods. The keyboard and mouse provide a mechanism for interacting indirectly with user interfaces. A mouse performs an action on screen that could more intuitively be represented by a touch action on the device. The ability for touch screens to directly manipulate interfaces on the screen brings computers closer to the methods a person would use to interact with physical objects. Used in pest management planning a touch capable tool would enable participants to directly interact with the environment. Touch interactive projectors enable direct interaction, collaboration amongst users, and are easily transported. A large touch screen device would be ideal for enabling local pest management planning sessions to easily interact with collaborative decision making software.

2.5.1.5 Computational Steering

Computational steering is a concept where a user can guide a computation as it happens. This enables a user to make changes as they occur or completely abort the process if it is not producing output as desired. Examples of areas where computational steering is used include scientific modelling and visualisation, engineering simulations and video games. Computational steering of scientific visualisations has enabled scientists to more effectively work through problems by reducing wait times for results and allowing changes to happen instantaneously.

Computational steering is commonly used in the field of computational fluid dynamics (CFD). CFD uses computational and numerical methods to simulate fluid mechanics. Interactions between liquids, gases and surfaces are simulated to enable the design of systems that rely on fluid mechanics. Some examples of this include improving the aerodynamics of vehicles, designing aircraft and simulating the flow of water in floods. Interactive computational fluid dynamics has recently become fairly common (Joshi and Ranade, 2003). The interaction between gases, liquids and surfaces are computed and displayed to the user in real-time. The enablement of steering in CFD simulations has improved productivity for users by reducing the time needed to experiment. Furthermore, the reduction in experimentation time enables more experiments to take place and allows more exploration to be conducted in the design process.

2.6 Combining Interactive Technology and Pest Management Planning

Pest management planning has been moving towards collaborative areawide methodologies over the past decade. A need exists for new tools that: promote collaboration and consensus building amongst stakeholders; ensure plans represent local values; incorporate the full range of local knowledge; and empower participants in making informed decisions. The previous section of this review covered a number of new and emerging interactive technologies that solve similar problems in different fields. In this section, a discussion of the highlighted tools and their potential applications and limitations to pest management planning will be conducted.

2.6.1 Interactive Modelling

Computational steering has enabled engineers and designers to rapidly model and simulate designs (Joshi and Ranade, 2003). A similar approach applied to pest management could enable planners and stakeholders to work in planning sessions to formulate, test, learn and re-formulate management strategies. This literature review has identified a number of gaps in the pest management planning processes that could be filed by interactive software. These gaps are restated below:

- Areawide pest management is limited in involving landowners to manage pests that do not directly impact them.
- Areawide pest management can remove the incentive for regions to manage their own pests in the hope that someone else will do it.
- Landowners and local councils often lack a full understanding of the pests and management activities being conducted in their regions.
- Decision support tools require expertise and experience that the some planners and stakeholders do not have.

The conservation planning literature described the importance of stakeholder engagement in planning. Long term adherence, viability and funding for conservation actions often relies on participants having incentive or interest in the planning process. Furthermore, local people have a wealth of knowledge and firsthand experience in their environment that can contribute significantly to the planning process. Pest management often requires pests to be managed across vast areas with the co-operation of large groups of stakeholders. Local knowledge and involvement from as much of the community as possible is invaluable to achieving success in pest management. The question that emerges from the literature is, *"What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?"*.

Interactive and intuitive user interfaces could offer the ability for stakeholders to directly manipulate models and simulations used in the current range of decision support tools. Groups of stakeholders could collaborate around a dispersal model to understand how their management actions influence the pest species over time. The participants in these sessions could develop an understanding of the impact of their actions and use this to iterate and improve their plans. These collaborations could be enabled by easy to use software on multi-touch tables. Using an interactive dispersal model would require participants to communicate their own actions and provide a visual medium to demonstrate why each participant needs to be involved.

2.6.2 Considerations for New Interactive Decision Support Systems

The potential for engaging and motivating stakeholders in pest management are vast. However, care must be taken in developing these tools. Visualisations of pest management data have been used since the conception of organised pest management. These visualisations serve as communication tools to engage, inform and elicit action from communities. Many of these visualisation techniques have been developed and refined over long periods of time to ensure they promote discussion and do not actively suppress alternate points of view. Inaccurate visualisations and datasets that are used in planning have the potential to cause widespread distrust of areawide pest management planning.

Orland et al. (2001) argued that GIS-based decision support tools and VR tools have different objectives. The original intention of GIS was to present an objective view of the data that is open for critique and evaluation during the planning process. However, VR technology is primarily motivated to create a sense of realism and immersion of users into the environments. Orland et al. (2001) argue that the sense of belief VR technologies create in the virtual world may stifle feedback and review of the participants. Although the aim is to engage stakeholders in pest management planning, the development of supportive interactive tools should leave the data open for critique and review. In the development of new tools, care must be taken to ensure the tools communicate the limitations and assumptions made when visualising the datasets.

Modelling species distributions and dispersal is a complex process requiring the planner to have specific expertise. Furthermore, the interpretation of these models often requires planners to understand the context and limitations of the data. Araújo and Peterson (2012) conducted a review exploring the criticism and misuse of distribution modelling. They noted a number of studies that found mismatches between predictions and observations. Araújo and Peterson argued that while some models were implausible, the majority of criticism centred around models being used to draw conclusions that it could not answer. The responsibility lies on the researchers developing models to understand the limitations of the data models represent. In an approach using interactive tools in pest management, it is a requirement for visualisations to accurately convey meaning. Designers of these tools ought to pay special attention to ensure that participants ask questions of the model in an appropriate manner.

2.7 Chapter Summary

This chapter has conducted a review of the literature concerning pest management planning, interactive technologies and the combination of the two. Pest management has moved from a field-to-field based approach to a larger areawide approach where the context of pests in an entire region is taken into account. This areawide approach is a complex process, involving numerous organisations and landholders. There are a wide array of decision support tools available to support the collection, analysis and review of data. These tools are applied in pest management to inform future strategies and to develop early intervention strategies. Throughout this literature review a number of gaps in the literature were found:

- Areawide pest management often does not create incentives for landowners or regions to participate in the process.
- Decision support tools were not intuitive or easily used by planners or stakeholders that do not have previous experience modelling species.

The advent of touch-based computing and augmented reality have opened a new arena for intuitive display and interaction with visualisations. These technologies now give users the ability to interact directly with complex visualisations. Pest management planning with interactive tools could allow a more diverse and specialised knowledge base to be incorporated into the planning. Local knowledge from participants could be directly incorporated into the planning scenario as management strategies. These strategies could influence the input of a model and provide participants with feedback on the quality of their plans. Simplified and direct manipulation of model inputs could enable non-expert stakeholders to use such a tool. If the processing of the input is fast enough, the tool could be used in an experimental manner to see how the environment reacts to different management strategies.

Chapter 3

Methodology

Chapter Overview

This chapter describes the research design and methodology used to answer the research question, *"What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?"*. An Activity-Centred Design (ACD) (Gifford and Enyedy, 1999) approach is used to explore the pest management space and develop an understanding of the existing processes. Activity Theory and Activity-Oriented Design Methodology (AODM) (Mwanza, 2002) are used to assist in the decomposition and understanding of the existing processes and activities. Findings from the exploration process were used to guide the development of a pest management planning tool.

The research methodologies are described first (3.1), followed by a list of the research tools used and their rationale (3.2). A detailed description of the activities undertaken during this research project is given (3.3), followed by the recruitment methods for participants and ethics requirements (3.3). Finally an overview of the recording and analysis methods are given (3.3) followed by a summary of the research methodology.

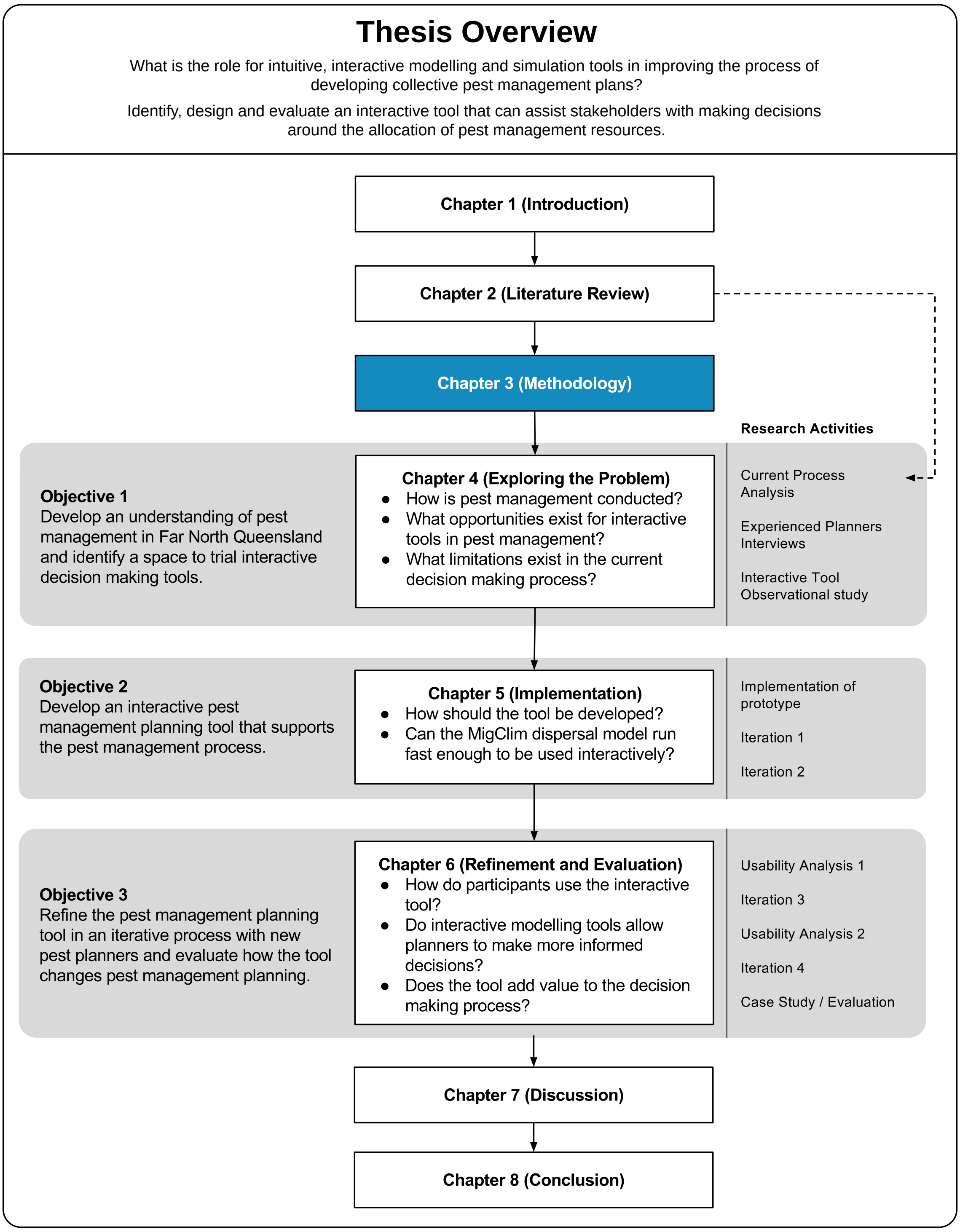

Figure 3.1: Diagram showing the order of research activities presented in this thesis. The blue highlight illustrates the current position in the thesis.

3.1 Research Theory: Activity-Centred Design

Human-Computer Interaction (HCI) is the field of research that seeks to understand how people interact with computers. HCI is a cross-discipline research field combining computer science, design, psychology and industrial design. Early approaches saw users as simply another component of the computer system and limited attention was paid to the needs, requirements and the environment of the users. HCI later progressed to a Human-Centred Design (HCD) approach where users were given consideration as complex components of the system. The change to a human-centric model emphasised the needs and objectives of the users. These objectives could be met through a collaborative process between humans and technology (Grudin, 1991). The user interface provides a means for people to interact with technology and in the 1990's research began to develop methods for improving the communication between human and computer.

In Activity-Centred Design (ACD) a broader perspective of the context that humans use to interact with computers is taken into account. The interaction between humans and computers that occur within a community is governed by motives, rules, culture and historical practices (Gay and Hembrooke, 2004). Activity theory, a model of human behaviour and the practice of work, is used as an orienting framework to ground the interaction between people, computers and the design processes in human psychology. Gay and Hembrooke developed an iterative design model (Figure 3.2) for applying activity theory to the contextual design processes. This ACD process emphasises the importance of examining the current practices and understanding the contradictions and limitations within them.

An ACD approach is used throughout this project to develop a tool to support decision making in the pest management planning process. This research project is one iteration of the ACD cycle. The project is broken down into several research components. All components of this study are tightly interwoven, and the findings of each feed directly into the next. The research components of this project are described below.

1. Understanding the activity taking place and the current practices, and using observations and interviews with stakeholders,

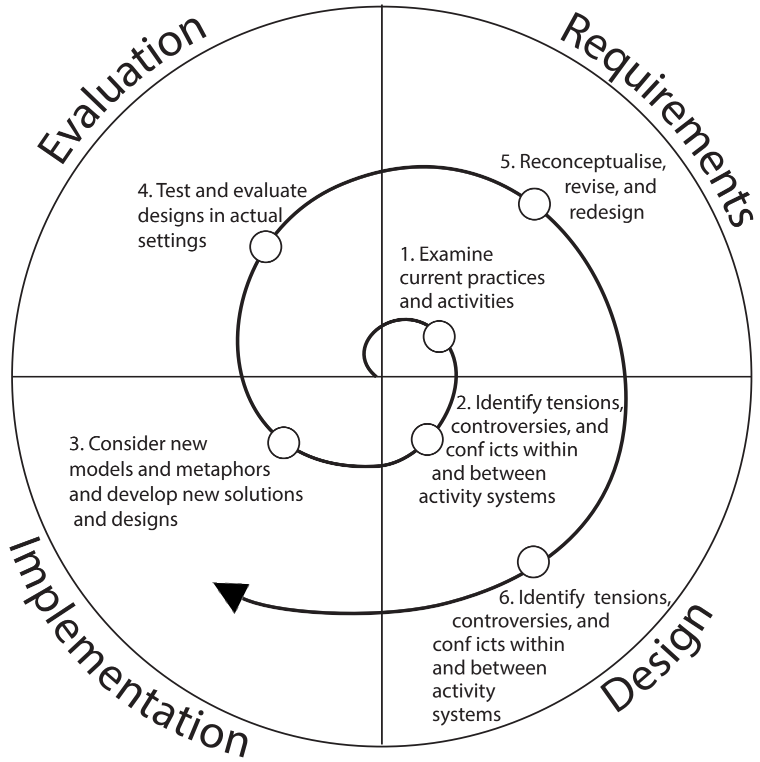

Figure 3.2: Activity-Centred Design process proposed by Gay and Hembrooke (2004). *Diagram by Bishop (2016).*

2. Identifying the tensions, breakdowns and limitations within the activity system/s using activity theory and activity-oriented design methodology,
3. Designing and implementing a software solution to support the activity,
4. Refining the user interface with usability testing sessions and conducting an evaluation in the real world.

This research project is made up of a mix of different methods and research tools to explore the research questions and objectives. Semi-structured interviews and observational studies were used to build a model of the current activity system and understand the current practices. Usability testing sessions were undertaken to refine the tool and ensure that it assists participants in achieving their pest management objectives. A focus group was run, with experienced planners, solving a realistic problem to evaluate the final tool developed during this process and to develop new directions for future research. Each of these tools and methods helps move through the ACD cycle.

The outcomes from the use of the pest management tool in a real setting were analysed using the criteria identified by McGrath and Hollingshead (1993). They identified three outcomes useful for the evaluation of collaborative tools amongst groups of users: task performance; user reactions; and participant relations. This analysis is then compared to the existing process to draw the final conclusions for this thesis.

3.1.1 Activity Theory

The first generation of activity theory began as a model of human behaviour where *'tools'* are used to mediate the interaction between humans and the *'object'* of activity (Vygotsky, 1978). The second generation expanded the model of tools facilitating activity in terms of the social contexts they are used in. Human activity is defined as the result of collaborative and collective work within groups of people (Leontyev, 1977). Leontyev expanded on the previous model introducing concepts of *'rules'*, *'community'* and *'division of labour'*. This was later developed by Engeström (1987) into the now well-known activity system producing the activity triangle (Figure 3.3). The third and most recent generation of activity theory, then adopted the use of multiple activity systems interacting to represent the network of collaborating people performing an activity (Engeström, 1987). This collaborative system approach allows the cultural and historical differences between different people or teams to be captured and viewed from the perspective of activity.

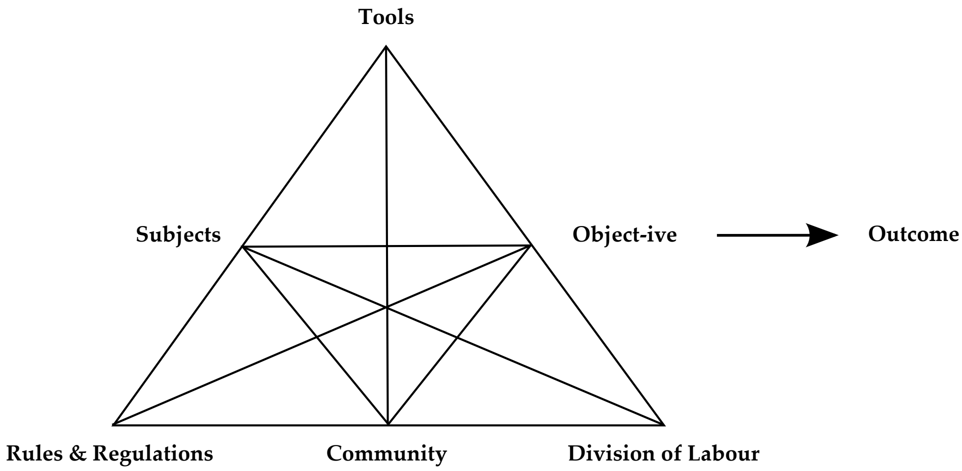

Figure 3.3: Second generation activity system developed by Engeström (1987).

The first notable systematic approach for grounding HCI in Activity Theory was made by Bødker (1987). This work developed a method for moving the focus from individual human factors to the broader settings of where the activity takes place, and the groups and communities who interact with computers. Technology is simply a tool which is used to mediate the interaction between people and the world and, therefore focus should be given to the wider context and environments that these tools are being used in. Bødker's work grew from contributions of others in the field (Bannon, 1991; Grudin, 1991) and became a core part of the Second Wave of HCI (Cooper and Bowers, 1995). Methods like activity theory, distributed cognition and situated action provided some different lenses to the world and a theoretical basis for analysis of interaction in the broader context Bødker (2015). Bannon argued that there was a need to understand *'people as actors in situations, with a set of skills and shared practices based on work experience'* (p. 25) in order to develop new methods for understanding the users of computer systems. This created the second wave of HCI, adding new tools and methods to the toolkit for developing an understanding of the work environments and the context of activity (Bannon, 1991).

A third wave later emerged when technology started to become more common in the home and everyday lives of individuals (Bødker, 2015). This wave identified new challenges as technologies expanded from predominantly supporting workplace activities to needing to provide people with utility in the explosive surge of personal computing. Research based on theoretical methods into the interactions and experience from industry have formed the basis for understanding how people use modern technology.

3.1.1.1 Activity-Oriented Design Methodology

Activity-Oriented Design Methodology (AODM) is a framework that has been developed to assist with the use of activity theory in research that looks at use practices with technologies (Mwanza, 2002; Mwanza-simwami, 2011). The framework was an expansion of Engeström's (1987) work on AT that situates findings in the context of social and cultural issues, in order to develop an understanding of the motivations behind human activity. AODM allows practitioners to apply the fundamentals of AT to HCI research in a methodological manner that does not require the same depth of knowledge one would typically require without using it. Although not a replacement for an understanding of activity theory it does assist in identifying further data collection activities and the revealing contradictions within an activity system.

AODM provides a toolkit for HCI researchers, containing methods, tools and guidelines for operationalising AT for studying activity systems. Four methodological tools are presented which help practitioners describe their area of investigation and decompose it into areas for further investigation.

1. The Eight-Step-Model: is a tool within AODM which supports the development of Engeström's activity triangle. It uses open ended questions to capture the activity system in the terms of AT to help the research communicate their understanding of the problem.

2. Activity Notation: which can be used to help decompose the activity triangle to identify the sub-activities within an activity system. The process of breaking the activity down into sub-activities reduces the complexity of analysing the system. During analysis the relationships and interaction between each sub-activity can be understood in the context of the main activity system. An example of the activity notation is provided in Table 3.1. The second row of the table can be read: How do Council Pest Management Officers use Enforcement to manage pests?.

Actors	Mediator	Objective
Subject	*Tools*	*Object*
Council Pest Management Officer	Enforcement	Manage Pests
Subjects	*Rules*	*Object*
Council Pest Management Officer	Pest Management Act	Manage Pests

Table 3.1: Decomposing the pest management process at local councils in Far North Queensland. Small sample showing how elements of the activity system are broken down into component parts.

3. A technique for generating research questions for further inquiry based on the interactions between the components identified in the sub-activity system.
4. A technique for interpreting research findings by creating a visual representation of the processes uncovered during the research process.

Behrend (2014) developed a framework integrating Action Research with Activity Theory to understand the shortcomings of their online writing resources. The framework showed how activity theory could be applied to user based studies of online resources. Behrend (2014) found that Activity Theory provided a mechanism to help them capture data and identify problems with the current online resources. Similarly Orland-Barak and Becher (2011) showed how Activity Theory could be used as a lens to gain a perspective on how small components of work practice are related to the bigger picture.

3.1.1.2 Choosing AODM and Activity Theory

Activity theory was chosen with AODM as the methodology for studying the activity of pest management. Findings from the study were used to guide the development of this pest management tool as used in this thesis. It enabled the researcher to uncover the current processes used in pest planning and develop a tool that could support the stakeholders in making decisions. However, this was not the only methodology used, some components of human-centred design methods were used to improve the usability of the tool.

Human-centred design approaches were the first methodologies explored for this project. Although a human-centred design methodology would result in developing a persona and scenario of each of the user types, it would lack an in-depth understanding of the activity users are performing. User-centred Design (UCD) has its strengths in co-creating user interfaces and tools that account for the user's current needs. This approach looks at adapting technology to suit the users, whereas an approach centred on activity would build an understanding of the underlying task to derive the requirements of the tools (Norman, 2005). The activity-centred process allows researchers to explore and develop novel tools that users may not initially see value in. Although both methods have competing foundations, they both borrow ideas and techniques from each other. Software and tools often go unused and fail when the underlying activity or the ability for humans to interact with them are ignored (Norman, 2005).

The decision to focus on the activity of pest planning over the human-centred design was later found to be validated. During the interview process most of the participants were requesting easier data sharing between organisations and a centralised data repository. Each organisation used different methods and tools for collecting, storing and working with data. From a research perspective, this is a rather trivial problem, and many centralised geospatial data repositories that solve this problem are commercially available. Having a focus on the underlying activity allowed the researcher to explore beyond these surface limitations of the current process. Following a strictly co-design process with these participants may not have resulted in the development of a novel tool that was not inline with the current research's goal to explore interactive tools.

3.1.2 Software Development and User Interface Design

Agile software development is a widely-used method in the development of software. Since lightweight software development methodologies first started to gain traction in the 1950's (Larman and Basili, 2003), this method has enabled software to be developed with continually changing feature requirements. New features and functionality are implemented in short cycles, commonly called iterations, allowing testing and user feedback to be integrated more often than in a traditional software development process (Martin, 2003).

The pest management planning tool to be created as part of this research project was developed using an Agile Software Development methodology. Short iteration cycles were used, with each adding to the feature set and/or improving the user experience of the previous version. The short iteration cycle allowed testing of the impact that individual components have had on the overall performance and usability of the software. Each iteration contributed significant changes to the code base and serves as the basis for the next phase in the interaction design process. The software was tested and observations made of the software being used by small groups of users. The iterations were not based on goals or specifications, however, they were a useful tool for grouping the research into phases for the purpose of the Thesis. Development of the user interface and the web service was a continuous process only divided by the short cycles.

Successful user interface design often relies strongly on the expertise of the designer. Although design rules and best practices exist they do not provide a standard methodology for mapping the user requirements and the activity to user interface components (Wood, 1997). HCI is an amalgam of Design, Technology and Psychology and the developer having a strong grounding in each is important for applied HCI. Effective methods used in HCI for user interface design essentially make use of best practice and design conventions (Wood, 1997) in combination with the input collected from focus groups and observational sessions.

3.2 Research Methods

The previous section discussed the theories and methodologies used in this project. These theories and methods each have a collection of tools that can be used to conduct research. The tools used as part of this study are discussed in this section. Semi-structured interviews were used to develop an understanding of the activities taking place in the current pest management process, from the perspective of different stakeholders. An observational study was conducted to build an understanding of interactive table surfaces used in practice and to explore how expert ecologists provided feedback to model outputs. Usability testing sessions engaged users with the developed software and helped refine the user interface. Finally, a scenario and a focus group was conducted with experienced pest managers to observe the software being used to complete pest management planning tasks in a realistic situation.

3.2.1 Semi-Structured Interviews

Semi-structured interviews are a form of interview where the area of study is well defined, but the participants are given freedom to vary their responses and add additional information (Drever, 1995). In contrast to structured interviews where the questions are delivered to participants in a predefined order, semi-structured interviews allow topics to be covered naturally. This approach allows the researcher the opportunity to probe for more detail into topics that may not previously have been known. Each interview can generate significantly different data and provide the researcher with responses that reflect each participant's perspectives around a topic. The variability in collected data can be difficult to analyse, however, using an activity theory methodology the semi-structured nature helps capture invaluable information and detail not easily captured by more structured approaches.

3.2.2 Observational Stuides

Observational studies are a commonly used tool in research that requires an understanding of human interactions or aims to explore a phenomenon (Runeson and Höst, 2009). These studies provide an empirical methodology for investigating complex and ephemeral real world issues. Researchers do not manipulate variables in an analytical manner or attempt to improve the process as would be done in action research. Observation data is simply recorded and analysed to build an understanding of the phenomenon. These case studies are often used in software development to understand real world activities and how people interact with technology. These observations can also take on a secondary role in the refinement and improvement processes of software whereby they are used to conduct pre-event and post-event studies (Baird and Riggins, 2012). Outcomes from these studies can be folded back into the software development process or can be followed up with further research to develop a detailed understanding of the end users.

3.2.3 Usability Testing Sessions

Usability testing is a central tool in UCD used to uncover problems with hardware and software relating to interaction and workflow. The goal is to evaluate the effectiveness of a tool in supporting users to accomplish tasks. Methods used for usability testing vary from the informal "hallway testing" to formal studies involving deep analysis to find any conceptual issues in activities taking place. Participants are observed using the tool, and recordings are made of any errors, mistakes or problems encountered by the users. These recordings can help identify usability issues, design flaws or communication issues with the software.

Finding usability issues is an important step in developing usable software. Selecting a sufficient number of users is essential to ensuring the majority of usability problems are found before the software is taken for further study or deployed to the end users. Virzi (1990) found that between four and five users identified 80% of the usability problems with an appointment calendar application. Nielsen and Landauer (1993) later developed a mathematical model that could incorporate a cost/benefit analysis into the study and found seven users to be ideal for small projects. More recent studies found that five users did not detect 80% of usability issues. Faulkner (2003) found only 55%-80% of usability errors could be uncovered with five users. Bastien (2010) studied users looking at four different websites finding only 35% of usability errors were found. The major discrepancies in these results between the earlier and later studies can most likely be related to the complexity and uniqueness more easily built into modern software (Faulkner, 2003).

Selecting the correct number of participants for usability analysis is a vague and variable area and often comes down to the purpose of the usability testing. In production environments and commercial applications, usability analysis should be conducted with large numbers of participants to ensure the product is of an acceptable standard for use. However, in research applications where the primary output is not the software a small number of participants may be more suitable for answering the research question. This research project does not aim to produce a commercially ready product but instead focuses on exploring the application of interactive technology to pest management planning. Therefore, a small number of participants can be used as the usability analysis only needs to ensure that the final tool is of a quality that can be evaluated in a fair manner.

3.2.4 Focus Groups

Focus groups first emerged in market research as a tool for guiding the collection of feedback from groups to inform product development (Morgan, 1996). A facilitator leads the group through a discussion around the topic of interest in a similar way to that conducted for a semi-structured interview. However, the group discussion stimulates input from participants, allowing them to build on the points raised by others and present information that the group can agree upon. Practitioners often use focus groups to collect detailed feedback from teams that work together to gather experience in the context of the group. Focus group techniques were adopted by the social sciences in the early 20th century and have often been used within mixed method approaches to attain a broader picture of the phenomenon being studied (Williamson, 2005).

Focus groups were adopted into the HCI realm as the focus has moved from individuals to groups of users undertaking activities mediated by tools and technologies. Different methodologies adopted their own techniques for integrating focus groups and best practices were formed around their use. These groups were further adapted into the standard toolkits of qualitative researchers as a method used for engaging large groups of people. Today, focus groups are often integrated into the software development process and provide valuable and, targeted feedback during the software development process.

3.3 Research Approach: Putting Theory into Practice

The research design used in this project uses a mixed methods approach across three distinct phases to support the decision-making process. Phase one (see Chapter 4) develops an understanding of the problem using AODM to analyse the existing processes and inform a series of interviews with stakeholders. Phase two (see Chapter 5) develops the findings from the first phase into an interactive decision support tool based on the MigClim dispersal model (Engler et al., 2012). Phase three (see Chapter 6) uses a series of user studies and trials of the prototype to identify usability issues and evaluate the tool with real users.

This project was initially conceived as an uninformed process to develop a pest management tool requiring limited input from the stakeholders who would end up using it. Few examples of similar work were known at the beginning of this project, and it was approached from a purely technical perspective. An interactive storm surge visualisation tool was one of the first proof of concepts constructed and was trialled in the real world with users. Although the storm surge visualisation tool became popular, the initial design of the tool was based on a simple problem. The storm surge visualisation tool provided a foundation for the researcher to understand how these interactive and participatory tools work in the real world. The pest management tool was a far more ambitious and challenging problem, and as such it quickly became apparent that a more methodological approach was required to understand the problem. Many nuances exist in pest management planning. Relationships between stakeholders, rules and regulations, and on the ground decisions have not been well described in the literature. A successful pest management tool would require a detailed understanding of the pest management process.

To build a better understanding of the existing pest management decision-making strategies, the pest management process in Far North Queensland was initially deconstructed and analysed to form the basis of this research project. Outcomes can be developed into simple research questions and tackled using user-centred design techniques, activity theory and computer science principles. Combining these with user interviews, user experience testing and a real-world evaluation allowed for the development of a software tool that can be used to support the pest management process. The findings from applying these research methods were developed into functional requirements and design requirements that were to be used during the implementation phases of this project. Each research component involved the refinement of the software implementation and engagement processes in an iterative manner. Software iterations were evaluated in the lab both by the researcher and with groups of users to refine the interaction process and improve the planning outcomes.

The research process is presented below in tables detailing when different research activities took place. The tables are laid out into three categories: exploring the problem; implementation; and usability testing and evaluation. Table 3.2 shows the activities undertaken to develop an understanding of the problem (Chapter 4). Table 3.3 shows the timeline of Development for the 5 software iterations (Chapter 5). Table 3.4 describes the iterative design process used with groups of users to refine the software and develop a tool that fits the needs of the stakeholders.

Activity	Date
Pest Management Forum	2 May 2014
Pest Management Working Group	3 May 2014
Interviews (6 conducted)	23 June - 30 July 2015
Observational Workshop	3 September 2015

Table 3.2: Research process in understanding the problem .

Activity	Date
Initial Prototype	October 2014
Iteration 2	18 August 2015
Iteration3	5 October 2015
Iteration4	15 November 2015
Iteration5	23 November 2015

Table 3.3: Software Development Timeline .

Activity	Date
Usability testing session 1	29 September 2015
Usability testing session 2	13 October 2015
Usability testing session 3	4 November 2015
FNQROC (Far North Queensland Regional Organisation of Councils), CSIRO (Commonwealth Scientific and Industrial Research Organisation) demo	11-12 November 2015
Focus Group	20 November 2015

Table 3.4: Usability testing and focus group timeline .

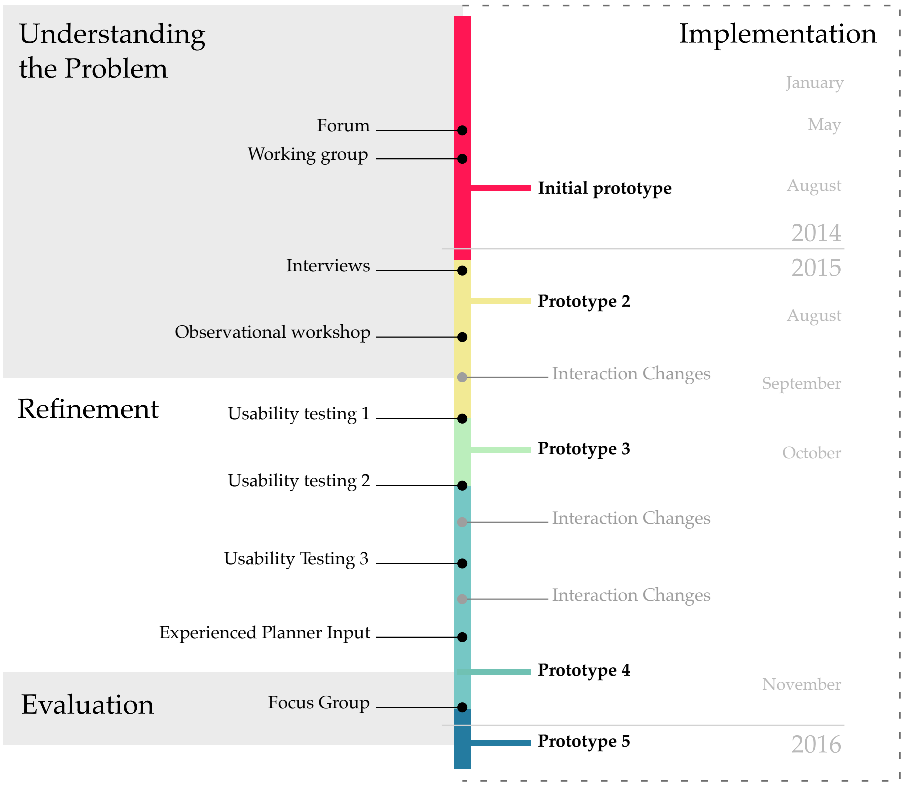

Figure 3.4: Timeline of the research activities undertaken as part of this project.

3.3.1 Decomposing the Existing Process

An analysis of the pest management planning process was conducted to develop an understanding of the advantages and disadvantages of the current approach. This decomposition looked for areas where simple interactive technology could support the decision-making process.

The initial data to establish the current process was collected by attending and observing public pest management planning sessions. Further understanding of the process was gained from mentorship from an FNQROC (Far North Queensland Regional Organisation of Councils) Natural Asset Manager and a CSIRO (Commonwealth Scientific and Industrial Research Organisation) species modeller, both involved in the Atherton Tablelands pest working groups. The researcher attended pest management forums in the Atherton Tablelands - where stakeholders would discuss their progress, and pest management working groups - where stakeholders would conduct planning.

Activity-Oriented Design Methodology was selected as a framework to assist with the collection and analysis of data. This analysis framework allowed for Activity Theory to be easily applied to an activity system and simplified the organisation of the collected knowledge. The Activity System provided a lens that helped highlight areas where understanding was limited or further data collection was required. Using the activity system allowed research questions to be easily developed for a continued inquiry into the existing pest management system. To answer these research questions, a set of interviews were conducted to collect more detailed feedback from individual stakeholders. The methodology for these interviews is described in the following section.

The on paper analysis of the existing processes using Activity Theory provided insight into the Pest Management process in Far North Queensland. From the forums, working groups and the review of the literature the shortcomings of the current process started to become apparent and provided the basis for a new planning tool to be developed.

3.3.2 Interviews

A series of interviews were conducted to assist in identifying areas that interactive tools could be applied to the pest management planning process. These interviews were conducted using a semi-structured approach (Rowe and Frewer, 2000) in an exploratory manner to build an understanding of pest management planning from the perspectives of different stakeholders. The outcomes of these interviews helped to identify motivations behind participants interests in the management process and problems when taking part in the planning process. All of the stakeholders involved were experienced in pest management and were currently working in pest management roles in Far North Queensland. Participants were asked questions relating to their organisation's involvement and how they viewed the planning process.

The interviews were conducted at each of the participant's workplaces, in their office or meeting rooms. The interviews began with casual introductory conversations to build a rapport with the participants. During the conversations, the researcher would transition to the topic of the interviews and discuss the process and ethical requirements along with the expectations of the participants. Participants were informed about the nature of semi-structured interviews and that they were free to discuss anything that came to mind. Once participants were aware of the ethical requirements and had consented to be interviewed, the researcher started the voice recorder and began the interview.

The initial questions were aimed at understanding the background of the participants, including their time in their current position, their experience with pest management and how their role fit into the organisation's goals relating to pest management. A full list of the interview questions are attached in the Appendix (Section 9.3 on page 263). A summary of the question topics is provided below.

The questions fell into the following categories:

1. Background
2. Organisations role in pest management
3. Relationships with other organisations and the community
4. Areas the pest management process could be improved, with or without technology

5. Their experiences with technology in the pest management process

The purpose of the interviews was to understand what influenced each type of stakeholder and their behaviours towards invasive pests, as well as their interests and needs. The findings from the interviews helped design a system that can support as much of the pest management process as possible.

The majority of the interviewed stakeholders were working in the same region and had tense relationships with one another due to differing perspectives and priorities. Stakeholders directed blame for past failures towards specific organisations or groups of individuals. When questioned about this in depth, it became apparent that the disagreements were often related to how funding was being spent or the other party having a different goal. Conducting further analysis after the completion of the interviews showed that the researcher's first impression may have been correct to some degree, but most groups observed have strong working relationships and a great deal of respect for the other organisations involved. These findings helped reveal that consensus building was an important requirement of any future pest management planning tool.

3.3.2.1 Participants

Stakeholders were initially approached by email (see Section 9.2.1 on page 257) to request their participation in the interview process. The majority of the stakeholders were already aware of the project from their previous involvement in the Pest Management Forums and Working Groups that the researcher had attended. Participants were selected so the group represented a cross-section of those typically engaged in pest management planning at the regional level.

Several landholders were invited to take part in the study. However, only one responded six months after the interviews had been held. Instead, a local farming representative group was selected to participate in the study and provide their insights on pest management at the individual landholder level. The representative group worked very closely with farmers and assisted in day to day pest management operations.

Six participants were selected randomly from a contact list that had been grouped by the different management layers. The number of candidates from each group that were interviewed are shown in Table 3.5.

Organisation	Participants
State	1
Local Council	2
NRM (Natural Resource Management)	1
Industry Representatives	2

Table 3.5: Interviews participant breakdown.

3.3.2.2 Data Recording and Analysis

The interviews were recorded using a voice recorder. Additional notes were taken in a research journal to record participants expressions and the body language not captured by the audio recorder. The recordings were transcribed using the online transcription tool *oTranscribe*[1]. The emphasis of the participants in the recordings and handwritten notes were integrated into the transcripts to ensure that they were included during analysis after being coded.

The interview recordings were manually transcribed using the online transcription tool OTranscribe. Expressions and reactions were included in the transcription to support later analysis. These transcriptions were imported into Nvivo 10 and coded using two different approaches. The first method undertaken was a thematic analysis (Boyatzis, 1998), using Open Coding (Strauss and Corbin, 1990) to collate responses into themes that emerged throughout the analysis process. The second set of coding aggregated out of order responses that related to the questions asked.

The first analysis organised the data into the following themes:

- Demographics: To understand the background and experience of participants in the field of pest management.
- Prominent Weed Species participants had worked on
- Confidence in control mechanisms
- Instances where participants have worked with other groups
- How the management objectives differ to what they see on the ground

[1] http://otranscribe.com (accessed 10/08/15)

- Ways they could see technology assisting in managing pests and weeds

During the thematic analysis of the interview data, it became apparent that information relating to the questions asked was often scattered throughout the conversation. Participants would often add additional information to previous questions as we discussed related topics that stimulated their thought process. To organise and collect this data into logical responses to the questions identified during the AODM process the dataset was coded again using the questions as codes to group the data.

3.3.3 Observational Study

The observational study was not a planned component of this study but was simply an opportunity that emerged from a discussion with an ecology research colleague. This study component focussed on how groups interact with each other and a large interactive tabletop and was conducted with existing software. The project centred around modelling the future ranges of a large array of North Australian species, under different climate change scenarios. Several species experts, ecologists and planning experts were invited to provide feedback on the model collaboratively. Many of the experts had decades of field and first-hand experience observing and studying the species investigated during these sessions. The goal of this was to develop a set of rules that could be used to refine and improve the accuracy of a future range model.

Feedback from participants was generated through group discussions about the species and why certain species were under or over represented by the model in particular areas. The outcomes of discussions about the model's future representation of the species would then be sketched onto the digitally projected map to highlight the expert's thoughts about particular regions. An example of a participant sketching an idea onto the map is shown in Figure 3.5. As the session progressed, the experts developed their sketches and discussion into rules created which could then be used in the model to reflect their experiences in the field.

Sketches and comments were captured using a table mounted interactive projector. The projector was connected to a laptop and allowed the participants to interact with the large projected display as though it was a touch screen. Whiteboard software allowed

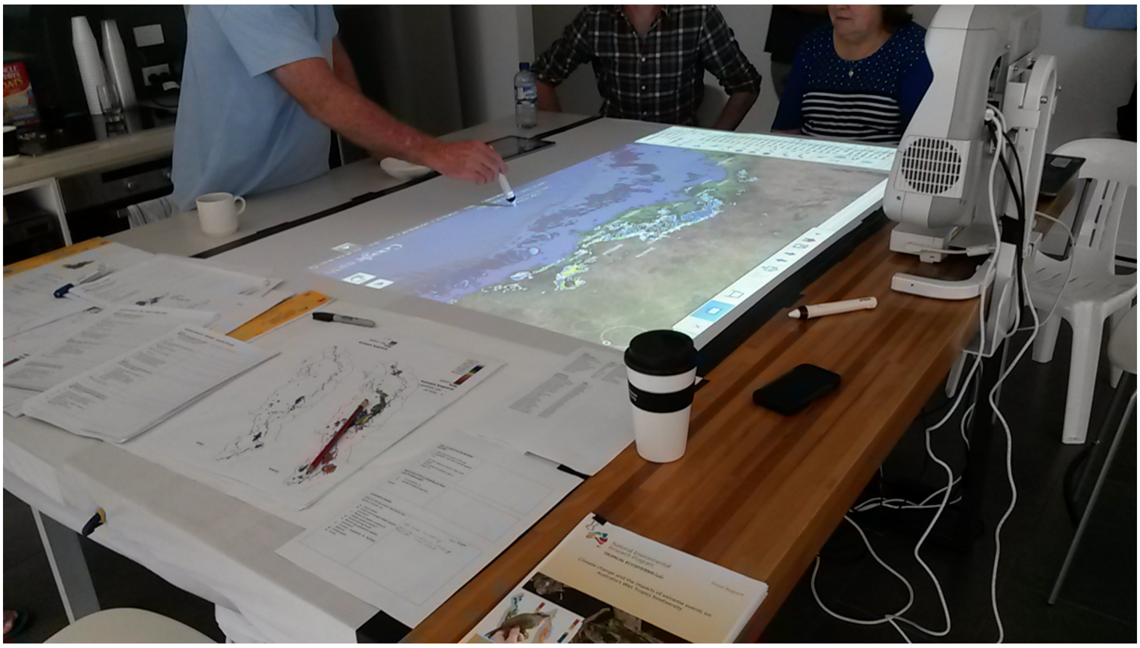

Figure 3.5: Participants sketching ideas onto a projected map during the observed workshop.

participants to digitally draw over anything that was projected on the surface and save the drawings for later use. The participants sketched ideas on top of the current and future ranges of species data. The projector provided an advantage over paper-based maps as sketches could be left on screen as the underlying data was changed. Participants would define the future ranges they thought were likely over the current known distribution, and then switch to the modelled future to make a comparison. Sketches on the table map were saved as images for later analysis by the researcher conducting the session.

Although the observational study was an unplanned emergent session, it provided the opportunity to develop an understanding of how collaborative planning worked around a touch responsive table. The study provided an insight into a successful use of a collaborative tool to capture knowledge from expert participants. Findings from this observational exercise proved to be useful in improving the user experience of the pest management tool and developing a training methodology (see Section 4.3 on page 106).

3.3.3.1 Data Recording and Analysis

Observations were recorded in an observation journal during the session. Ideally this session would have been recorded, however, with the location of the session, it was not feasible to get a camera or voice recorder at such short notice. While the session may not have provided the same depth of analysis that a recording would enable, it did provide many insights used in the development of the interactive tool.

3.3.4 Developing the Prototype

The observation of the pest planning sessions and the on-paper analysis provided insight into the existing processes and helped identify areas that interactive technologies could be used to assist the management process. From these findings, a prototype interactive pest management planning tool was developed. An agile software development process was used, which focussed on developing the software in a staged manner and verifying the components along the way. There were five iterations of the prototype software developed throughout this project. Each iteration was tested with small groups of users to inform the development process. The final fifth iteration, developed after the final evaluation, substantially improved the performance of the software but was not tested with the participants.

The first two iterations focussed on testing the individual components needed to implement a pest management tool. The second iteration allowed the MigClim model to be run from a web-browser and produced species dispersal simulations which would be played back to the users upon completion of the model run. The model could be adjusted by defining areas as unsuitable for a pest to grow. Each model run would overwrite the last one, and different versions of the plans could not be created. The changes made to the MigClim dispersal model reduced the runtime of a typical planning dataset at 1km resolution covering the Wet Tropic Bioregion, from 2.5 minutes to 20 seconds.

Prototype two and three were tested with staff and student participants to identify unexpected behaviour and make improvements to the tool. The testing sessions revealed a number of interaction and conceptual problems encountered when participants were using the tool. In some cases, participants would become frustrated or hesitant when attempting to perform actions, and they also expressed the need for additional information to support their decision-making process. These findings were adapted into changes to the software to improve the experience of the users when developing plans (see Chapter 6).

3.3.5 Refining the MigClim Model for Interaction

During the initial analysis, it was identified that modelling was useful for determining the targets that required action to be taken. However, the modelling required that an expert that was familiar with configuring and running the model and could not be done during the planning sessions. Integrating modelling into the planning session would require meetings to be reconvened so modelling could be conducted between them. This severely limited the utility of modelling as new information takes a considerable amount of time to be integrated into the process. To improve this, the modelling needs to take place in a timely manner during the sessions, to give stakeholders the opportunity to integrate new knowledge.

Incorporating the dispersal simulation into the process would allow pest planners to make adjustments and add new data without the need to organise a new meeting. Furthermore, a software tool that integrated the modelling and decision-making processes could allow stakeholders to test their management plans against a dispersal model and to perform comparisons between different approaches. The current process does not allow stakeholders to validate or inform their planning decisions beyond their expertise. Integration of a model into this process could help inform decisions and allow stakeholders to validate their management strategies.

To determine the feasibility of implementing this type of modelling into the pest planning process, an analysis of the modelling tools needed to be conducted. The model would be required to run the dispersal simulations within the time-frame of a pest management planning session. Although it is hard to determine the maximum run-time stakeholders would accept without an existing tool to study, given that this tool aims to support the existing processes, we can make an informed estimate as to what would be an acceptable run-time. To allow as much analysis of the developed plans, the model should ideally be able to run and visualise data multiple times during a one-hour session while leaving ample time for discussions to take place. In the sessions observed, a large portion of the time was dedicated to capturing the current distribution, validating the existing data and determining the areas for management. To support the planning sessions with their current structure the tool would ideally have visualisations available to the stakeholders within one minute. This would allow multiple iterations to be conducted after the collection of the initial distribution with discussions and re-design of the management plan following the completion of each model run.

A series of optimisations were implemented on the MigClim dispersal model to improve the run-time. During the dispersal modelling, MigClim uses an algorithm that runs in polynomial time to find plants that are suitable for dispersal. A new algorithm was developed that conducted the source plant search in linear time. Furthermore, the model was adapted to run in parallel and aggregate model outputs in real-time. These optimisations reduced the model run-time to under the one-minute time limit previously defined.

A systematic methodology was used to test the improvements in the software and ensure that the statistical nature of the MigClim dispersal model was retained. Outcomes were analysed and compared to the original modelling algorithm to determine the performance characteristics. The dispersal simulations from both models were compared to ensure algorithm changes had not affected the validity of the model.

In these tests, the model was run in the production environment used for running the pest management software, to establish the length of time that users would experience, waiting for the model to complete. Although the tests were run in a production environment, the model was run independently of the pest planning tool to determine the performance impacts of the changes themselves. Each test was run by a shell script calling the model as though it had been run by the web service.

Given the stochastic nature of the algorithm, each model was run 100 times to ensure that the results were statistically significant. Observations during the development process were that the model run-time remained fairly consistent across multiple runs and more testing was not be required. The outputs from each development build were compared to ensure that the changes to the algorithm did not change the outcome of the model.

A test script was written to run the models 100 times each (attached in Section 9.7). Between each run, all of the output years were summed into their respective aggregate files. The aggregate files were produced by adding the outputs together using the *gdal_calc* command line tool provided with the *GDAL* (Geospatial Data Abstraction Library). To compare the two models' aggregate outputs the SDMTools Istat function was used to assess the statistical similarities between the two model outputs. The "I statistic" is a measure of niche overlap between two species distribution models that was first introduced by Warren et al. (2008), which produces a result between 0 (no overlap) and a 1 (identical).

3.3.6 Usability Testing

The goal of the usability testing sessions was to minimise the effort required from users to integrate this tool into their planning process. Participants were asked to complete several tasks using the prototype pest management tool. These tasks were observed by the researcher to determine how the software met the participant's needs, and identify any issues experienced by the user interacting with the system. Steps that users struggled to perform, or took longer than expected, indicated that training was too brief, the user interface did not reflect the user's needs or that there were conceptual problems with how the tool was used to solve problems.

Three usability testing sessions were run on the James Cook University campus in a small conference room. This space was selected as it was located near most of the participants and had a suitably large meeting table to set up the interactive projector. Each session began with the researcher introducing himself and the tool to the participants. A short presentation was then given on the capabilities of the tool and the pest species that the participants would be developing a small plan around during the session. A demonstration was given during this presentation to familiarise participants with the pest planning software and use of the interactive projector.

The participants were asked to perform four tasks to get them comfortable with using the system and help them understand the capabilities of the tool. Each task was a component of developing and testing a pest management strategy with the tool as follows:

Define a New Population A new population of the target pest has been discovered in this region. You must add it to your map.

Define a Management Objective The new species is spreading quickly, define an objective to manage it.

Run the Model Run the model to see how your management strategy has played out.

Compare Different Management Methods Create a new strategy around your population and compare it to your last strategy.

Managing a Small Scenario More populations have been discovered and you have been given $50,000. Develop a new strategy within the budget.

Once the participants had completed the first 5 tasks, they were then asked to develop a small pest management strategy by defining additional objectives and with the aim of meeting a budget. The scenario began with the discovery of new populations of the target species for the participants to manage. Tasks conducted during the participants training were allowed to be repeated to add additional management objectives to the new species incursions. Analysis of these scenarios allowed the researcher to understand how participants were solving problems using the tool and identified areas where this problem-solving process could be improved in the next iteration.

Assistance was provided as necessary while the participants completed the tasks. However, all the assistance provided was recorded and incorporated into the analysis phase. The tool is currently targeted for use in a setting where an expert planner is running a session and stakeholders would only require a partial understanding of how the tool worked during the training. The approach used in the usability analyses was based on findings from the observational study, where the participants did not need to recall a large portion of the training but would re-learn skills as they were required.

3.3.6.1 Participants

The usability analysis participants were selected from James Cook University staff and students. All of the participants had no previous experience with pest management planning and none had any previous experience using the tool developed in this project.

The tool was designed to be used by stakeholders who had no previous experience using modelling tools and needs to be simple to both learn and operate. Staff and student participants fitted the same demographic as participants who were currently involved in the pest management planning session. However, they had a similar level of experience in the planning process as disinterested stakeholders. This lack of experience helped to ensure that the training conducted before the operation of the tool, covers all aspects of planning to ensure it was suitable for engaging varying levels of experience in the real world. Students and staff with no planning experience were ideal as test candidates for usability analysis and to ensure the tool is easy to use and that the training provided at the start of the session was suitable for all levels of expertise. The mix of students and staff involved in the Usability Analysis sessions is shown in Table 3.6.

Type	Participants
Staff	3
Student	3

Table 3.6: Usability Analysis participant breakdown.

3.3.6.2 Data Recording and Analysis

The usability testing sessions were recorded with a camera to allow a review of the users performing tasks and interacting with the tool after the session was complete. These sessions were also observed, and notes were taken to support the analysis of the recordings. An additional audio recorder was placed close to the participants. During the session, users were asked to talk through problems they had in completing the tasks and to highlight any actions that had resulted in unintended or unexpected responses from the software.

The camera was mounted above the interactive projector and allowed for the capture of participants around the table having discussions, as well as their interaction with the tool and what was happening on screen. During the first usability testing session, audio from the camera and sound recorder was partially muffled by the sound made by the projector and the mounting method. A noise removal filter was applied using Audacity[2] to remove the sound of the projector fan and background noise, which allowed

[2]www.audacityteam.org (accessed 10/10/16)

for the transcription of the majority of the audio contents. After reviewing the first focus group the camera was mounted in a similar position, however, was attached to the steel projector mount instead of to the projector itself. The additional sound recorder was placed further away from the projector and closer to the participants. This improved the quality of the audio and allowed for easier analysis and transcription.

The usability testing sessions were recorded on video and transcribed using Nvivo 10. These transcripts were annotated with both the tasks and actions that participants were performing using the tool. A thematic analysis was conducted to identify the major themes throughout the process. Tasks were analysed using a task analysis methodology (Diaper and Stanton, 2003) to explore problems that participants were experiencing when using the tool. The findings from these analyses were used to improve and refine the pest management planning tool.

3.3.7 Case Study

A case study was conducted to evaluate the tool developed throughout this thesis and answer the research questions defined at the outset of this project. Six experienced planners from Far North Queensland were involved in a pest management planning scenario. A quasi-real species, "*Dangleberry*" was used as the target species for the exercise and participants were asked to develop a pest management strategy around this species. Participants were trained in using the tool in a similar way that would be used during the usability analysis sessions. However, some participants were eager to begin and started experimenting with different management objectives and strategies even before the session had begun. The experienced planners began using the tool much faster than was observed in the usability testing sessions and two of the participants helped to complete the demonstration.

Dangleberry, the fake species used in this case study, is based on *Miconia calvescens*. The habitat suitability and dispersal kernel used in the MigClim dispersal model were both based on existing *Miconia* datasets. Initial populations of *Dangleberry* were adjusted into areas closer to the locations that were managed by the experienced planners involved in the case study. All of the participants were aware of *Miconia,* and several had involvement in the eradication program. The species was adjusted from *Miconia* to more closely model a new incursion of a species and to reduce the impact of existing strategies and expertise on the planning scenario. A pseudo-real species was created to attempt to seperate existing biases, tensions and plans from the results around how the tool works in this study. In retrospect a real species may not have influenced the results as much as originally anticipated.

A focus group session was held at the conclusion of the pest management session. This session was used to gather additional feedback from the experienced planners in a semi-structured manner. Participants were asked a series of open-ended questions around the value of the tool, its limitations and if they could see it being used for real pest management planning. Results from the planning scenario and focus group were used to evaluate the pest management tool developed in this thesis.

3.3.7.1 Participants

Case study participants were approached in a similar manner to the interviews. Participants were emailed asking if they would like to take part in a pest management planning scenario using a new interactive decision support tool. All of the participants approached agreed to take part. Participants were limited to six as this was the number of participants that could be comfortably accommodated around the interactive table surface. This table surface was smaller than the one presented in Section 4.3 (on page 106), that comfortably fit ten people around the table. The breakdown of participants involved in the Case Study is provided in Table 3.7. Participants worked in neighbouring shires within Far North Queensland, they have previously collaborated on high priority projects, however they often don't work together conducting planning of lower priority pests. These lower priority pests may however have significance across their respective regions. For example siam is managed only to protect assets in most regions, however the region one participant oversees has eliminated all incursions and kept their region free. The participants all stand to benefit from easy collaboration and participation in planning between each of their respective regions and properties.

Organisation	Participants
State	1
Local Council	2
Regional	1
NRM	2

Table 3.7: Case Study participant breakdown.

3.3.7.2 Data Recording and Analysis

The case study was recorded with a GoPro camera as described for the Usability Testing (see 3.3.6.2 on page 74).

The case study analysis expanded on the analysis methods used in the usability testing sessions, as defined in the previous sub-section. All of the audio was transcribed from the recordings using Nvivo 10. Tasks being completed and the actions of participants were integrated into the transcript. The transcripts were first passed using two thematic analyses. Themes of conversation and comments were identified and grouped and the tasks performed by participants were also grouped. This analysis focussed on several aspects:

1. The process of using the tool. Example questions trying to be answered: Was the tool easy to use? Did it behave unexpectedly or cause frustration?
2. Stakeholders ability to develop a plan.
3. The utility the tool provided to pest management planning.

The data and outcomes of these analyses were evaluated against the framework developed by Innes and Booher (1999) for evaluating consensus building and complex adaptive systems used in collaborative planning. The framework presents seven criteria that are essential for successful collaborative consensus building approaches. Criteria in the framework address the social cohesion, group diversity, quality of information and opportunity for critical thinking. Each criterion was explored and discussed in the evaluation of the case study.

3.4 Detailed Participant Selection and Recruitment

Participants were selected from a list of contacts kept by FNQROC of stakeholders actively involved in the Tablelands regional pest management workshops, forums or other pest management groups in far north Queensland. Prospective users were contacted by email with a flyer detailing the research project and an overview of what they would be expected to do on the day. A copy of the email and information sheets are attached in the Appendix (Section 9.2 on page 257). These materials emphasised the importance of open and honest feedback in the session and the need to gain an understanding of how the participants felt about the software in feedback.

Stakeholders from Far North Queensland were categorised by the scale upon which they conducted planning and operations. A pictorial representation of the categorisation is provided in 1.1 on page 4. This categorisation is based on previous work conducted by Peterson et al. (2007) addressing the planning framework that was used for conservation in South East Queensland, and Hill et al. (2008) looking at Cassowary conservation in Mission Beach, QLD. Although organisations like the Queensland Parks and Wildlife Service are State Government organisations managing vast expanses of land, they typically conduct pest planning and operations at the regional level. For the purpose of this research, the researcher considered that some organisations may act at multiple levels.

Landholders typically are not involved in the pest management planning process at this level. Farmers manage large portions of land and can have massive influence over the spread of pests through communities. While landholders undertake pest management activities on their properties, their primary interests are in the productive land. This project would ideally attract farmers to the decision-making process, however, sparking interest from new participants falls outside of the research question. This project does not seek to exclude interested farmers or landholders but is purely focussed on improving decisions made by the existing stakeholders who are involved in the process.

3.4.1 Ethics

Following the university's requirements to meet the Australian ethical standards, these studies were submitted to and approved by the JCU ethics committee. The following studies were completed under the JCU ethics approval H5894. The approval allowed for (a) interviews with stakeholders currently engaged in the pest management process, (b) usability testing with users across multiple sessions, and (c) focus groups assigning tasks to groups of users to perform in the software and observing how it is used.

3.5 Chapter Summary

In this chapter, the methodology used throughout this thesis has been described. Background information on all of the research approaches, methods and tools were presented and discussed. The methods data collection, recruitment and analysis were described, and a rationale was given for their use. Each of the components presented throughout this methodology sought to answer the research question, *"What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?"*. The next 3 chapters report and discuss the findings using the methodologies presented in this chapter.

Chapter 4

Phase 1: Exploring the Problem

Chapter Overview

This chapter explores pest management planning to identify where interactive tools can assist managers in building consensus and informing decision making. An analysis of the existing process was conducted using Activity Theory and Activity-Oriented Design Methodology (AODM). The findings from this initial analysis were expanded using a series of interviews with experienced pest managers. Finally an observational study was conducted seeking to understand how experts communicate their local knowledge and form consensus using an interactive projector. This chapter is divided into three sections:

- Current Process Analysis (4.1) describes the existing processes used in Far North Queensland for pest management planning.
- Interviews (4.2) describes the interviews conducted to build on the findings of the analysis of the current process.
- Observational Study - War Room Style Planning (4.3) describes the observational study conducted with expert ecologists around an interactive projector.

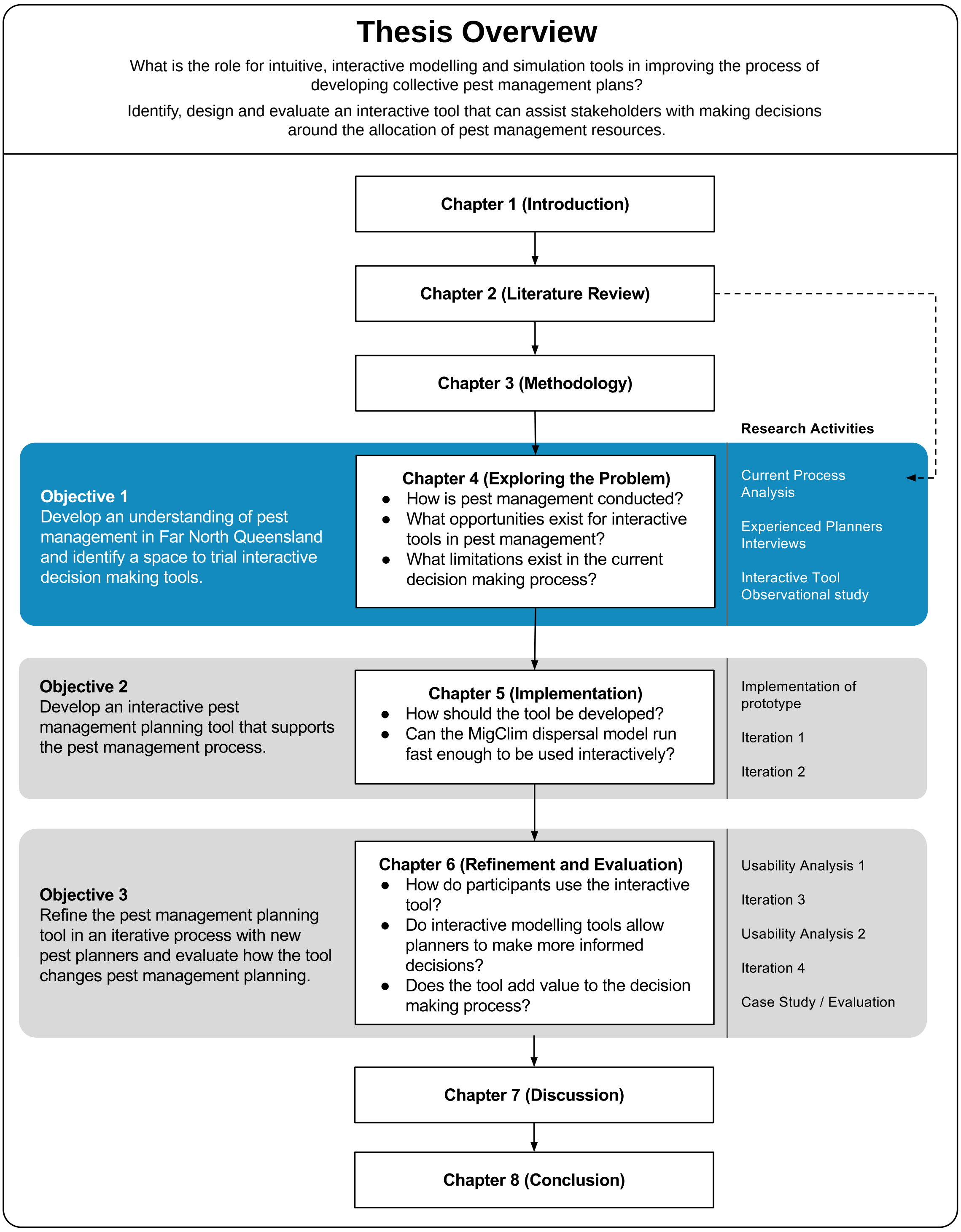

Figure 4.1: Diagram showing the order of research activities presented in this thesis. The blue highlight illustrates the current position in the thesis.

4.1 Current Process Analysis

Invasive species can cover wide expanses in remote and difficult to access areas presenting a complex and time-consuming management problem. Collaboration among stakeholders and careful targeting of resources are essential for managers to control invasive pests across large spatial extents successfully. Interactive tools have the potential to help inform management strategies and encourage consensus building as these strategies are developed. New tools and approaches to pest management planning must work with the current practices to add value to the decisions being made.

4.1.1 Pest Management Forum and Special Working Group

To develop an understanding of the pest management process currently used in Far North Queensland (FNQ), a review was conducted of the publications from local councils, Natural Resource Management (NRM) groups and pest management working groups. I also attended the Atherton Tableland Regional Pest Management Forum and a special working group. Attending these groups served to help me understand how the processes reported in the literature related to pest management in practice. A brief description of the two groups is provided below from my perspective.

The pest management forum was conducted in the council chambers and was open for the public to join in. However, only one person that was not related to an organisation attended. The forum consisted of representatives and staff from different organisations including City Councils, Terrain NRM, Queensland Parks and Wildlife Services, Biosecurity Queensland, Far North Queensland Regional Organisation of Councils (FNQROC) as well as contracted field staff. The forum had 19 people in attendance. During the forum, members shared their progress around their current projects and newly found populations of pests. The Biosecurity Queensland representative shared updates on the Four Tropical Weeds Program and their progress on research into the effectiveness of new pesticides on several pest species.

The pest management working group was comprised of five people. The working group was focussed on developing management strategies for Turbina (*Turbina corymbosa*), a scrambling vine spreading through patches of rainforest in the Atherton

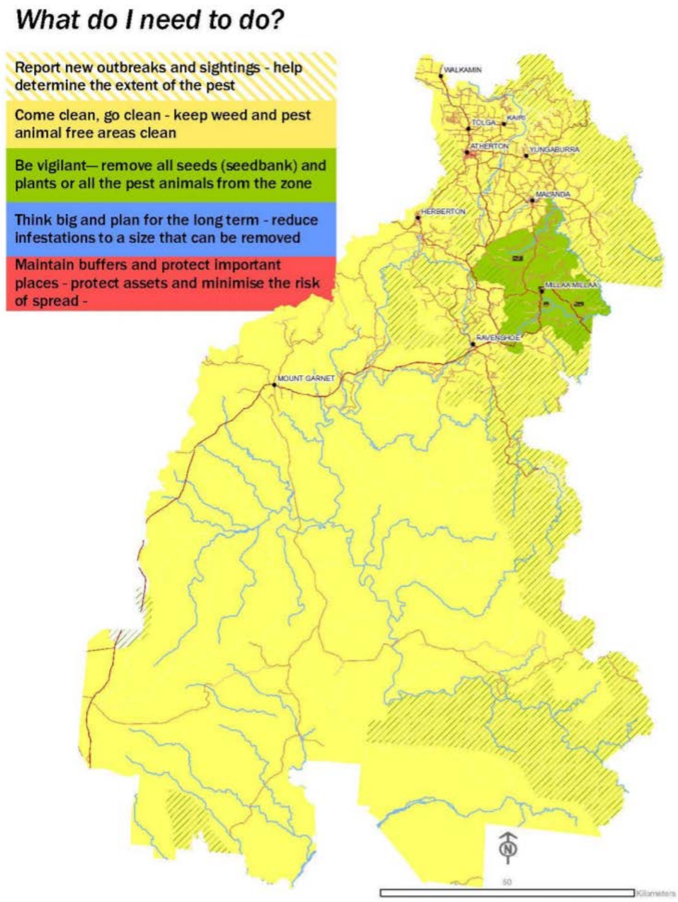

Figure 4.2: Atherton Tablelands Regional Council strategy for managing *Turbina corymobsa*, an outcome of the pest management working group.

Tableland region. Participants were seated in a conference room around a table facing a projector. A laptop was connected to the projector running ArcGIS to allow access to mapping and distribution data. The laptop was operated by one of the group members with expertise in planning and GIS tools. As the discussion around the weed evolved, the group would request different datasets or areas to be shown on the map. The group came up with management objectives for spatial areas using cadastral layers to clip management objectives to property boundaries and natural features. A strategy map detailing the objectives of future management of *Turbina* was produced. A later iteration of the map developed in the working group is shown in Figure 4.2.

Participation in the forums and working groups were extremely helpful in developing an understanding of how pest management planning and operations work. Production of population distribution data was substantially more difficult, time-consuming and costly than anticipated. Surveying remote or hard to access areas often required helicopters and trained personnel. All of the participants involved during the forum and working group were passionate about their jobs and were extremely knowledgeable about pests across the regions they worked. The insights from the literature and the observations from the two sessions that I attended have been incorporated into the description of the current planning process to form the foundation for this research project.

4.1.2 Description of the Current Planning Process

From the literature and my involvement in the pest management planning sessions, a conceptual process of pest management planning was developed. Planning methods differ depending on the scale the planning is conducted. Expertise, funding and collaboration also influence the selection of planning methodologies. In this thesis, the focus is given to planning at the local and regional level. A simplified explanation of the two planning scales is given below.

Regional Planning Process

The regional planning process at a glance is relatively straightforward (an example is shown below). Planners and stakeholders collect and collate occurrence data of the subject pests. These occurrence records are used to support the discussion of the threats posed by each population. Objectives are prioritised and developed around the funding and staffing limitations of each land manager. For example, areas of ecological significance may be of higher priority for protection than catchments where the pest species have existed for long periods of time. GIS mapping tools are used to define the populations targeted by each objective.

1. Occurrence data of the species is collected.
2. Impacts and threats are determined.
3. The amount of available funding and resources each member can make available is discussed.
4. Priorities are developed for the pest in each area.

5. Zones are assigned to the priorities to develop a map showing the work to be undertaken in each area.

Local Council Planning Process

The local planning process is similar to the regional process, as highlighted in the example shown below. Local council staff collect and collate occurrence data of the pest species in their local government area. The impacts and threats are assessed using a scoring matrix to identify the species that are most beneficial to manage. Priorities are developed around these species to ensure resources are directed to areas they are most needed. A pest management plan is drafted following the prioritisation process. This draft is then opened up for consultation and input from the community.

1. Occurrence data of the species is collected.
2. Impacts and threats are determined
3. The viability of different management strategies and the available funding is assessed.
4. Priorities are developed for each species in the pest management plan.

Planning is not Simple in Practice

Although these planning processes look fairly straight forward when described analytically, they are much more complicated in practice. Collecting data, building consensus and identifying optimal areas for targeting a pest is a complex process. Field operators must know where to look to collect accurate population data; pests in remote areas can often go unnoticed and if left unmanaged, can be a significant cause of reinfestation in surrounding areas where the pest has previously been controlled. Building consensus amongst stakeholders and the community requires balancing and prioritising many different objectives and points of view. Once priorities are defined, the areas for work to take place need to be identified. Remote locations are difficult and more costly to access, and landowners may be uninterested in co-operating.

Invasive pests are not restricted by property boundaries or land ownership. Therefore, managers must liaise with large numbers of landowners and land managers. For pest control mechanisms to be effective, planning must take a wholistic approach and manage pests across multiple land tenures and regions. Each of these landholders and land owners have their own opinions and priorities on how pests should be managed. For example, a cane farmer will prioritise managing pests that affect his crop but may not manage pests that impact the neighbouring dairy farmer. Landholders have a stake in the pest management process across an entire region. For a plan to be successful, the views and opinions of these stakeholders need to be valued to achieve the best possible outcome for a community.

Defining the locations to target pest control is a complex process. Typically planners rely on their intuition and expertise to make decisions about the allocation of resources. Researchers or modellers of species distributions can often be involved in the process to help prioritise the allocation of resources. New populations may often be introduced during working groups. As species dispersal models cannot easily be run during planning sessions, the working group would often need to reconvene days or weeks later to ensure all stakeholders have input into the process once new models have been run. This is not always viable, as busy or uninterested stakeholders may not have the motivation to return for follow-up sessions. Furthermore, experts simply do not have the time or resources to be involved in every decision about every pest in every region. Therefore, an approach needs to be developed that allows informed decisions to be made quickly without the continued involvement of expert planners.

4.1.3 AODM Breakdown

The findings from the previous sub-section gave insight into the current pest management planning process. The complexities of pest management planning are well described in the literature. However, the objective nature of the scientific literature fails to emphasise the struggle planners have to endure for successful outcomes. More experience and understanding of the pest management process was required to develop an interactive tool that could help pest managers in making real world decisions. To guide this exploration, AODM was used, which provides four methodological tools to apply

Activity Theory to complex systems. The remainder of this sub-section presents a summary of the Eight-Step Model, the developed activity system and the questions for further research that emerged from this analysis.

Activity of Interest

The activity undertaken in this study aimed to understand the pest management planning process in the Atherton Tablelands region, with the goal of identifying areas that technology can aid in the decision making, education and engagement of stakeholders.

'Object-ive'

The main objective of this activity was to improve the targeting of resources in pest management planning meetings with groups of stakeholders. My objectives in this process were to focus on areas that interactive software could assist in informing, educating and engaging stakeholders in the decision-making process. This technology should facilitate discussion and comparison between each stakeholder's motivations and objectives.

Subjects

Subjects involved in this activity were identified as representatives of organisations or government agencies with a stake in managing pests. Subjects often included individual landholders with a financial interest or interested individuals from the community.

Tools

1. Local Councils and agencies tasked with pest management are supported by instruments within the *Pest Management Act (2001)* (QLD) to gain entry to properties, seize evidence, enforce compliance and issue infringements.

2. Researchers and expert planners have access to modelling tools to help understand how pest species are likely to move across the landscape.

3. Local councils have access to templates and ranking tools for developing pest management plans.

Rules & Regulations

1. Each stakeholder is required to represent their own organisation's interests
2. Individual stakeholders are governed by the *Pest Management Act (2001)* (QLD) and their Local Council policies.
3. Local council's pest management policies are governed by the *Pest Management Act (2001)* (QLD).

Division of Labour

1. Landholders are responsible for their own properties under the *Pest Management Act (2001)* (QLD). This extends to agencies e.g. Queensland Parks and Wildlife Services are responsible for the management of pests in national parks and protected areas.
2. Biosecurity Queensland is responsible for high priority and declared weeds across the entire state.
3. Local councils are responsible for the management of all pest and weed species in their area.
4. Industry groups are responsible for representing their members' interests.
5. FNQROC are tasked with facilitating collaboration and information sharing between different localities and agencies.

Community

The majority of stakeholders represent their own or their organisation's interests in the pest management planning process. Stakeholders often have vastly differing views of which pests should be managed. Pest plans are developed in consultation with stakeholders in that locality.

Outcome

The outcomes of dissecting the pest management planning process in this manner are to identify areas that can assist with:

- Engaging more stakeholders in the process.
- Developing stakeholder understanding of the impacts of pests on their property to the surrounding community.
- Enhancing decision making quality with improved information collection tools, visualisation or analytical capabilities.

4.1.3.1 Far North Queensland Pest Management Activity System

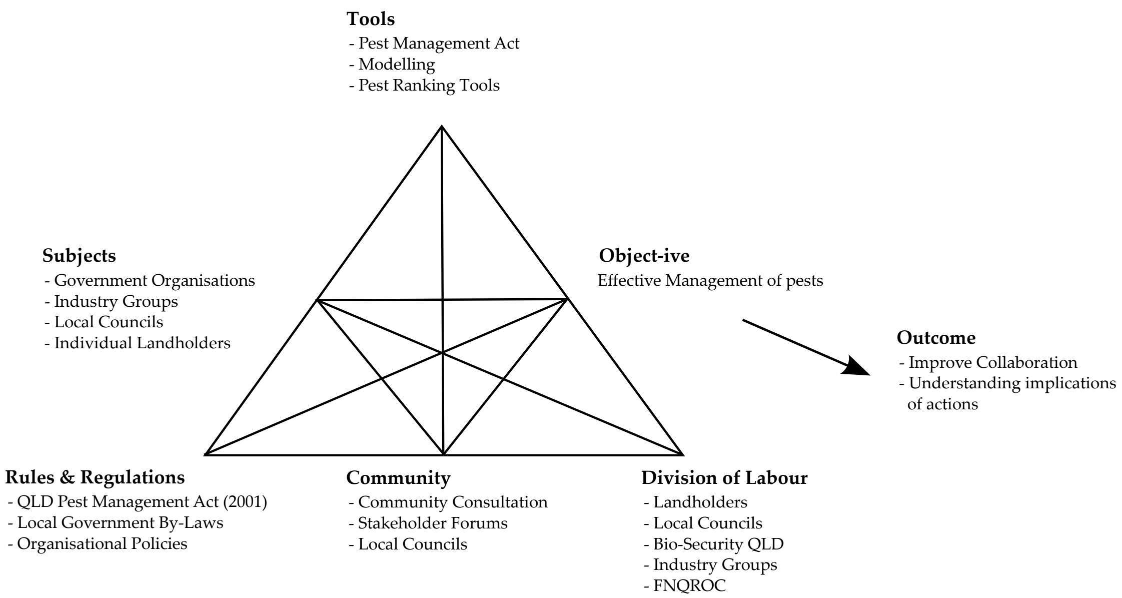

Figure 4.3: Activity system showing the pest management process in Far North Queensland

4.1.3.2 The Research Questions

The activity system was broken down using the AODM Activity-Notation to identify sub-activities. Through the decomposing process, it became apparent just how complex the activity system for managing pests in a region was. The difficulty that regional bodies experience when developing pest management plans was well understood by the stakeholders who were involved in the planning process. However, as an external observer, the system as a whole was quite complex and difficult to analyse. To assist with this analysis, AODM provided a methodical approach for identifying gaps in knowledge and in generating research questions for further investigation from the activity system.

Each sub-activity was further broken down into independent activity systems that interlinked with the other activities. These sub-activities represented the undertakings of individual stakeholders which were a small part of the larger pest management system. This model represented the processes undertaken in the real world whereby tasks are delegated to individuals or groups with limited oversight. However, the impacts of the actions taken by each have consequences that affect the entire region. For example, farmers are required to manage pest species on their own property. Information, advice and often assistance are made available to them. However, they act independently. The effectiveness of the farmer's management efforts are dependent on the wider communities pest management efforts to stop re-incursion onto their property.

The activity system was broken down using the activity notation and turned into research questions using the AODM framework. A large number of research questions were generated using the activity notation methodology. Many questions were duplicates or were easily answered with the existing literature and were removed. The edited list is available in the appendix (Section 9.3.1 on page 263). Three overarching themes emerged from the activity notation: data collection; methods of targeting pest species; and collaboration between stakeholders. These areas for further research were developed into interview questions and are described in the next section.

4.2 Interviews

Successful problem-solving software must provide value and utility to the end user (Cockton, 2004). Designing software to provide users value requires a solid understanding of the existing approaches and problems faced by those who would use it. To develop a detailed understanding of pest management planning, a series of interviews were arranged with stakeholders and planners that were actively involved in the process. Participants were asked a series of questions to explore how data is collected, how they collaborate with others, and how pests were targeted. The outcomes of these interviews were used to shape the requirements and functionality of the prototype pest management planning tool discussed in the next chapter (Chapter 5).

In the previous sections of this chapter, AODM was used to organise my current knowledge of pest management. The analysis allowed gaps to be identified, both in the literature and my knowledge. A series of themes emerged from these questions. Below, these themes have been structured into overarching research questions that were answered at that point in the research.

- How do pest managers collect and store data about pest species?
- How are species targeted by pest managers and stakeholders?
- How do stakeholders collaborate and work together to solve problems?
- How do stakeholders and managers see technology helping them?

This research was aimed to support collaboration amongst stakeholder groups, so it was important to allow respondents to speak freely about pest management. The names of the participants have been changed, and their respective organisations were not listed to provide a level of anonymity. Due to the length of the interviews and anonymity requirements, some sections of the transcripts have not been presented in full in this thesis. The findings from these interviews were used to inform the development of the pest management software described later in this thesis (Chapter 5).

4.2.1 Summary of Activities

The interviews for this research cycle took place in June and July 2015 at the interviewee's workplaces. The interviewees were selected from a cross-section of stakeholders across all tiers of the pest management planning community (see Section **??** on page ??).

The interviewees were selected based on their ongoing participation in pest management activities conducted with FNQROC. The interviews were recorded using an audio recorder and a notebook. I manually transcribed the recordings using OTranscribe and imported them into NVivo. Data was coded using open coding and grouped into themes using NVivo. The emerging themes are presented in this section along with transcript excerpts as supporting evidence. Discussion of the interviews is presented below organised based on the theme.

4.2.2 Participant Roles and Responsibilities

All of the participants had been working in their organisations for seven or more years and had been living and working in the FNQ region for between 10 years and their entire lifetime. The interview participants were all currently involved in pest management in the region. Each locality shared similar species of pest plants. However, the extent of each species impact varied substantially. The different groups and councils from the area held a pest management forum twice a year to discuss strategies and share insights from across the region.

All of the regions surveyed were part of the Siam Weed (*Chromolaena odorata*) eradication program. The Douglas Shire has managed to prevent the naturalisation of Siam Weed in their region but were actively still fighting the weed. The other shires interviewed had reverted to selective control to protect their assets and minimise further spread.

4.2.2.1 Local Organisations

Two participants from the local planning level were selected to be interviewed. Both were in pest management roles from local councils in FNQ. The participants, Steven (L1) and Clinton (L2), were in co-ordination roles managing the natural environment across their respective shire. They were both involved in managing invasive plants and animals along with other aspects of land management including managing fuel load.

> *Steven (L1): "I've been working for council and local government for 14 years now. That time has been in land management, though the title's changed a few times." ... "I basically started on the ground doing all the hard yards and leading by example. I work on any nasty invasive weeds here in Douglas".*

> *Clinton (L2): "I'm the co-ordinator of natural environment, so I run the strategy and budget side of our natural environment program, which includes pest management. Through that the key driver for that process is our pest management plan."*

The local councils were responsible for the management of pest species across their local government area including private property. Councils worked in partnership with other organisations and landholders on treatment strategies. Biosecurity Queensland and FNQROC provided information on optimal times for treatment and the best pesticides to use. Cooperation with Biosecurity Queensland was essential to the management of pests declared under the national eradication program.

Educating and assisting private property owners to manage pest plants and animals on their property was an important role of the local councils. To facilitate their roles, they had the authority to issue notices and fines to non-compliant property owners.

4.2.2.2 Regional Organisations

Interviews with pest managers from two state NRM organisations (S1, S2) were also conducted. Both of these organisations were responsible for the management of large areas of land including a lot of remote and difficult to access areas.

The first organisation (S1) was tasked with the prevention and management of invasive pests and diseases. Research into current and potential pest threats was undertaken to understand their dispersal mechanisms and characteristics of these pests. Treatment and management methods to control these pests were developed to assist themselves, landholders and other land management groups.

> *Natalia (S1): "Seven years in this position, in this job in weed eradication. We are set up as national cost shared eradication program, so we are targeting six species for eradication from mainland Australia, because some of our weeds are found on some of the islands, so it is a national eradication program even though it's run on a regional basis. So we get some of our funding from Queensland government, Commonwealth government and other states and territories."*

Natalia's organisation (S1) coordinated with other agencies to manage the declared pest species in Queensland. They provided information and treatment advice to assist landowners in the management of their own weeds. Within the study area for this project, FNQ, S1 are currently focussed on The National Four Tropical Weeds Eradication Program which targeted five species of weeds (listed in table 4.1) that had potential to become seriously damaging invasive species.

Species
Limnocharis (*Limnocharis flava*)
Miconia (*Miconia calvescens*, *Miconia nervosa*, *Miconia racemosa*)
Mikania Vine (*Mikania micrantha*)

Table 4.1: National Four Tropical Weed Eradication Program - Species targeted for eradication

The second interviewed state organisation (S2) was responsible for vast areas of land. Their responsibilities included the management of public facilities such as camp grounds and walking tracks along with other NRM responsibilities such as pest plant and animal management and fire management. Anthony (S2) had been involved with the current organisation for nine years and managed the natural resources on their designated land.

> *Anthony (S2): "I've been the resource ranger it's called, I target all the NRM issues, whether it's pests or fires, whatever it is. I've worked a year at Biosecurity, so I've been doing it for a while."*

Anthony's organisation (S2) was predominantly focused on the protection of their sites, and thus pests that did not have a significant impact on the ecology ranked lower than those that did. This was in contrast to the previously described organisation (S1) that had a focus on particular species across all of the landscape.

4.2.2.3 Landholder Groups

Representatives from two industry groups (IG1, IG2) were interviewed to gain perspective of their organisations and the farmers they represented.

Donald (IG1): "I'm the manager of ####[1], #### is a not for profit organisation, umm, so, we're actually funded 50% by the local mill and 50% by the growers. Now we have about 99% of the area under cane as our member. Our membership is voluntary. To the group we provide basic services, like pest and disease services, agronomic support, some precision ag services and drainage and levelling work as well. As a side-arm our group also does contract work for commercial companies, for universities and NGO's like terrain."

Robert (IG2): "We are a representative organisation, so we have members who supply the mill and we're also part of the #### network state wide. We deal with grower issues at a mill area level, local authority level, so we do interact with the Cassowary Coast Regional Council, Terrain [NRM][2] and various government departments from time to time. I have been involved with Landcare and Cassowary management and that sort of thing. So fairly aware of what goes on in the area."

Both of the landholder representative organisations had been set up to assist farmers with improving the productivity of their arable land. They provided knowledge, advice and some assistance to farmers to manage pests on their properties.

4.2.3 Management Process

4.2.3.1 Resources

Resources available to the groups conducting pest management were very limited. All of the council and organisational participants highlighted small budgets and limited staffing which made managing pests a difficult process.

Me: "How effective do you think you are at managing pests?"

Steven (L1): "In pest management we very rarely seem to have wins, weed control is just so long term. We've been doing it now for over a decade and I can only count on one hand, our actual wins. Where we can actually

[1] Pound symbols denote names that have been removed

[2] Square brackets denote my additions to clarify meaning and improve readability.

use the word eradication and actually say we've got rid of that. umm... so... When you say how effective, it comes down to doing what you can do, with the resources we have, and a lot of our weeds are just so long term. In the programs, using Miconia as an example, the seed's viable for 16 years and every time the crews out there find a mature plant or fruiting plant, start the clock again. It's just so long term and ongoing to actually, have these wins."

Steven (L1) described the pest management process as a long persistent struggle to keep their pest species under control. Pest species needed continued long term effort and any lapses in this effort required the process to be started again. Further, weeds could cover large areas that could be difficult to access, making identification and treatment a difficult and time-consuming process. Steven goes on to express concerns around the availability of money and staffing to keep up with the work required to manage them.

Steven (L1): "I feel that our biggest challenges are resourcing and staffing.", "with four people stretched over the whole shire, how much can they really do."

Targeting resources where they would have the most impact was essential to the successful management of pests.

Steven (L1): "Our resources are very limited with a small council. We very much need to be able to prioritise, where our resources go and what we focus on."

Anthony (S2) also expressed issues with resources in the areas he managed. He was solely responsible for pests across an entire region. However, contractors were often hired to assist with funded projects.

Anthony (S2): "Most things don't get a leg in the door, even if they are worthwhile projects, just not enough available funds, so things that are the flavour of the day or have been recognised as a national eradication project target will always get up first, everyone else has got to go begging for the scraps."

Anthony (S2) continued to explain that as the sole person responsible for pests in the area they managed it was a balancing act between work in the field and administration tasks. He had to keep on top of his administrative duties to maintain good records of the work conducted and populations he had sighted. These records were a valuable resource to others who work on pests in the same region so as to better manage their objectives.

4.2.3.2 Targeting

New populations of pests are generally discovered in two ways, 1) through systematic delimitation or 2) an accidental discovery by an experienced field worker. Delimitation exercises were conducted to identify the current distribution and extent of each species.

> *Me: "Do you target where the search areas are, based on some kind of suitable habitat, or some kind of modelling?"*
>
> *Steven (L1): "Most of our work is targeted mainly from previous survey work, aerial survey, a lot of times we used to do Siam, but for Hiptage we'll do aerial survey and we'll spot the pest plants from the air. Then the guys GPS them and ground truth the infestations. So we've got a lot of data on our known infestations and if we had more resources, we'd like to extend our search and delimit bigger areas, but currently with four people, we're really just stretched to go to our known sites, for a lot of our weeds."*

Steven (L1) explained that the search areas were limited by the resources available to them. Other respondents also reported similar scenarios. Due to the size of the areas managed and the limited resources available for delimitation, pest species could often reproduce undetected for long periods of time. Even when pest populations were found, they may not have been treated due to the difficulty of access or resource limitations. However, a discovery of a species that was declared as 'high-priority' in the national eradication program would always require delimitation to be conducted around that species. Sightings of these species would be reported to Biosecurity Queensland to coordinate the validation, removal and delimitation of the surrounding areas.

> *Natalia (S1): "I mean as surveillance teams, any fruiting plant on one of the species we chase, triggers a 1km dispersal buffer. If you find fruiting plant*

way out the back of a foot hill, that puts it another 1k further up the mountain, so it can be a long [way]. Doesn't sound that far, the way the bird flies."

Delimitation and producing absence data was important for programs aiming to completely eradicate species. Large and difficult to access areas had to be surveyed over long periods of time to confirm that a species no longer occurred in an area.

Species that were well established or were no longer supported by large eradication programs were managed predominantly at a local level through pest management plans developed by regional councils. Pest management plans were legislative requirements of all local councils and were publicly available documents. The plan detailed the council's strategies for managing pests in their shire and goes through a community consultation process before being finalised. The plan helped direct resources and funding to the species that posed the most risk to their region. Data about the current distribution was captured and used to prioritise the actions taken to manage that species. The ranking methods employed by the pest management plan score species based on a range of factors, including the potential for damage, distribution, priority and achievability. Final scores were calculated and ranked to provide a priority list for targeting resources.

Clinton (L2): "The pest management plan is our strategic framework, I guess. That helps us prioritise our actions and our areas where we work."

This scoring method, however, did not capture the spatial component of where the resources should be allocated. Populations in some areas may have been well established but geographically contained by natural features such as mountains, rivers or man-made infrastructure. Other populations may be new and fairly limited in a region. These areas are ideal targets for early control as they prevent the establishment of new seed banks and can have prevented the colonisation of new areas. Decisions about the treatment or non-treatment of pest populations often rely on the expertise of the manager or operator.

Anthony (S2): "Something like Siam Weed, which is really established in this area now... There's areas where we completely ignore it, because it's too far gone...yeah...or it's in a weed wasteland. So, what are we really protecting? There's not much there. But then it gets a foot in the door, like the North

Johnstone Gorge. It's in a pretty remote area, pretty pristine area, Siam is achievable because it's just got there. So righto let's put our effort into that."

4.2.4 Data Collection

Data on the distributions of pest species was collected by organisations involved in managing invasive species. This data was used to target species and develop strategies for managing pests. Most of the participants surveyed still relied on paper record keeping and manual data entry for the majority of their findings.

> *Natalia (S1): "From the data entry point [in the field], they've just got the waterproof notebooks."*

Participants were aware of new technology and devices available to their field workers for data collections. However, they did not fully meet their needs.

> *Natalia (S1)"Now a lot of people try and say, no because if you had a Trimble, you'd get rid of all that double handling and it'd be straight across into your system."*

Natalia (S1) went on to explain that the difficult terrain and conditions their field staff worked in made it difficult to use an electronic device.

> *Natalia (S1): "At the end of the day they are field labourers that are doing this hard work out in the foothills of uneven terrain. They're trying to get them to use 20 different dropdown fields on your Trimble. They're probably not going to do it. At the end of the day, it might not be the latest face of technology, but.. I think our research or the data we're producing is certainly up there in terms of analysis."*

These records were then manually entered into an access database by a part time data entry worker. The available data collection devices did not fully meet the needs of the participants in this study. However, paper records still worked reliably and met the current needs of the participants.

4.2.4.1 Community Reports

Each organisation surveyed that were involved in the collection of data had a different method for collecting, verifying and recording populations of weeds across the landscape. All of the organisations accepted reports from the community via phone, email or in person. An example from one of the councils surveyed.

> *Steven (L1): "Detection's great, a lot of farmers come in here 'what's this weed'. We ID it for them and,.. at times we use the legislation as compliance to go, you need to do this at this time of year. Depending on the situation, but yeah, we tend to help landholders who are willing to help themselves."*

These reports of species are coming from untrained community members, and a staff member is required to confirm the validity of the sighting. Steve went on to mention that they tend to prefer not to use the legislation as an enforcement tool and are more than happy to help residents and organisations manage their own weed problems. However, a staff member would be sent out to the site to confirm the reporting and take the necessary actions towards dealing with the weed.

> *Anthony (S2): "a lot of the information you get from landholders is pretty invaluable" [...] "a lot of the time, you can't access a [site] except to go through private property, so you always make sure you talk to them."*

Boundaries were shared between private landholders, councils and public organisations. Communication with the neighbouring properties enabled Anthony (S2) to build an understanding of what was going on in the difficult to access areas he managed. The other participants also highly valued that information that was provided by the community as it helped build a better understanding of the current problem. Even false positives were still valued as it showed that the community had taken an interest and was actively looking. However, two participants noted that reports from the community could be quite rare. Community reports were especially lacking for high-priority, low-density weeds that presented future risks like those managed by Biosecurity. These types of weeds were typically new to a region and could often go undetected due to their limited occurrence.

4.2.4.2 Data Storage

All of the participants followed their organisation's policy for storage of their distribution and treatment records. However, each organisation had their own unique method for storing the data. The participants noted that this was problematic when it came to sharing data with other organisations and often planners were incapable of sharing data due to incompatibilities and discrepancies between reporting methods.

> *Anthony (S2): "Unless everyone's utilising the same dataset or same information, then it doesn't really work."*

All of these datasets were stored in standardised geospatial formats and could be converted and combined quite easily by an experienced GIS specialist. However, a number of the organisations had limited technical support when it came to everyday geospatial data manipulation.

> *Clinton (L2): "Biosecurity has their own software program, Terrain has got varying ones of pig data catchments and stuff. Ergon has got its own system. None of them are compatible. It's not cohesive data collection. We look at how do we get a regional platform sorted. But agencies like Main Roads, they work across the whole of Queensland. Totally different mechanisms in every catchment. They're not flexible enough to have a different system for everywhere. But we really need their data and vice versa."*

Each organisation had their own data storage standards and systems that made it difficult to share among each other. Four of the participants reported difficulty in getting access to data they needed. The participants who did not mention having problems (IG1-2) were not as reliant on data sharing. The landholders they represented often did not need to share data with their neighbours.

4.2.5 Collaboration

4.2.5.1 Working with Other Organisations

All of the organisations that participated in the interviews were engaged with one another to share population data and information, and to assist with weed treatment and surveys. In some cases, organisations were actually *required* to undertake cost-shared tasks in cooperation with other organisations. These cost sharing tasks can cause tensions when organisations do not agree with the priorities or objectives of the projects they were involved in. Of the participants interviewed, two gave examples of the other's organisation when asked about their collaboration with other organisations. This provided excellent insight into difficulties from both perspectives.

> *Me: "So in that instance where, you're going out to get a Class One weed, are there cases where someone else has had an interest in getting rid of the weeds around that Class One weed? and have you worked with them to sort of... collaborate?"*
>
> *Anthony (S2): "Yeah, we used to have two national eradication programs based out of Biosecurity at South Johnstone. So there was the Siam project that's been dropped and the Four Tropical Weed one. So we still do the Four Tropical Weed targets in conjunction with them. So... because they are a national eradication program, we're obliged to still have input and you know give in kind contribution. Yeah, and we do... and it chews up the biggest... like 90% of our Class One budget." [...] "BUT if there was a review of that project and went the way of the Siam project and was dropped, we wouldn't be obliged to do it anymore, and I can tell you we wouldn't be spending 90% of our budget on those targets."*

Although Anthony (S2) understood the importance of the national eradication program, there were disagreements over how their budgets should be spent. Anthony's aim was to keep the pristine, unaffected environments free from all pest weeds that threatened them and thus their management efforts generally focussed on protecting those pristine areas and containing other existing populations. While the national Four Tropical Weeds Program aims to eradicate five particular species of weed from Australia, irrespective of their presence in pristine or areas infested with other weeds. The requirements for the organisations to collaborate appeared to cause tensions. However, both of the interviewees took the time to highlight the importance of each other's work and discuss their strong working relationships.

4.2.5.2 Working with Landholders

Collaboration was a necessity for all of the organisations and landholders involved in the process. However, the degree of collaboration varied substantially between different organisations and landholders due to the differing perspectives and roles. For example, (S2) worked with landholders along shared boundaries. They are motivated to do so because they did not have easy access to all areas of their property. Collaboration was essential to understanding what was going on within their protected areas.

> *Anthony (S2): "a lot of the information you get from landholders is pretty invaluable, so while we're out there working and then a lot of the time, you can't access a park, except to go through private property, so you always make sure you talk to them. see what's going on, see what they've noticed or what they've got problems with. you always sort of share your information and they get information from us too".*

While landholders provided valuable information about the pest species on neighbouring properties, they can be reluctant to report pest populations on their own properties. During the AODM process earlier in this chapter it was identified that the local councils with authority to issue fines to landowners for the presence of weeds on their properties, made landowners wary, which undermined the goal of collecting information from them. Landowners who did not have the time, money or interest to treat their weeds risk compliance notices and fines, making them reluctant to share information and adding to the complexity of pest management planning. The local council participants interviewed both discussed those issues when asked about their involvement with landowners and the community.

> *Clinton (L2): "We have the resources to go down the compliance or coercion lines. But also, very aware that some of the weed cycles are between*

the process that has got to be taken. After a notification and another notification, the weeds probably seeded and gone by then. All you've done is created an enemy."

In Steven's (L1) case they preferred to provide assistance instead of issuing compliance notices. Their strategy was aimed at encouraging people to seek advice and inform the Council of pest populations on their property rather than ignore the problem simply to avoid fines.

Steven (L1): "In [this] shire 80% of the land here is state owned, it's national park and... definitely the success of our programs is having a nil tenure approach. There's no point treating a weed up to a fence line... no point if the neighbours are going to seed over the fence, and pest plants are very similar to pest animals. The classic example... A feral pig doesn't know where the border is, he doesn't know where the property boundary is."

Although this created additional work for Steven's (L1) team, it did allow their team to gather more information on species across the land they manage. With a reduction in unreported populations, the dispersal potential of pest species could be greatly reduced.

4.2.5.3 Working as a Community

Clinton (L2) described a group of neighbouring farmers that had problems with Hymenachne (*Hymenachne amplexicaulis*) clogging their creek and causing drainage issues on their farms. The neighbouring properties had started working together to manage their shared problems.

Clinton (L2): "We initially gave them a bit of a boost on Hymenachne control. This is a catchment that's got not much free board between flooding their cane and not. They're in a wetland basically, so any weed blockage causes major drainage issues for them. "

Although Clinton (L2) initially assisted them with control and advice, the catchment had become mostly self-sufficient and council really only had to intervene to help bring uncooperative landowners into line.

> *Clinton (L2): "They identified one creek coming in that's a constant source of weed. And that's where we come in with the axe to go... (chopping gesture into his hand... laughter) in a nice way... just to explain we've got a whole group of landholders here, you're affecting their properties."*

I followed up by asking if the social burden was enough to motivate landowners who were influencing their neighbours is enough for them to become more involved.

> *Clinton (L2): "Sometimes... Look if that worked beautifully then <removed> would be squeaky clean property. He bought that property with the problem and has been trying to get on top of it. It's a big issue."*

4.2.6 Outcomes

The results from the interviews have been organised to address the research questions posed at the beginning of this section.

4.2.6.1 Data Collection

Data collection and occurrence records were captured predominantly using paper field notebooks and manually entered into digital systems. Some of the interviewees used GPS systems. However, they did not collect anything other than geographical points. Metadata was added by hand when the worker returned to the office. Participants noted that newer data collection technologies could improve their processes however they were either too expensive or difficult to use in the rough terrain. The delimitation and collection of pest distribution was a difficult and time-consuming task on its own. Different organisations and councils cooperated by sharing information and resources with one another to achieve shared objectives.

4.2.6.2 Targeting Management

Pest management resources available to the surveyed participants for pest management were limited and could not support the complete management of all species in a region. Targeted approaches to funding and treatment was a necessity for all organisations involved in managing pests. Targets were decided through a prioritisation method that looked at the threat, distribution and conceivability of managing each species. While the funding targets, overlapping responsibilities and cost sharing could cause disagreements about the allocation of resources, the two disagreeing parties (see Section 4.2.5.1 on page 102) still had a strong working relationship. Each side understood the significance of the other parties work. The decision makers need to be able to communicate and defend the importance of their prioritisation to gain the co-operation of other parties.

4.2.6.3 Collaboration and Community Input

Two participants provided an example of neighbouring farmers co-operating on a shared problem. Both participants used the same group of farmers as an example. The farmers had problems with weeds blocking water drainage from their properties.The council provided initial assistance and support, but the group of farmers took over and became self-sufficient in managing their own invasive species. However, not all landholders were as proactive at managing invasive pests on their properties. Landholders may simply be unaware of their pest species and the legal requirements to manage them. Furthermore, landholders may be motivated to withhold information from local councils and Biosecurity if they were unsure of the assistance they could receive or were worried about fines or their farm being quarantined.

4.3 Observational Study - War Room Style Planning

This observational study was an opportunity that emerged during the analysis of the interview data. The study was based around a project developing a new model for predicting suitable habitats for future species. A group, comprised of ecologists, herpetologists and a mammalogist were asked to provide their expert guidance on the development of the model. An interactive projector was set up on a table, and the scientists asked to sketch notes on the future habitats predicted by the model. The decision makers gathered around the table to collectively define rules and objectives, much like a stereotypical war room from movies where generals debate strategy around a map table. Different map layers underneath the planners sketches could be changed, zoomed and moved to help them compare different model outputs.

The session was an opportunity to understand how participants with different areas of expertise worked around an interactive display to build consensus. Observation notes were recorded over the two-day planning session. Participants were experts selected for their knowledge of particular species and their experience in the field. The observations and discussion are reported below.

4.3.1 Training Participants to Use the Interactive Projector

The session began with a brief introduction to familiarise the participants with using the projector and to provide an overview of what they would be asked to do over the two-day session. Participants were shown that they could use their fingers on the interactive projector screen, just as they would on an iPad. Pens could also be used to draw on the surface. Each pen had the capability of remembering the colour it had selected, and both could be used simultaneously.

4.3.2 Results

4.3.2.1 Problems with Finger-Based Touch Interaction

The interactive projector was set up with the finger sensor to enable the projection to function much like a regular touch screen. I had only used this previously to see how well it worked. It was very responsive and seemed like it would be a very useful addition to the planning session. This would allow the participant to just draw without having to share pens.

However, in practice, while the touch was responsive and worked well, the unfamiliarity with the technology caused breaks in the discussions amongst participants. This occurred when participants were tracing around an area. The projector would interpret pointing and dragging as a touch input, resulting in the whole map being dragged around or the inertial scrolling in Google Maps flinging the relevant map off screen. These errors caused the speaker to become flustered when they became aware of their error. This seemed to preoccupy and interrupt the natural flow of their discussion, hindering their presentation. A further problem encountered by the finger touch sensor was the presence of paper notes and other objects on the table triggering the sensor to detect a touch input. An hour into the first session, I discussed with the group the option of unplugging the touch sensor and to just reverting to the pens.

Participant: "No, I think it's fine."

Facilitator: "I think it's going well."

One of the participants and the facilitator seemed okay keeping the finger touch. However, some of the group seemed hesitant. On reflection, the response of the other participants was probably due to uncertainty about what unplugging the sensor actually meant. Following the removal of the touch sensor, the participants slowly began gesturing to geographic areas and appeared to become more comfortable using the system.

4.3.2.2 Pausing to Think with a Touchscreen

Communication between the participants while drawing boundaries seemed to be very important. The participant drawing the shape would stop at certain points to query where the boundary should follow exactly. From an interaction sense, the participant would draw a line segment, pause with the pen still depressed where they had stopped and then continue moving after discussing where they should draw next. This seemed like a natural part of the decision-making process for the users as it allowed discussions of general areas to take place by as well as discussion about the more precise definition of a boundary. Users would happily make mistakes and either undo, erase or scribble them out to support the discussion. This refinement process allowed participants to combine their knowledge of different areas to create a bigger picture of a species.

- There was confusion between the projector on-screen menus and the projectors on computer menus.
- Pens sitting just off the bottom of the screen would still register as hovering just off screen. (This caused issues with moving the mouse).
- Reaching the other side of the screen was an issue, Users passed pens to other participants to change actions if they could not reach the palette.

4.3.2.3 Large Screens Require Long Arms

During the sessions, it was observed that users had to expend a fair amount of effort to reach tools that were not located near them. This resulted in users passing the pen to the person closest to the tool palette to change tools. While the command palettes were movable, they were not often moved as they were out of the way on the side of the screen. The participants were often reminded they could move the tool palette closer to them to select a tool. However, they seemed more comfortable passing the pen back and forth.

4.3.2.4 Discovering New Tools

Halfway through the first day, the users needed to undo what they had done. Up until this point, the group had been using the eraser to rectify their mistakes. As they selected the eraser, I interrupted and suggested that they should use the undo button to undo the line they had just drawn.

> *Me: "Maybe you should use the undo button for this, you didn't draw much."*

The group seemed somewhat surprised that there was an undo button. During the remaining 1.5 days of the session, the participants used the undo button frequently and only occasionally used the eraser tool. This took me by surprise as I had assumed the participants were aware of all the tools available to them. I proceeded to give the group another description of all of the tools available in the tool palette.

Early on the second day one of the group members started looking at the tool palette more in depth.

Dialogue

> *Participant: (Looking and pointing at tool palette)*
>
> *Participant: "Are these the colours we have?"*
>
> *Me: "Yes."*
>
> *Participant: "Let's try pink." (selects the pink highlighter colour and draws on map)*
>
> *Participant: "Oooo, that's new."*
>
> *Me: "It looks like a highlighter."*

Participant "That's useful."

Similar to the day before, I had assumed the group's knowledge of all the tools available to them. Even though the group had the tools demonstrated to them several times now, they gravitated towards the tools they most commonly needed. The discovery of the highlight tool demonstrated that although they had been using the projector for almost 8 hours, they still had a limited understanding of what they could do.

4.3.2.5 Knowing what mode users are in is problematic

The interactive projector enables two modes when in the laptop based whiteboard mode.

Mouse The mouse mode allows the user to interact with the computer as though it is a large touch screen. The pens and your fingers move the cursor around and activate the left click when you depress either of them.

Whiteboard The whiteboard mode allows you to draw lines and basic shapes on the screen without interacting with what is displayed on the computer. This allows the annotation of what is currently on the computer screen.

During these sessions, the participants were mostly working in the Whiteboard mode to annotate over maps displayed in Google Earth. However, they were required to switch back to the mouse interaction mode whenever they needed to move the map to look at a different area. There were many instances where whiteboard mode had been disabled to save a picture of the annotations and was not re-enabled before participants tried to draw things. This resulted in the map being moved instead of performing the intended action of drawing on the map. Moving the map back was usually not a huge concern. However, it was complicated when participants wanted to continue their drawings after changing layers.

4.3.2.6 Group Interactions

The group of participants were initially given a training session on how to use the interactive screen with the pens and their fingers as described in Section 4.3.1 (on page 107). Training, however, did not include any hands-on components for the participants.

Participants seemed quite hesitant at first, only interacting with the tool at the bare minimum. As they were asked about the validity of the model, all of their analysis was done by describing their feedback verbally and by pointing at the map. After a few ideas had started coming back from participants, the facilitator asked the participant directly to draw their concerns onto the map. The participant seemed hesitant about using the interactive projector. Reflecting on the process, it is apparent that the problems with the finger based touch system reported earlier contributed to participant uncertainty in using the system.

First Day During the first two hours, users gained confidence in using the system. This was partially interrupted by the finger touch sensor causing issues with they way the participants naturally worked. After transitioning away from the finger sensor, users started to become more comfortable using the system. Users were drawing on the maps and writing comments with the pens by the end of the first two hours.

The users had access to four colours of pen in the tool palette. Fairly quickly the users began to standardise what each colour was used for. When the incorrect colour was used some of the other group members would speak up and suggest changing to the colour they had used on the previous page. Although this was not proposed by the session facilitator, the group took it upon themselves to produce consistent work to make it easier to understand.

After users had returned from lunch, they became aware of the undo function after I had pointed it out to them. Although it took a few reminders, they soon started preferring it over the eraser as it simplified the process of removing things they had just drawn.

The researcher observed the participants slowly becoming more comfortable using the tool, interacting with others and expressing their opinions. Thoughts and ideas seemed to be expressed more freely, and the group collaborated to unify their knowledge of particular regions into a single representation of that. At the conclusion of the first day, it appeared as though the participants had become fairly comfortable using the interactive projector.

Second Day The difference in collaboration and confidence in the system between the end of day one and start of day two was surprising. Although none of the users gained extra experience with it overnight, the opportunity to rest and perhaps gain perspective made a noticeable difference. Participants seemed keen to learn what else they were able to do with features of the system and were began playing around with more colours and tools. As a result, the users discovered that the highlight tool could be used as an extra colour and due to the larger brush size, would allow them to fill large areas. Generally, they became more casual when interacting with the tool.

4.3.3 Summary

The session allowed for the successful collection of expert knowledge about future species ranges under climate scenarios. The research project described in this thesis is an attempt to build software for pest management that uses a similar approach to that taken by the participants in this observational study. Many of the findings of this study were incorporated into the pest management planning tool described in the next two chapters. A summary of the important findings has been provided below.

The sessions were incredibly productive and useful to the researcher conducting the session when making improvements to the model. Model runs for 28 species were analysed over the two days, producing maps that incorporated the knowledge of all of the experts in the room. Maps from these sessions were taken and used to refine the model and produce future climate scenarios for a large array of species.

None of the experts had previously used an interactive projector and participants were excited to be using it to provide feedback. However, initially, the participants did not actively engage with the tool but had to be prompted to use the tool to support their discussion and provide their responses. Most of the skills learned by participants using the tool resulted from them of being directly asked to perform a task. Participants did not explore the tool voluntarily until the second day.

Using the finger touch system at the start of the planning sessions appeared to be a hinder the experts from performing their natural presentation process. While it did provide a certain level of interest and excitement among the participants initially, on reflection, it required the participants to change how they would normally discuss and present concepts. These limitations were an important factor to consider in the development of collaborative tabletop based mapping systems as they could distract from the task at hand.

A list of the findings from the observational study is presented. These were used throughout the development and testing of the pest management planning tool.

- Tools need to be easily accessible by the participants.
- Movable tool palettes do not work if the user cannot reach the handle to move it.
- Participants need hands-on experience to fully understand the range of functions the tool is capable of.
- Becoming comfortable with using the tool takes time and experience.
- Prompting users and giving them tasks builds confidence and experience.
- The ability to pause mid-drawing and check with other group members before continuing helped to capture consensus from multiple people without needing to revise quickly.

4.4 Chapter Summary

Research tasks undertaken in this chapter used AODM to help identify several areas in the pest management process that could be improved through the use of interactive tools. Targeting activities and limited resources are one of the major limitations to the effectiveness of planning. Methods used for targeting often have a strong reliance on the expertise of the planner. This section will discuss the contradictions and limitations found and develop them into a set of functional requirements as well as introduce a concept for a new interactive tool to support decision makers.

4.4.1 Contradictions and Limitations

From the analysis of the current process and AODM in this chapter, several contradictions and limitations in the current pest management process were found.

- Enforcement powers of local councils discouraged reporting of pest populations by residents and landowners.
- Spatial targeting decisions were made using the expertise of decision makers. There was no method for easily incorporating dispersal modelling into the sessions.
- Targeting decisions were often made with little consideration of the wider impact across the region.
- Collaborative working groups required a skilled GIS user to interact with data and maps.
- Budgets were limited, and prioritisation is essential.
- Planning sessions were fairly short and difficult to organise.
- Information provided by the community was valued but needed to be validated.
- Communities were inclined to work together when they understood the problem.

4.4.2 Refining the Scope of the project

Decision making at the regional and local government level is often limited by the knowledge and understanding of those involved. Consequently, strategies are often developed without full respect of the bigger picture. Dispersal models have the potential to inform and improve pest management strategy but are often not incorporated into the planning process. To further improve the allocation of resources a scientifically validated analytical process, such as dispersal modelling, should be combined with the human based process. The addition of analytical tools would enable experienced local planners to further their understandings, explore new methods and help justify their final decisions.

The interviews helped build an understanding of how neighbouring properties were impacted by one another. Each land manager had their own responsibilities, perspectives and aims across the land they managed. Neighbours did not always share the same objectives, and their actions could influence neighbouring properties or their entire community. When information was shared between neighbours and organisations, it helped build the collective knowledge that could be used to improve the targeting of management actions. Allowing land managers to see the impacts their pest problems had on neighbours and communities would help build understanding and engagement throughout the community. An example of this was provided by two of the interviewees (see Section 4.2.5.3 on page 104). A local catchment of farmers was able to collaborate with neighbouring properties that were a major source of their pest problems.

Visualising managed and unmanaged scenarios over time could assist in communicating the importance of collaborative management to broader audiences. Current decisions are made by planners without full knowledge of the surrounding region. Although consultation and collaboration do take place, it is difficult for consensus to be reached amongst groups with competing interests. Allowing planners and stakeholders to visualise how their actions influence the wider network could help build consensus amongst stakeholders who may have limited interest in pest management planning.

4.4.2.1 Target Users

Although individual landholders and farmers could offer a level of detail previously not captured in the process, encouraging their involvement extends beyond the scope of this research project. While some landholders are engaged in the process, the majority appear to be interested in the productivity of their land and not the wider region. The organisations and industry bodies interviewed reported limited involvement from individual landholders. Therefore the tool should be targeted towards the organisations, stakeholders and landowners currently involved in the process. Further work could focus on creating a tool to educate and encourage new community members to become involved in the pest management planning process, however it is out of the scope of this project.

Chapter 5

Phase 2: Implementation

Chapter Overview

This chapter focuses on developing the findings from the previous chapter into a theoretical design and implementing a usable prototype for testing. It begins by describing the conceptual design of the prototype tool, followed by a description of the final implementation. The chapter then jumps backwards chronologically to describe how the implementation was developed using an iterative process. Each distinct stage of development has been grouped into an iteration. There were five iterations in total. Iteration one and two are described in this chapter while the following chapter describes iteration three and four, along with the usability analysis and scenario used to shape the design of the tool. Iteration five is discussed in the appendix as it was developed after the final evaluation, yet it still contributes to the final outcomes of the thesis.

This Chapter is divided into four sections:

- A Conceptual Overview (5.2) describes the conceptual design of the pest management planning tool.
- Implementation Overview (5.3) describes the final implementation of the tool developed in this project.
- Iteration One (5.4) describes the first iteration of the prototype planning tool.
- Iteration Two (5.5) describes the second iteration of the prototype planning tool.

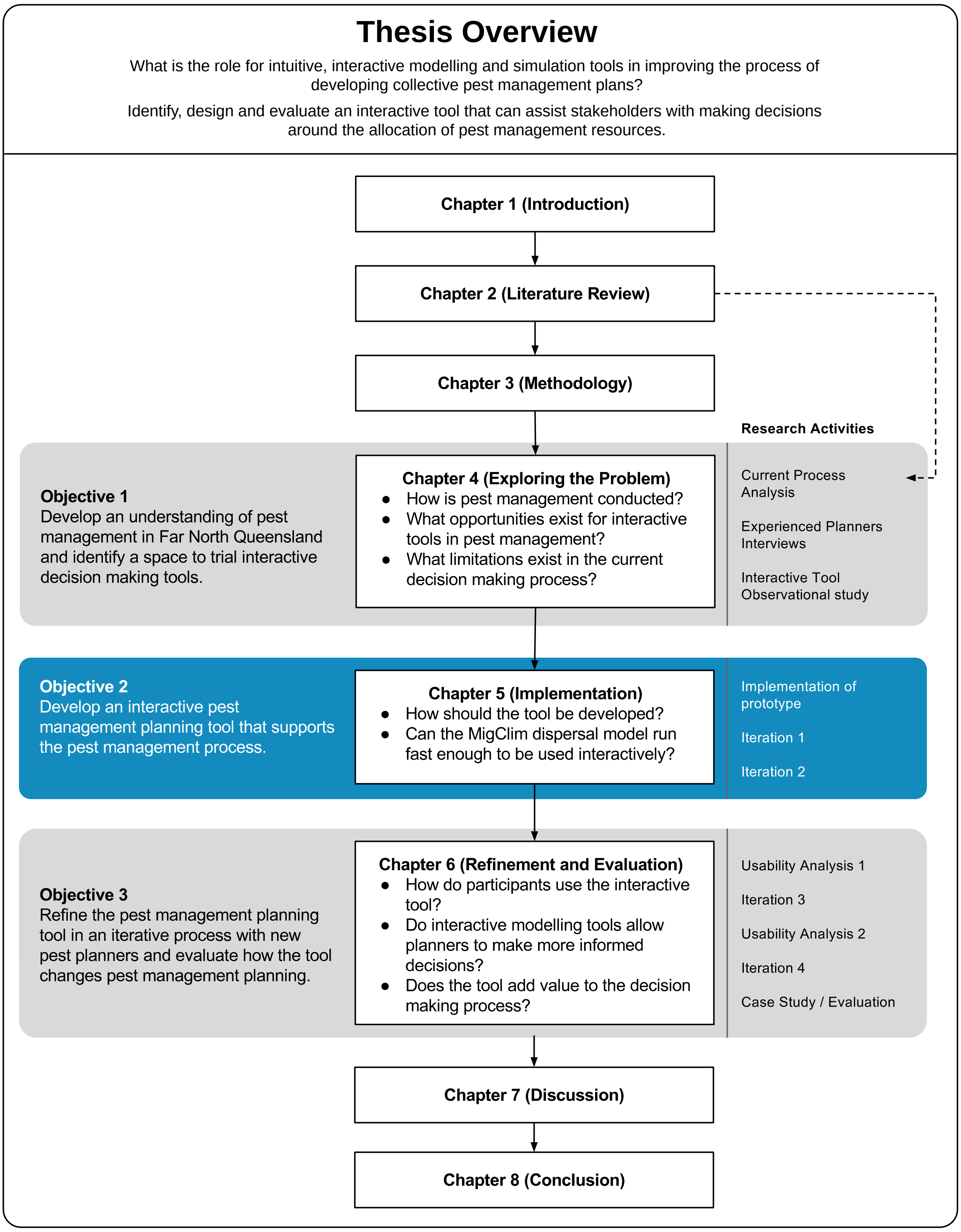

Figure 5.1: Diagram showing the order of research activities presented in this thesis. The blue highlight illustrates the current position in the thesis.

5.1 Introduction

The design of this collaborative planning tool was based on the qualitative studies undertaken in the previous chapter. Stakeholders, managers and operational staff were interviewed to establish the perspectives and requirements of each user group in the planning process. The outcomes of the interviews were used in conjunction with an Activity-Oriented Design Model to develop the workflow and use case of the planning tool. The development of the tool advanced using an iterative process with usability testing sessions to determine the best methods to foster engagement, encourage collaboration and ensure effective outcomes could be reached. The usability testing sessions built an understanding of best practices for applying interactive technologies to the planning process. An evaluation of the planning tool was conducted using real invasive species management problems from the Atherton Tablelands region. The local land owners, managers and operations staff are the participants that use the tool to design plans for several invasive species in their area. This research determined the impact that technologically augmented engagement meetings had to improve communications between different groups and enhance the pest management decision-making process.

To encourage collaboration and engagement of users, visualisations of the modelled future invasive species dispersal are projected onto a table-sized map, reminiscent of the strategisation scenes in war game movies. Management actions can be drawn directly onto the map using finger tracking software that simulates a touch surface. Strategies are pushed to a cloud service that models the impact user-defined actions have on future pest dispersal. An estimate of the work required and financial cost to achieve the user defined objectives is also calculated. The predicted future range of a pest is rendered as an animation using a mapping server and displayed in the user interface.

5.2 A Conceptual Overview

Detailed and reliable planning is crucial for pest managers to manage pest populations with limited resources effectively. Planning is undertaken at all levels of land management and often involves identifying priority pests across the region they manage. Management targets are often defined for pests to assist with the allocation of resources across a region. Vulnerable areas or land that provides certain values to the region are often prioritised by stakeholders. When complete weed removal is not possible, areas, where weed control goals are the easiest to achieve or the most assets would be protected are targeted. Prioritised species and spatial management targets form the basis of the pest managers strategy and help target resources to pests that pose the greatest threat to the region.

Currently, modelling and simulation tools are not widely used in pest management planning. The decision support modelling and simulation tools often require expertise to configure and use them. This research project explored how these tools could be made easier to use and could be configured to allow everyday planners and stakeholder groups to make use of these scientifically validated models. To assist planners with strategic decision making a dispersal model will be used to provide simulations of pest species. The dispersal model is connected to a user interface that visualises simulations and allows users to interact and modify pest management strategies. Strategies will be developed by defining management objectives, similar to the ones currently used for pest management planning in FNQ.

The decision support tool developed in this thesis has two distinct sections, a user interface and a modelling and mapping pipeline. The user interface allows the user to interact with the modelling tools from a higher level. The modelling and mapping pipeline controls the modelling of future dispersal, financial estimation and visualisation of outputs. A modelling controller manages requests and actions from the user interface to initialise compute nodes, start modelling runs, manage the rendering of maps and modify input parameters to the models. This is explained in more detail in the next section (Section 5.3 on page 128).

5.2.1 Functional Requirements

The functional requirements for the pest management tool were developed from the findings of the Literature Review (Chapter 2) and activity-centred design (Chapter 4). The pest management planning process was broken down into independent tasks that could be performed using an interactive tool. A summary of the tasks identified for the development of a pest management plan are defined below:

Define New Populations: Existing data about infestations of a pest across the planning area is collected from the participants. Infestations are reported by defining an area on the map that contains the species. The data is typically confined to 100ha grid cells in the existing approach referred to in Section 2.4.4 (on page 32). However, for the purpose of this project, the data can be captured at a finer resolution and converted to a 100ha grid when the data requires exporting.

Define Management Targets: Management targets are determined through group discussion and prioritisation. Each target represents a specific group of actions to be taken to control the pest species. Actions are defined across a specific area, typically bounded by a polygon and are colour coded to easily communicate the management targets across a region. Management actions are often selected in the context of the current distribution of the species or a likely future distribution. Drawing, editing and deleting actions are a requirement to allow the creation and modification of management plans.

View Outcome of Management Actions Across Time: Management actions are modelled as a part of the species dispersal so as to produce a spatial and temporal simulation of a species, providing a clear visual depiction of the pest species range increasing. Playback of the dispersal simulation is controlled by the users to allow them to move through time freely or to playback the entire simulation as an animation. Metadata about the dispersal of the species will be linked to each time period to give a numerical overview of the distribution of the species and costs associated with managing it.

View The Suitable Habitats Of A Species: The habitat suitability model is used to help plan the management of a particular species. It provides a quick overview of the suitable range for a pest species to grow in. Furthermore, the inclusion of the underlying suitability model can be used to demonstrate how the simulations function to those not familiar with dispersal modelling.

Create and Compare Multiple Planning Scenarios: Being able to create and compare different management plans will enable participants to generate multiple strategies to determine the best management methods. The tool could duplicate a current plan and create new blank plans. An overview screen of all of the plans would allow comparisons to be made between different plans.

View Requirements to Meet a Defined Management Target: A pest management target can be defined on a map by anyone, however understanding the requirements needed to meet a management target requires an in-depth knowledge of the discipline. Ideally, an estimate of the required work to implement a management plan would be useful to compare different strategies for managing a pest. By making a few assumptions about the density of a species this process can be greatly simplified into a count of infested hectares requiring treatment in a given year. Although this process does not capture the nuances of pest population density in a 100ha grid cell or the staffing required for management activities, it can provide a metric which is useful for quick comparisons between different planning scenarios.

View The Costs of a Management Plan: Displaying a cost estimate would allow for quick and easy comparison between different management strategies. As the availability of funding is one of the major limiting factors in pests management, the financial comparisons between different strategies would enable managers to develop budget proposals showing the costs and benefits of an array of options. Cost metrics could simply be a function of a per hectare cost multiplied by the infested hectares requiring treatment in any given period.

5.2.2 Workflow

The proposed functionality described in the previous subsection was developed into a workflow to organise the tasks into logical groupings. The groupings are a collection of the related tasks that are required to conduct pest management planning using the previously proposed decision support tool. Grouping these tasks in the user interface ensured that tools the participants are looking to use are easily accessible when required.

The groupings are developed into a workflow that was then later developed into the user interface of the tool.

The functional requirements were sorted into logical steps of the process using an affinity diagram. The three groups were then given the labels: Data; Planning; and Review. Each group defines the specific goals related to the functional requirements within it. Table 5.1 depicts where each of the functional requirements were placed during the grouping process.

Data	Planning	Review
- Define New Populations	- Define Management Targets - View Outcomes of Management Targets Across Time - View the suitable habitat of a species - Create and compare multiple planning scenarios	- View Requirements to meet a defined management target - View the cost of a management plan

Table 5.1: Functional requirements grouped into categories.

The three categories were developed into a workflow diagram to describe how the tasks completed by users connect (see Figure 5.2). Each category became a screen in the user interface, and the functional requirements are the actions that can be performed on each screen. An additional timeline screen was added to allow participants to make comparisons between different strategies created throughout the planning process.

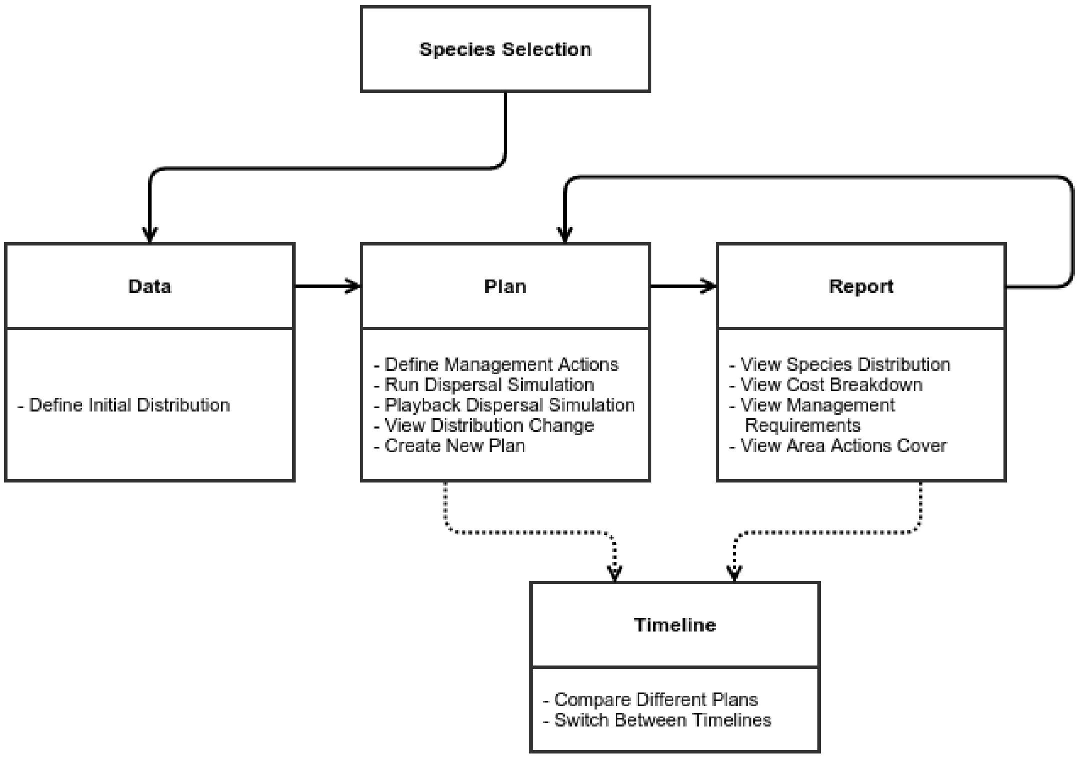

Figure 5.2: Flowchart depicting the workflow of the pest management decision support tool user interface.

5.2.3 Dispersal Model

The modelling component of the software must be capable of interpreting actions and delivering accurate and timely results for near real-time experimentation and simulation of the different scenarios. The swift operation of the dispersal modelling is integral in achieving responsive, near real-time feedback and in abstracting the modelling complexity from the user. In order to determine which areas are suitable for an incursion by a species, it is important that the modelling and visualisation pipeline are optimised, and that management actions are combined with the habitat suitability and current distribution.

The dispersal modelling stage represents the most computationally expensive component of the tool, and it requires optimisation so as to minimise bottlenecks. MigClim (Engler et al., 2012) was selected as the dispersal model due to its robustness, simplicity and straightforward method to simulating invasive species dispersal. Dispersal scenarios in MigClim are run in a stochastic manner by iteratively calculating the probability of invasion of unpopulated cells (Engler and Guisan, 2009). Invasion probability is determined by the suitability of a cell for invasion (from a habitat suitability file) and the distance to a currently populated cell based on invasion and distance probability values.

MigClim produces a new distribution model at each yearly time step. The modelled distribution for each year is saved to disk in a separate ASCII presence-absence grid file and is written at the end of each time-step. The resulting ASCII grid file is uniquely named based on the species distribution it represents at a point in time and the specific management actions. Files are stored in a hierarchical structure that identifies the actions of each run. The modelling controller marks the layer as available to the front end as each time-step is written to disk.

5.2.3.1 Limitations

One important feature of this tool is that it allows users to define management actions on the map to interact with the dispersal model. However, MigClim does not natively support management actions as an input. Therefore each action is interpreted as an adjustment to the suitability of an area for a species. These actions only represent the suitability of establishment in an area that is being actively managed. For instance, an area highly suitable to incursion by a pest, yet zoned as actively managed may not be at risk of infestation. The species has a substantially reduced probability of infestation due to human intervention. Therefore, the managed habitat suitability file represents the effective suitability of a weed to grow provided there is ongoing human management.

5.2.4 Interaction

The literature review identified the importance of allowing users to interact naturally and easily with the data in order to improve stakeholder participation. By reducing the complexity of the decision support and mapping tools, new non-experts could more easily be able to participate in the planning process. Furthermore, encouraging collaboration between stakeholders was an important step in developing more effective plans for regions spanning multiple governance localities. Further, improved participation and collaboration amongst neighbouring land managers could help develop more targeted and effective management plans.

In order to improve participation and collaboration, the pest management planning tool was developed around a "war room" style scenario, where each member could share their expertise in the development of a plan. This design was based on the observations of the working groups and interviews conducted in Section 4.2 (on page 90). During the Literature Review (Chapter 2), a number of interactive technologies were identified that could support pest management planning. An interactive projector was selected as it enables groups of participants to collaborate on a relatively large screen. Furthermore, interactive projectors are affordable for pest management groups with limited budgets. The user interface (described later in this chapter) designed for an interactive projector is also capable of being used on a smaller touch screen device such as a tablet or laptop.

An Epson 595wi interactive projector was used to create a large interactive touch surface on a table. The projector offered the ability to track either fingers or special pens to interact with the computer. Interaction with a computer running Windows 7 was very similar to using a mouse with the left click button. A pen or finger, when moved across the surface, behaves in the same manner as clicking and dragging. The projector was very simple to use with existing applications and simply required the installation of drivers and calibration of the projector.

5.2.5 Why Build for the Web?

The World Wide Web has grown vastly over the past 30 years, each year offering more interactivity and richer media. The internet has become common across Australian households and has opened opportunities to enable access to information and learning tools previously unavailable to the majority of citizens. Internet access although common, is still not quite ubiquitous across Australia, many regional areas lack affordable high speed access creating a digital divide. However, the opportunity to reach a growing array of participants using the internet is undeniable. The opportunities for citizen science, collaborative planning, community engagement and education tools are vast and currently unparalleled and mostly untapped.

This pest planning tool was built as a web-based service to reach and garner input from much wider audiences than traditional planning. Furthermore, it can help engage those unable to attend workshops. Broader access to the community offers the potential for aggregating vast amounts of local knowledge from the citizens who are most familiar with the areas and pests of interest. Collectively, this level of participation and involvement can provide levels of information and understanding that was not previously available to planners.

Typically, the data-driven decision making has been separated from community engagement due to complexity of the planning process. While the final outcomes of planning have always been made available to the general public by way of pest management plans, opening the process to a wider audience and making the decision support tools more accessible would allow more local knowledge to be captured and incorporated into the decision-making process. Not only would this additional information provide a finer understanding of local pest management scenarios in an area, a further benefit of broader engagement in the process would be the democratisation of the decision making.

The internet offers many advantages as a method for deploying collaborative decision support tools in terms of reach, availability and ease of use. Despite these, there are disadvantages related to the scale at which applications can be affordably built. Loading data files larger than a few megabytes and doing computationally intensive work is restricted by the available computer infrastructure and the available network bandwidth. Furthermore, web-browsers are typically limited in their ability to store large files and undertake computationally expensive tasks locally.

It is simply not feasible to load large GIS files for rendering in a browser when network connectivity and computer performance are unpredictable. Typically, pre-rendered tiles are generated on a web service and served to a user as tiled image set. A web mapping application only needs to load the rendered image for the area currently being viewed in the browser. This tiling approach has limitations in how the underlying GIS data can be interacted with by the front end. For instance, animation is fairly processor and network intensive as a new image must be loaded for each frame of the animation.

Although the web has a number of limitations, its accessability, availability and ability to build one application to run across a large number of devices make it an ideal choice for collaborative planning tools.

5.2.6 The Progression of This Spatial Planning Tool

The development of the decision support tool was done iteratively, involving both bench testing in the lab and usability testing with groups of users between each iteration. The prototype tool went through five iterations throughout the course of this research project. Each represented a major change in the underlying operation of the software or a major change to the user interface. Each of the iterations had a focus on specific areas of the pest management planning problem to produce a fast, reliable and easy to use tool. Although the process is described as discrete iterations in the thesis, the development process was essentially fluid and the iteration numbers used here are simply a descriptive tool. This chapter describes the first two iterations (see Section 5.4 on page 147 and 5.5 on page 154).

The pest management decision support tool began as a technical project that aimed to develop a method for integrating the dispersal model into an interactive tool. When the testing of the dispersal model began, it was identified that it ran too slow to be used effectively in working groups. The first two iterations focussed on improving the runtime of the dispersal model and development of an interactive user interface. Once this was achieved a series of usability testing sessions were conducted to begin incorporating the feedback of potential end users. These usability testing sessions identified several interaction problems with the prototype decision support tool that were improved in the following iterations.

5.3 Implementation Overview

Note

This section describes the implementation of the pest management planning tool. While the user interface and the model optimisations discussed in this section are inconsistent with the chronological order of the rest of the thesis, this section serves as a reference for the final implementation, and aims to provide a better understanding of the tool, before progressing to the usability analysis and evaluation. This section provides an overview of the architecture of the pest management tool. The concepts discussed in this section were developed over the five iterations and in conjunction with the user studies detailed in Chapter 6.

The pest management tool is comprised of a collection of different pieces of software, libraries and custom-built code, connected together to enable easier management of pest species. The framework can be divided into two distinct sections, the user interface and the web service. The web service is responsible for modelling, data storage and making the data available to the user interface. The user interface is responsible for visualising datasets and interacting with the backend. 6.

5.3.1 User Interface

The user interface is designed to facilitate discussion and enable users to compare ideas. The user interface was built as a web application using Hyper Text Markup Language version 5 (HTML 5) and Javascript. A number of libraries and frameworks, listed below, were used to simplify the development of the user interface.

OpenLayers[1] is a web mapping library that was used to display the map tiles and features from the GeoServer and MapServer. A custom animation plugin for OpenLayers was built to animate raster layers from the Web Map Service (WMS).

Bootstrap[2] is a widely used web development framework that provides a large number of common user interface components.

[1]https://openlayers.org/ (accessed 10/02/16))
[2]https://getbootstrap.com/ (accessed 10/02/16)

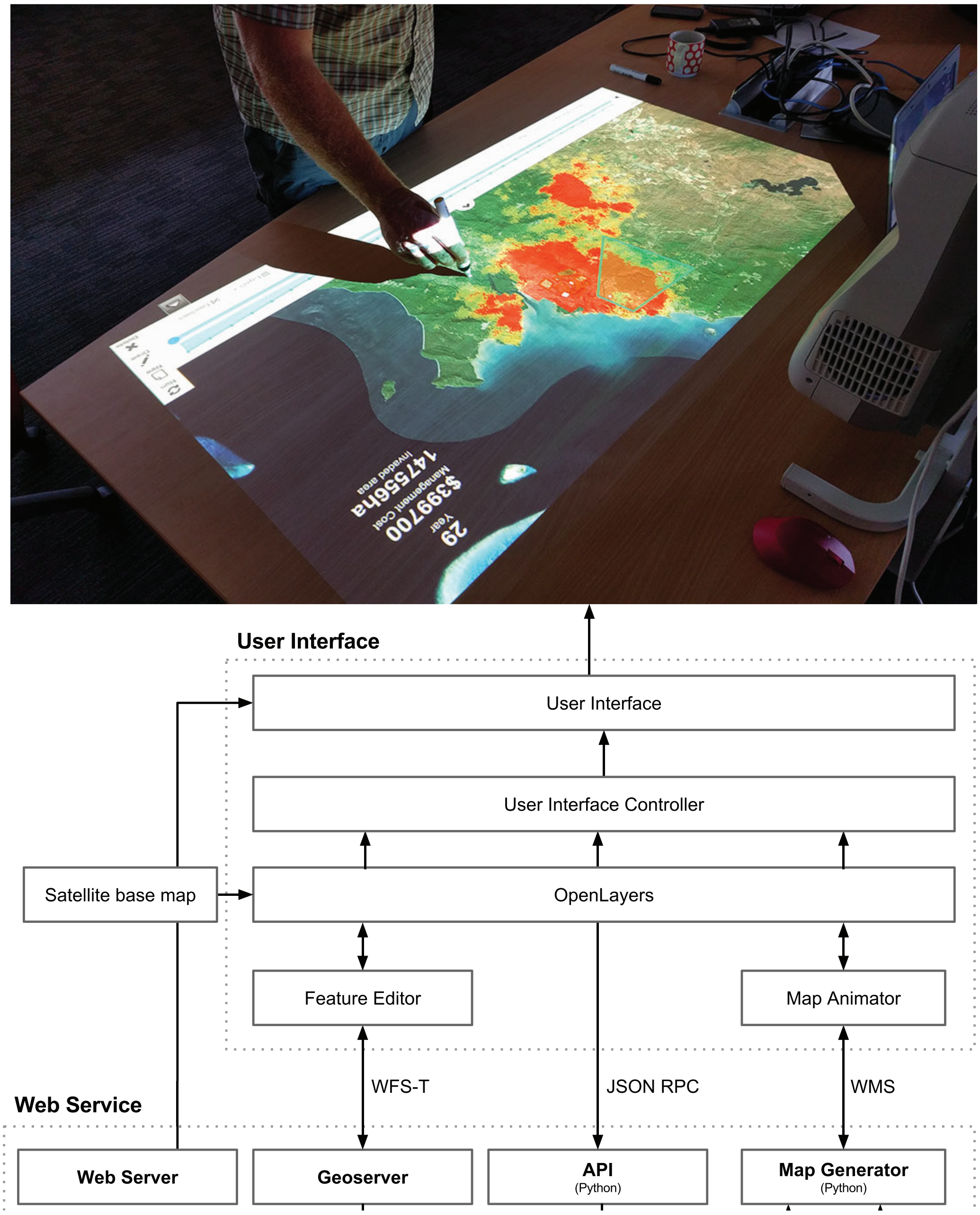

Figure 5.3: User Interface diagram.

A controller was developed to manage OpenLayers and also to connect the user interface components to the correct Remote Procedure Call (RPC) actions (see Figure 5.3). The controller has a persistent WebSocket connection with the web service that provides immediate updates on the model statusn. The application programming interface (API) notifies the controller when a new dispersal step is ready and when new statistics are available from the dispersal model

5.3.1.1 Design Overview

The Data and Plan views are most commonly used for the review and interaction with spatial data. These pages were designed with the map as the primary component. The additional tools on this view serve as a means to interact with the map. The planning page allows management strategies to be designed around the simulated dispersal scenarios. Each scenario is comprised of the management actions drawn on the map by the users.

5.3.1.2 Common Controls

The user interface has several common elements across all of the views to ensure consistency in the design.

The toolbar, shown in Figure 5.4, is made up of several different components including buttons to switch between views, map settings, planning settings and a 'no action' toggle button. The management interface buttons toggle between the different views in the tool. Each interface incorporates the common controls as well as a specific set of tools for that particular interface. The zoom buttons adjust the extent of the map view. The toggle button switches between the current scenario and the unmanaged scenario. When clicked, the underlying dispersal model and statistics switch between the no action and current scenario. If the user was viewing a managed scenario, they can quickly refer to the unmanaged scenario to make comparisons and figure out how their strategies compare to taking no action.

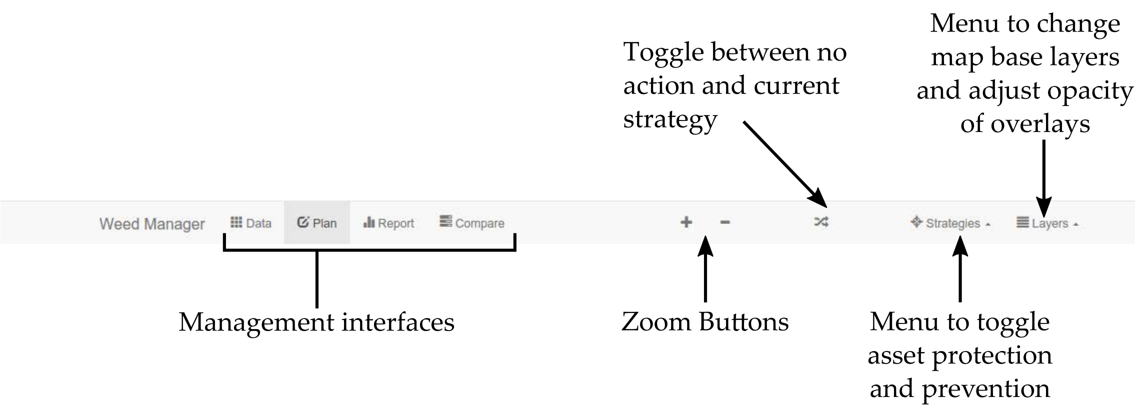

Figure 5.4: Toolbar, showing the view selector, map controls and layer switching shortcuts.

The strategies menu (see Figure 5.5) allows users to adjust the management strategies that are not defined on the map. For the purpose of this study, we have pre-defined the asset protection boundaries. These were defined using existing spatial extents for high priority national and state forests. Users can toggle the asset protection on and off to view its influence on their management strategies. The prevention campaign buttons adjust the total expenditure required for prevention activities. Higher spending on prevention lowers the risk of human factors influencing dispersal. Although this is a fixed value, participants in the final focus group requested the ability to enter their own costs and values for prevention.

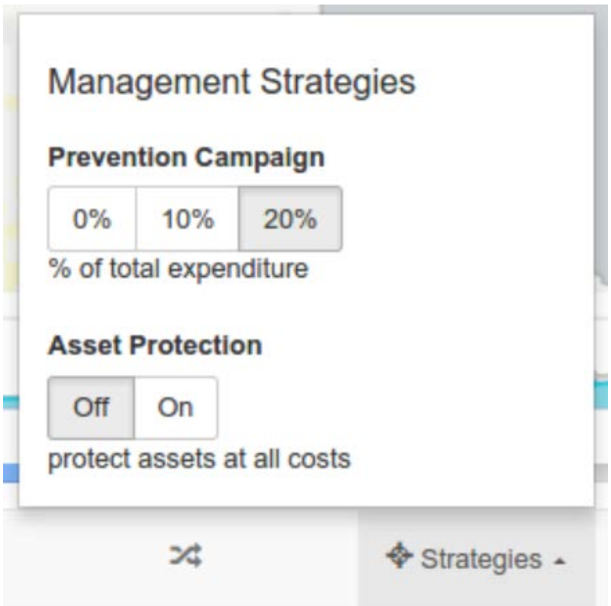

Figure 5.5: Management strategies selection menu.

The layers menu (see Figure 5.6) allows the base layer of the map to be changed and the opacity of the overlays to be adjusted. Three base layers are available: satellite imagery; a light grey map that has subtle details; and a generic coloured map.

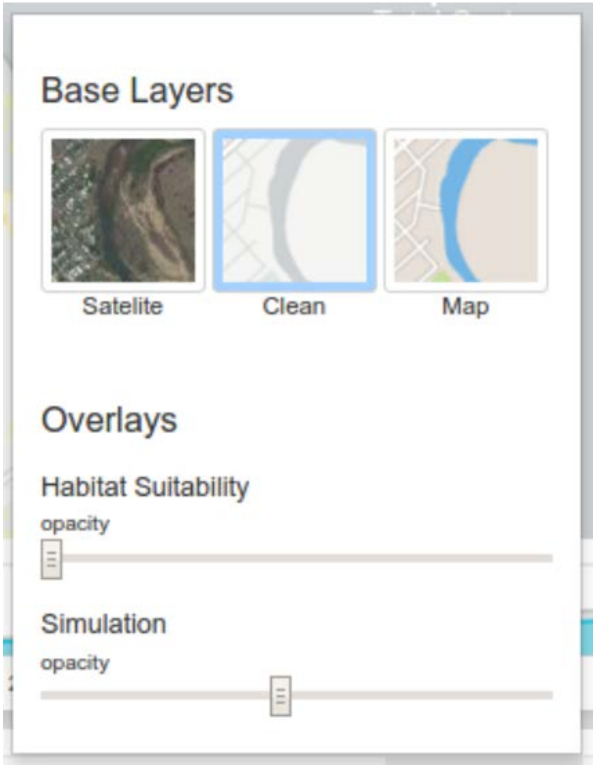

Figure 5.6: Layers menu.

5.3.1.3 Data Interface

The interface view (see Figure 5.7) enables users to report new occurrences of a species by drawing them directly onto the map. Additional items are added to the side palette that allows users to draw and save new occurrences along with tools to edit and delete existing occurrences. The interactive features which can be performed with the population data are as follows:

Draw New Population New populations are drawn by selecting the Draw tool and tracing the extent of the species they are reporting onto the map. The drawing is finished when the user closes the polygon.

Edit Existing Population The Edit tool enables the users to change the shape or size of existing populations. This is achieved by tapping the edit tool, tapping the population they wish to edit and moving the handles to reshape or resize the population.

Delete Existing Population The Delete tool enables the user to delete and existing population. This is done by tapping on the Delete tool and tapping on the population to be removed.

Save The Save button updates the distribution layer and re-runs the no-action model.

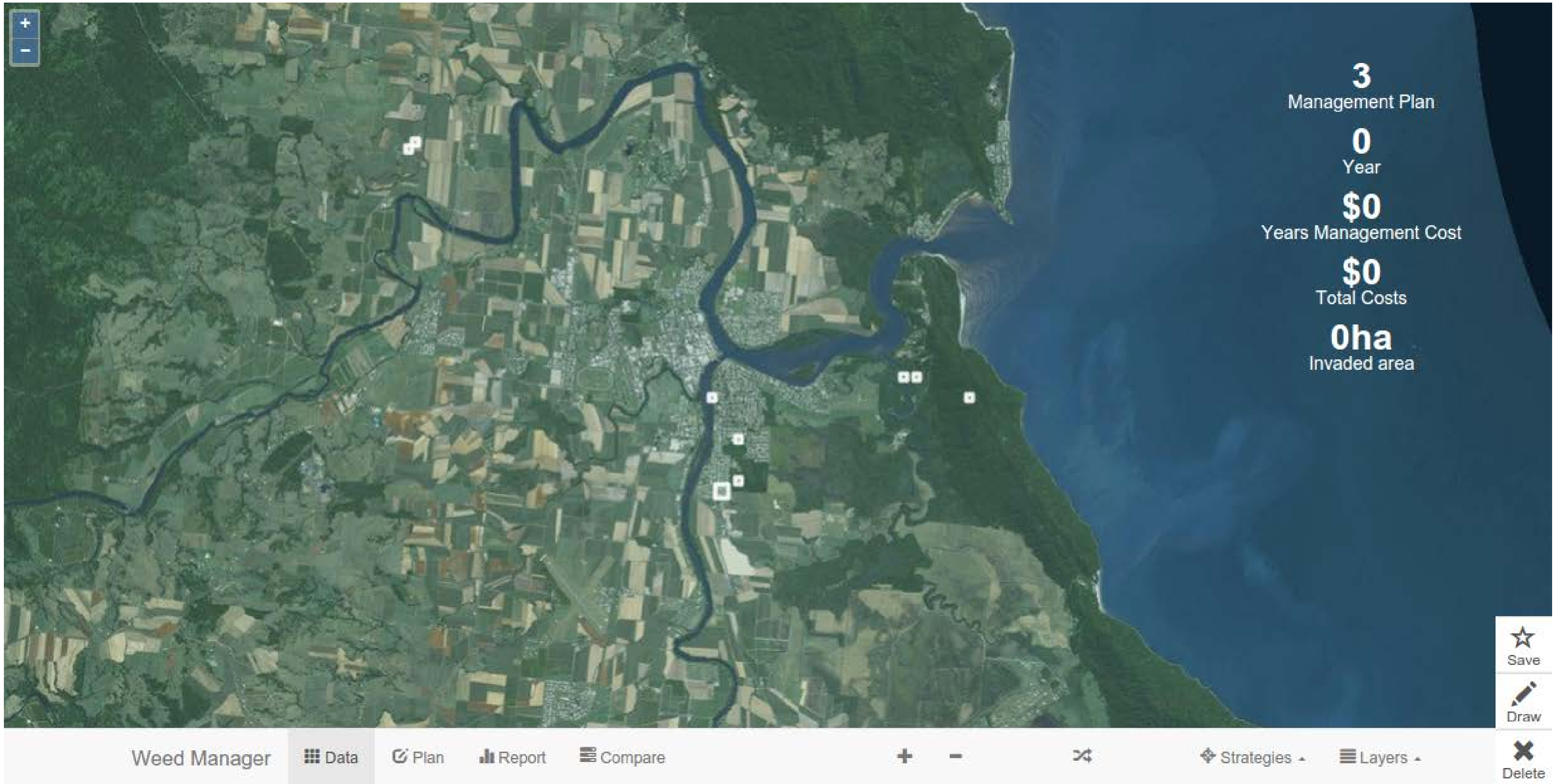

Figure 5.7: Data interface view. This interface allows participants to add new populations of the target pest species. Current pest populations are shown as white squares.

5.3.1.4 Planning View

The planning interface (see Figure 5.8) allows management strategies to be designed around the simulated dispersal scenarios. Each scenario is comprised of the management objectives drawn on the map by the users. The planning pages show the current management actions drawn onto the map. The management actions are colour coded based on the existing management strategies used in the FNQROC pest management planning strategy.

At any point during the design of a management plan, the dispersal model can be run to visualise how the current strategy impacts the pest species on the map. This enables an iterative design process, where the addition of each management action can be tested and modified as necessary. Each re-run of the model overwrites the previous run unless the current management plan has been saved as a duplicate. By saving the plan, a new entry is created on the timeline, which can be accessed by opening the timeline selector.

The functions made available in this view are:

Run Model The model is run by clicking the Run button on the tool palette.

New Timeline A new timeline can be created by clicking on the new button on the tool palette. This opens a dialog asking the user if they would like to create a new management plan or a duplicate of the current plan (see Figure 5.9). New or duplicate management plans are shown in the timeline interface.

Draw Management Actions Management actions can be drawn onto the map by selecting the draw tool and tapping out the points required for the polygon.

Edit Management Actions Editing management actions are achieved by selecting the Edit tool from the command palette, selecting the management action to edit on the map and then moving the handles to edit it. The edit is finalised by clicking away from the management action.

Delete Management Actions Deleting management actions can be accomplished simply by selecting the Delete tool from the tool palette and selecting the management actions on the map to be deleted.

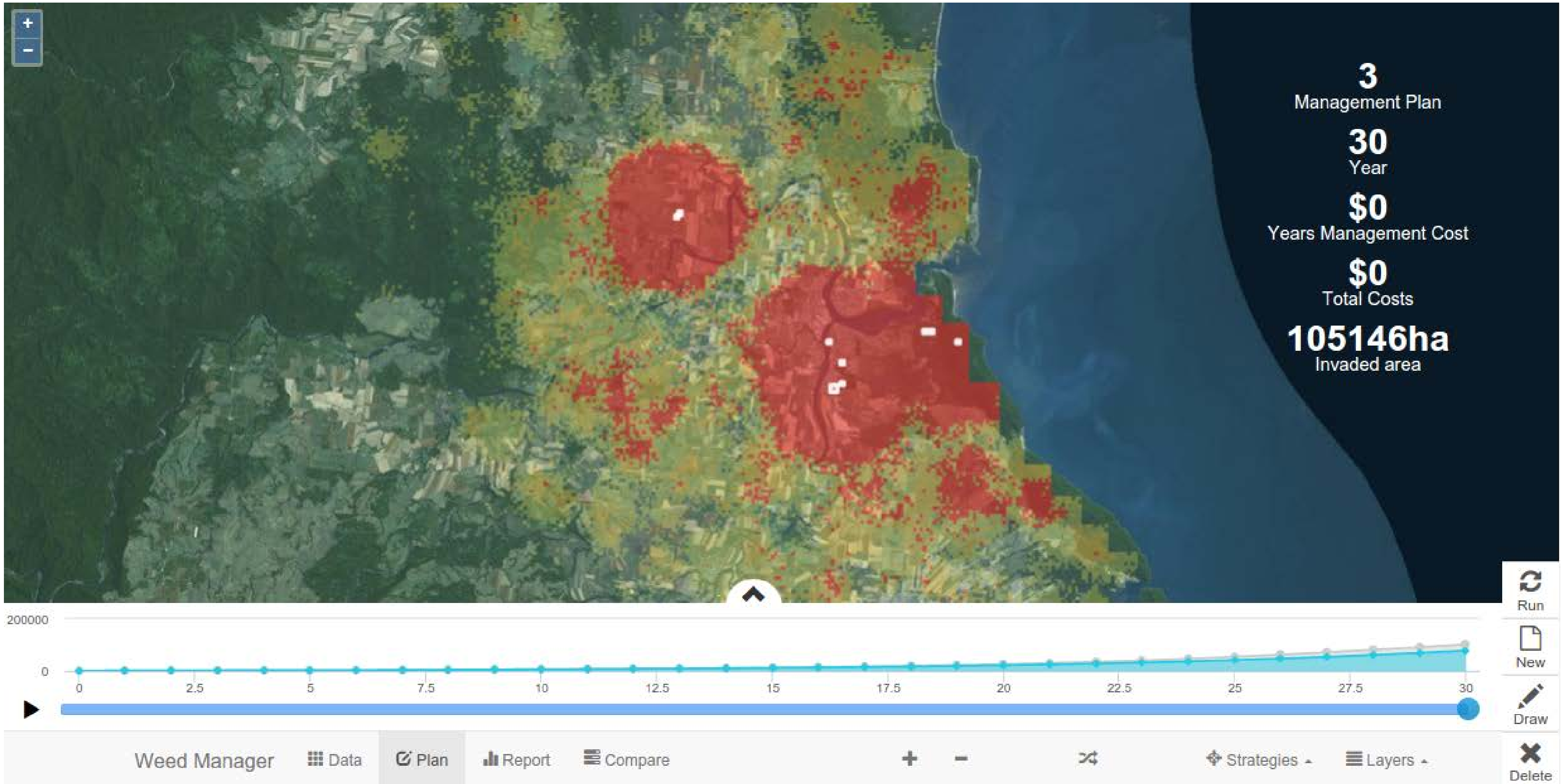

Figure 5.8: User interface screenshot showing the planning view. Red, orange and yellow overlay denotes the likely areas infested by the pest species over 30 years with no management. Red has the highest probability of established pests at this point in time, orange has a moderate probability and yellow a low probability.

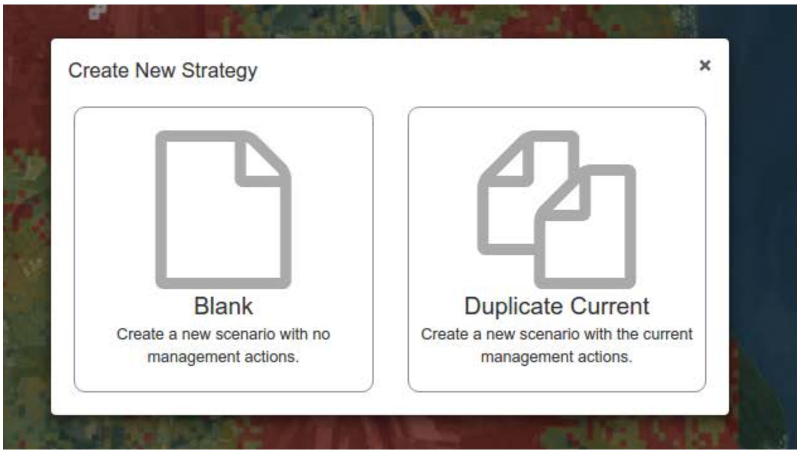

Figure 5.9: The create new plan dialog.

5.3.1.5 Report View

The reporting view shows a summary of the modelled actions and costs associated with achieving the management objectives (see Figure 5.10). This interface does not allow users to interact with any of the components on the page and is simply a visualisation. The numbers at the top of the page represent the total area requiring management over the 30 year period for that type of management action. The top segment of the graph shows the forecasted area of land that needs to be managed in a given year to achieve the management objectives successfully. The bottom segment of the graph shows the costs associated with those management actions.

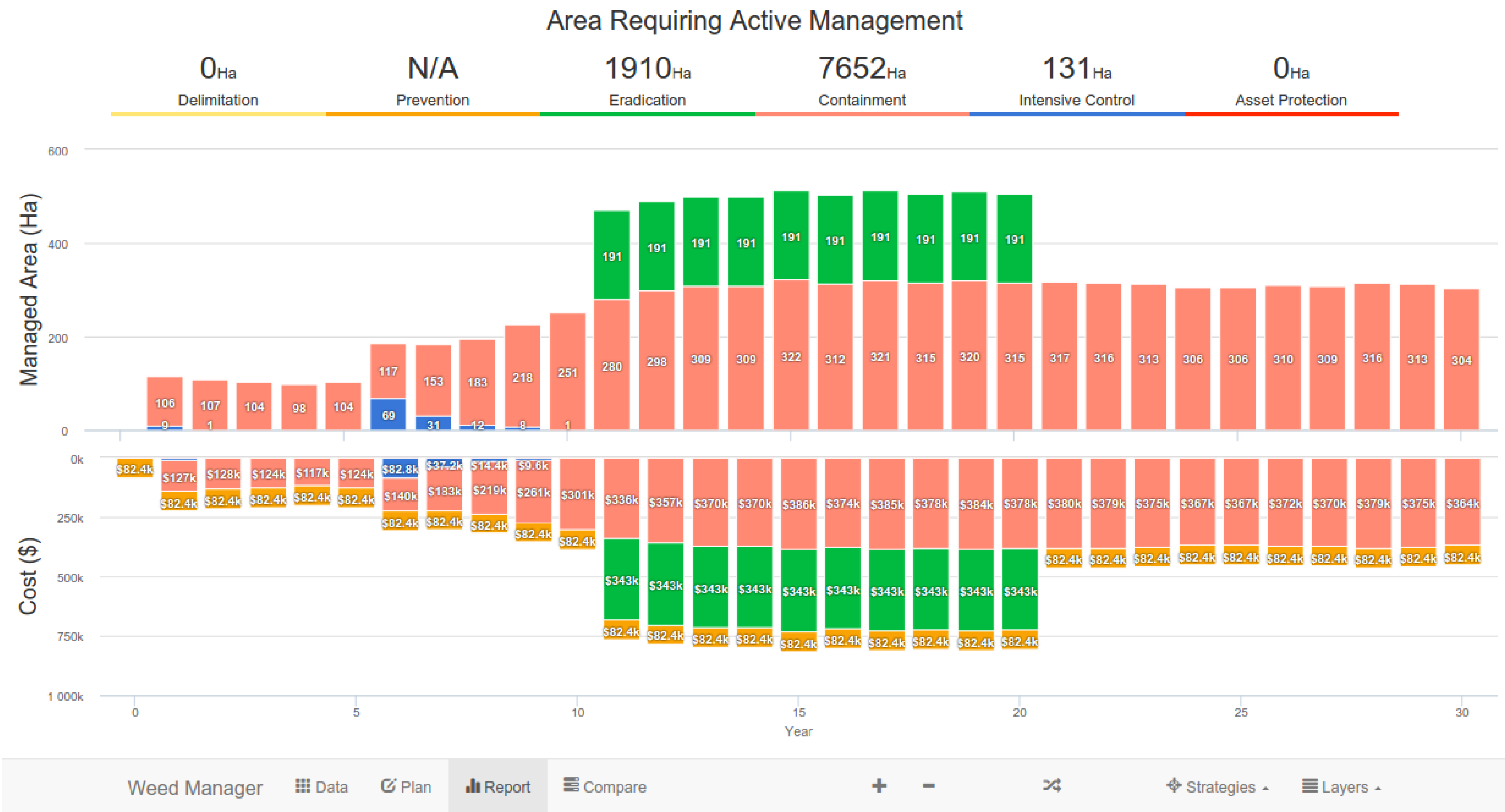

Figure 5.10: User interface screenshot, showing the reporting view. The top graph shows the area requiring active management to achieve the colour coded objectives. The bottom graph shows the costs associated with each objective.

5.3.1.6 The Timeline

One of the goals of this project is to facilitate discussion around different strategies and targets. To achieve this, a timeline that enables the comparison of different actions and gives a visual representation of the proportion of landscape covered by the pest, to help enable quicker comparisons between scenarios. Each year of each scenario shows the amount of land covered by that species at that time. Scenarios become visible on the interface as they are saved and run through the model.

Figure 5.11 shows the interface enabling different timelines to be compared. Each card represents a management strategy that has been designed in the tool. The associated cost and required work over 30 years to achieve that management objective are shown. The graph at the bottom of the card shows the distribution of the species. The grey line shows the no action scenario and the blue line shows the distribution of the species with those management actions taking place. When eradication is conducted immediately (as seen in the right most card) the species distribution stays at zero.

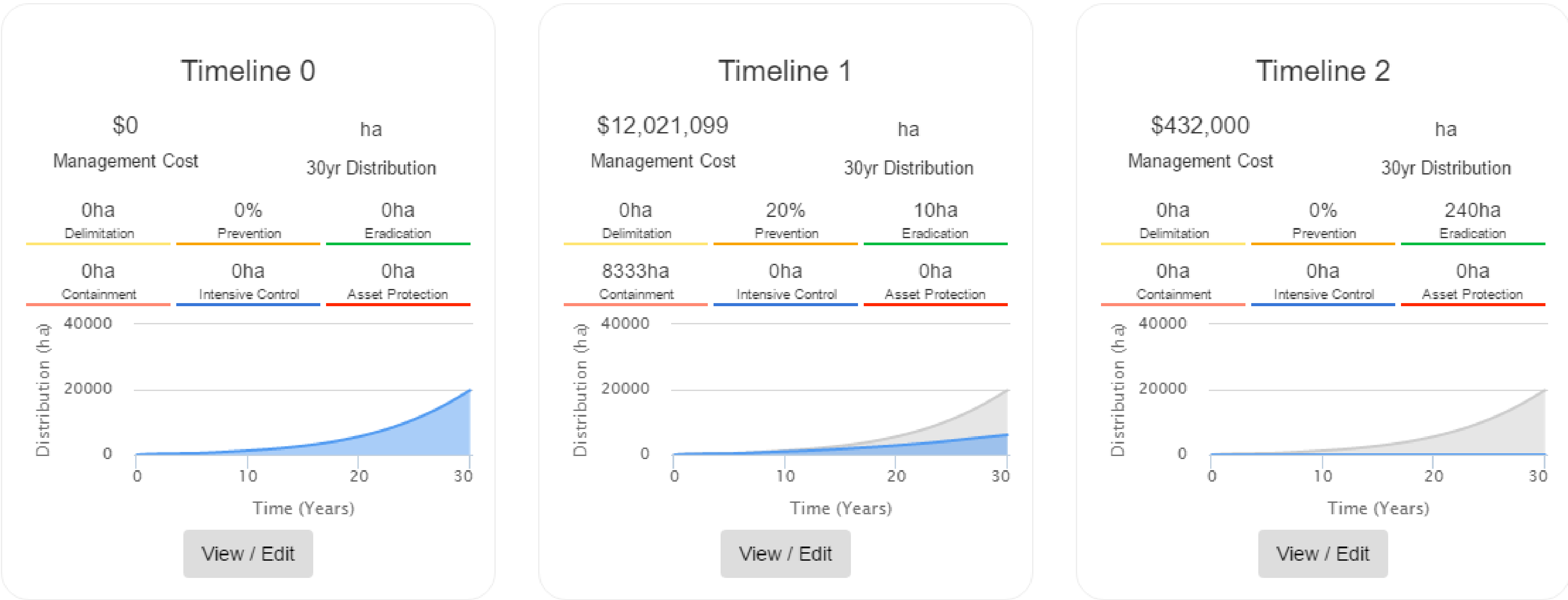

Figure 5.11: Timeline interface, showing three different management strategies. Note the price differences and distribution graphs. Left: No action scenario. Middle: Limited eradication and predominantly containment scenario. Right: Conducting eradication across all populations from the first year.

5.3.2 The Web Service

The web service is designed to model, store, manage, process and serve data to the front end (shown in Figure 5.12). Data from user interaction, the dispersal model, initial distribution and habitat suitability data is all managed and available to be queried by the front end. Before being run through the dispersal model, the input data is pre-processed and converted into suitable formats for processing. The model runs a dispersal simulation using the processed data and produces a raster file showing the spread of a species at each point in time. Raster files are rendered using a Map Server as they are requested by the front end. Additional statistics model run data are pushed to the front end as they become available via a WebSocket.

A large amount of data is managed by the web service to allow it to run simulations and provide data for visualisation on the front end. Vector data is stored in a PostGIS database while raster data and the statistics for each dispersal simulation are stored in the file system. Habitat suitability, dispersal simulations, rendered simulations and layers are stored using a directory structure on the file system. Management objectives and initial distributions of layers are stored and are queryable by other backend services in the database. Statistics generated from dispersal model runs are stored as JSON in an object store and served directly to the user interface.

Simulating the dispersal of a species across the landscape with the management actions defined in the user interface is done using a modified version of MigClim. These changes allowed the model to use the management objectives to influence how the species spread over the environment with human intervention. The modifications to the MigClim model that allows it to incorporate management objectives into dispersal simulations are described in more detail in Section 6.4.1 (on page 184).

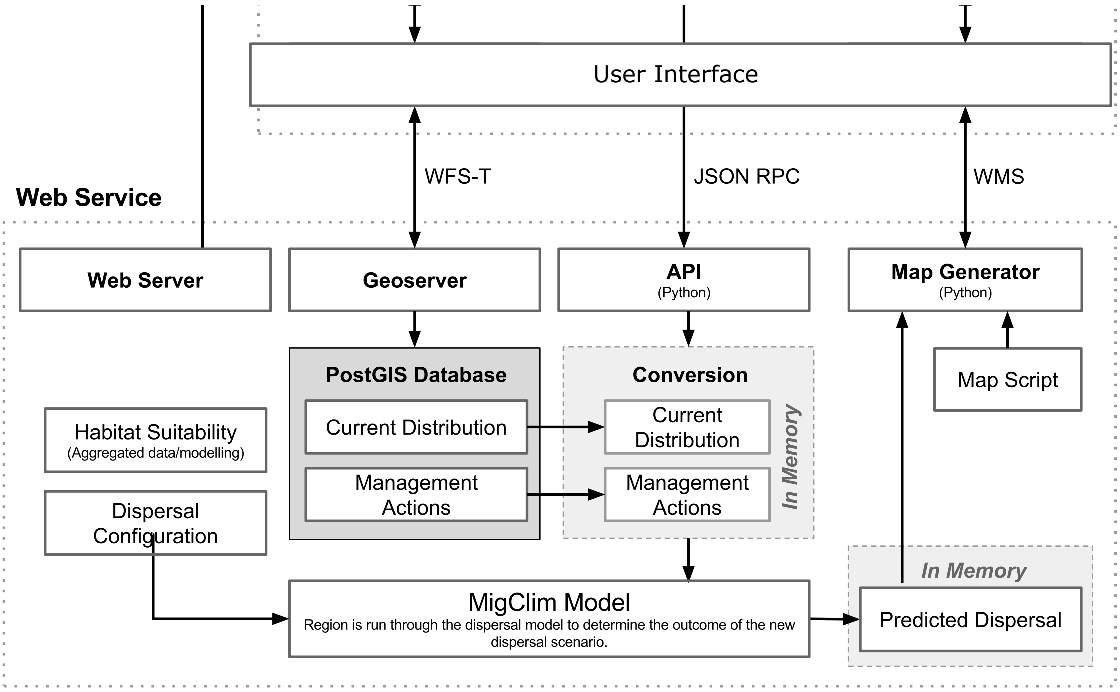

Figure 5.12: Architecture diagram showing how the web service is built.

The decision support software was developed using existing tools, software and libraries as much as possible to minimise the amount of work required to produce a prototype. A list of some of the existing tools used is provided below:

MigClim is a widely used dispersal model. MigClim was used to model the dispersal of pest species over time.

MapServer[3] is a web map server that was used to render the output of the dispersal model

GeoServer[4] is a web map server, similar to MapServer, that was used to serve management objectives and presence-absence data as WFS-T (Transactional Web Feature Server) layers. This allowed participants to edit the population data of the pest species and define and edit management objectives.

5.3.2.1 Data Storage

PostGIS is used to store vector data representing the current distribution of each species and the management zone assigned to each area. The data is represented in two tables,

[3]http://mapserver.org/ (accessed 10/02/16)
[4]http://geoserver.org/ (accessed 10/02/16)

one for the distribution and one for the management zones.

The management zone table contains the zones for each species across all timelines and time steps. The management zone table has the following metadata associated with each record:

- Timeline
- Time
- Species
- Zone Type

The distribution table tracks the users that entered the data and when it was entered. Identifying the person entering the data is necessary to allow the pest managers to follow up with individuals on previously unknown occurrences. The current distribution table has the following metadata associated with each record:

- User
- Time
- Species

Dispersal model creates an individual GeoTIFF file for each of the time steps it models. In the case of this project, 30 files were created, one for each of the 30 years that was modelled. The raster files are first written to an in-memory file system to improve the write performance of the model. This reduces the delay for complete dispersal model steps to be visible in the user interface. When the model run is complete the raster files are compressed, reprojected and archived on the non-volatile storage.

5.3.2.2 Pre-Processing

Before the model can be run, the data needs to be processed and converted to the correct format. The model requires the habitat suitability, the current distribution of the species and the management objectives layer to be loaded.

The initial concept for enabling the model to simulate management actions was to define the actions as effects on the habitat suitability model. For example, active management in an area would not change the underlying suitability of the habitat, but it would make the habitat unsuitable via human intervention and continuous control. The management types would then simply be defined in terms of their specified impact on the habitat suitability. However during the further development of this concept, it becomes apparent to the researcher that a suitability layer could not fully capture the dynamics of management actions.

The management actions intended to be defined on the map have the following properties.

- Actions are transitional: An action is defined starting at a particular year but may transition into a different method of control in the future.
- Cost of action is dynamic: The cost of implementing a management action varies between the different types of control that is undertaken. For instance, all mechanism costs are defined by the number of plants being removed from an area. However, different actions have different costs associated with them. For example, an intensive control operation would target only a certain percentage of mature species, but could also be defined as asset protection and would warrant the removal of all species both mature and immature.

This presents a challenge for incorporating active management into the habitat suitability layer. The AAIgrid file only supports a single layer, thus for any year that an action changed a new habitat suitability layer would need to be generated and loaded. As the generation of the AAIgrid files are a significant part of the time in running the model, it is not an ideal mechanism to export the management actions to the model. Table 5.2 presents a comparison of three methods for solving this problem. The single management action layer was the final selection and was implemented during the development of Iteration Two.

	Single Suitability Layer	Multiple Suitability Layers	Single Management Actions Layer
Generation Time	Slow	Very Slow	Fast (no complex transformations or intersects)
Action Transitions	Unable to support any transitions	Unlimited support for transitions of actions	Supports up to 3 transitions
Costs	Unable to vary based on objective	Unable to vary based on objective	Calculated per objective
Limitations	Unable to identify or transition objectives	May require a lot of suitability layers and would slow the model down considerably. May run into memory issues	Requires an additional layer to be generated and loaded.

Table 5.2: Comparison of different methods for defining management actions to the model.

5.3.2.3 Mapping

The pest management decision support tool developed in this thesis is predominantly built around maps and geospatial visualisation. This project has several different types of spatial data that need to viewed, animated and edited. The maps must be served in a format suitable for use in OpenLayers. The types of datasets are listed below:

Habitat Suitability (raster): the habitat suitability layer needs to be viewed in the user interface. This is stored in a GeoTIFF (iteration 5) or AAIGrid (iteration 1-4).

Pest Distribution (vector): the distribution data is a vector dataset that needs to be viewed, modified and saved in the user interface. These are stored in a PostGIS database.

Management Objectives (vector): the management objectives are stored as vector data and represent the objectives drawn onto the map. These are stored in a PostGIS database.

Dispersal Simulation (raster, time component): the dispersal simulation is a time-series raster layer with a separate file for each year modelled. The simulation steps are stored in GeoTIFF files. These are dynamic and change often.

Completed dispersal simulations from the model are saved as a presence-absence raster file for each time step. Displaying the dispersal simulations in the user interface requires the raster files to be rendered with styling information in a suitable format. Using the MapServer WMS, standards compliant raster files are rendered into viewable images and served in a standardised format that allows them to be tiled and geo-located. Each dispersal simulation steps was rendered as it was required by the user interface.

MapServer was also used to render the habitat suitability layer. The management objectives and dispersal simulation were served from GeoServer using the Transactional Web Feature Service (WFS-T) standard. GeoServer was connected to the PostGIS database and stored the additional metadata with the objectives and polygons.

5.4 Iteration One

Note

This section resumes the chronological order of this thesis. At this point in the research project a series of limitations in pest management planning were identified in the literature; observational sessions and interviews had been conducted; and a conceptual design had been implemented. This section will be the first of four to describe the first iteration of the pest management decision support tool.

The first iteration focussed on building a new type of decision support tool that took modelling tools that were conventionally difficult to use and made them serviceable by people who have no experience modelling species distributions. During the development of this prototype, the MigClim model was modified to improve its run-time. The search algorithm used for finding source dispersal cells in the model was identified as a major bottleneck. A new algorithm was implemented, and analysis was conducted to ensure the statistical validity of the model output.

Figure 5.13 depicts the interface of this first iteration of the prototype pest management decision support tool. Some of the major differences to the version described in the previous section are listed below.

- The MigClim dispersal model uses the habitat suitability layer to incorporate management objectives instead of using a separate layer. This makes the model incapable of calculating the cost of management actions.
- The MigClim dispersal model runs fairly slowly and is unable to combine multiple model runs efficiently.
- The user interface is fairly slow and unusable at times.

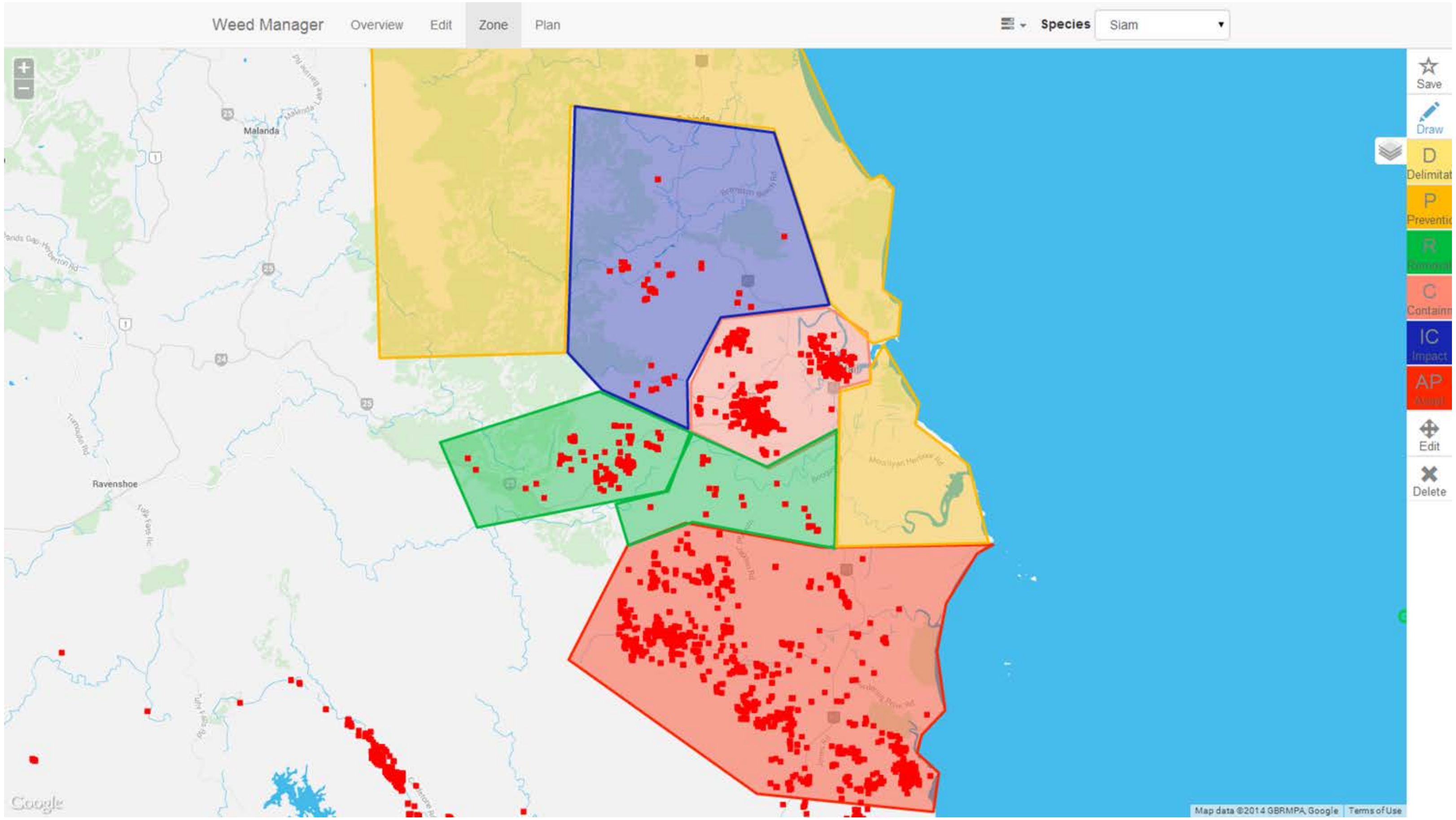

Figure 5.13: The first iteration of the prototype pest management planning tool.

5.4.1 The Web Service

5.4.1.1 Management Actions

The first iteration of the prototype used a different method for incorporating management objectives into the dispersal model (illustrated in Figure 5.14). Management objectives are queried and exported from the database using the GDAL Rasterize command. The objectives layer is combined with the habitat suitability using the GDAL Merge command to reduce the suitability of the selected areas to zero. The combined file is written to disk before the model is run.

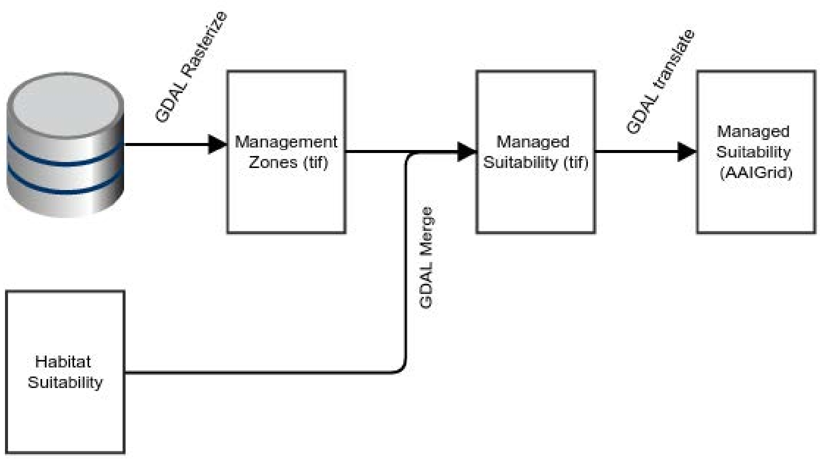

Figure 5.14: Managed Suitability Generation Process

5.4.1.2 Post Processing Model Output

The output from the model was written to a RAM disk to improve the write performance of the model. The output files were in an uncompressed AAIGrid format. Considering the software was designed for the model to be run often, it was not feasible to keep all of the runs in memory. Similarly, the runs need to be rendered into a format suitable for MigClim.

Each dispersal step from the model was rendered to a PNG (Portable Network Graphic) ready to be served to the user. This worked with the front end animation strategy by having all of the images pre-rendered and ready to be served. The second advantage of this was that the output files from a model run no longer need to be stored.

As each file was rendered and saved to the file system, it was deleted from the RAM disk as the original data was no longer needed. The final rendered files were typically under 50KB each, so storing multiple pre-rendered model runs is trivial. At that point, the files only needed to be served to the user interface using a generic web server.

5.4.2 Algorithm refinements

MigClim was originally designed to be run by researchers in the lab from the R programming language or from ArcGIS. While it is an effective tool for modelling the dispersal of species it was not designed to run in a collaborative environment where a fast run-time was critical to its continued use. The MigClim implementation was improved during this study by manipulating the search algorithm that looked for source populations when modelling a dispersal step.

During the dispersal simulation, the MigClim implementation iterated through all of the cells in the distribution matrix searching for unoccupied cells. For each unoccupied cell that is found, that is capable of being colonised, a search is conducted in the surrounding cells for an occupied cell. The dispersal distance specifies the number of cells checked in each direction. In this case where n is the dispersal distance, and assuming no cells are capable of colonising the current cell, n^2 cells are checked. When the current distribution of the species is low, the algorithm may spend a large portion of time out of range of a viable source cell. Furthermore, as we move along one cell at a time the current search algorithm re-checks $n^2 - n$ cells checked during the search for a viable source in the previous cell.

To reduce the re-checking of unviable cells, a new search algorithm was implemented that kept track of unsuccessful searches where no source cells were found. When a search did not return any occupied cells, a flag is remains checked to identify that nothing was currently in range. During the search in the next grid cell along the row, the checked flag identifies that $n^2 - n$ of the new search range does not contain a source pixel. The previously searched cells can be ignored and the remaining n cells can be searched for a viable source.

A major advantage of this algorithm is the search space is substantially reduced in distribution layers that are sparsely populated. This search algorithm works well for datasets that may have large amounts of unpopulated space. As the number of populated cells increases the performance benefits of this search algorithm diminish. However, as the populated cells do not need to search for new source pixels, this method would not have any significant impact on the run-time of highly populated distributions.

5.4.2.1 Testing Methodology

To determine the performance difference between the original algorithm and the modified algorithm, each model was timed with separate runs of 100 times in two independent tests against one dataset. The time for each dispersal step was recorded and saved into a CSV file. The run times were then compiled and analysed and compared using their mean run-times. Both models were compiled as they were in the standard MigClim package using the GCC -O3 optimise option. The SDMTools Istat function was used to compare the niche similarity of the two models. A more detailed description of this methodology is provided in the Methodology (Section 3.3.5 on page 70).

MigClim was configured to model the dispersal of Miconia across the Wet Tropics Bioregion over a 30 year period. In all of the simulations, the dispersal model was run using an identical parameter file shown in the Appendix (Listing 9.1 on page 269). The Miconia data set was made up of 5045 x 3084 cells covering the Wet Tropics Bio-region. The subject weed, Miconia, is commonly dispersed by the wind, water, frugivorous rodents and birds as well as human activity (Csurhes, 2008). The full configuration file is available in the Appendix (see Section 9.7.3 on page 269).

5.4.2.2 Testing Hardware

The performance tests were conducted on a Lenovo E440, a $1000 consumer laptop with the following specifications.

Component	Specification
Computer	Lenovo E440 Laptop
CPU	Intel Core i7-4710MQ, 2.5Ghz Quad Core
RAM	16GB DDR3L
Storage	SSD,HDD,tmpfs
OS	Ubuntu 14.04
Software	GCC 4.8.4, R 3.0.2

Table 5.3: Hardware and Software used for running tests.

5.4.2.3 Results

The SDMTools Istat function calculated a value of I : 0.992066.

An I value of 0.992 is very close to identical, however, it still has some variance between the two simulation aggregates. A coloured comparison was created in QGIS to evaluate where the differences were between the two layers. The difference layer was calculated by subtracting each individual pixel in the standard output from its respective pixel in the optimised output. Figure 5.15 shows the aggregate of the optimised dispersal simulation with and without the coloured difference layer displayed over the top. These are discussed in the following section.

The mean total time across 100 runs taken for the model to complete is shown in table 5.4.

Model	Mean Run Time
Standard	22.43s
Optimised	5.94s

Table 5.4: Mean Total Run Time of the standard vs optimised model

5.4.2.4 Discussion

The core populations that were continually infested show no differences at all and have been colonised 100% of the time. Surrounding the core populations are the areas colonised by the LDD (Long Distance Dispersal). Due to the low probability of a LDD event, there was some variance between the two models in the fringe areas. However, these differences were to be expected from probability models, even over 100 runs. Based

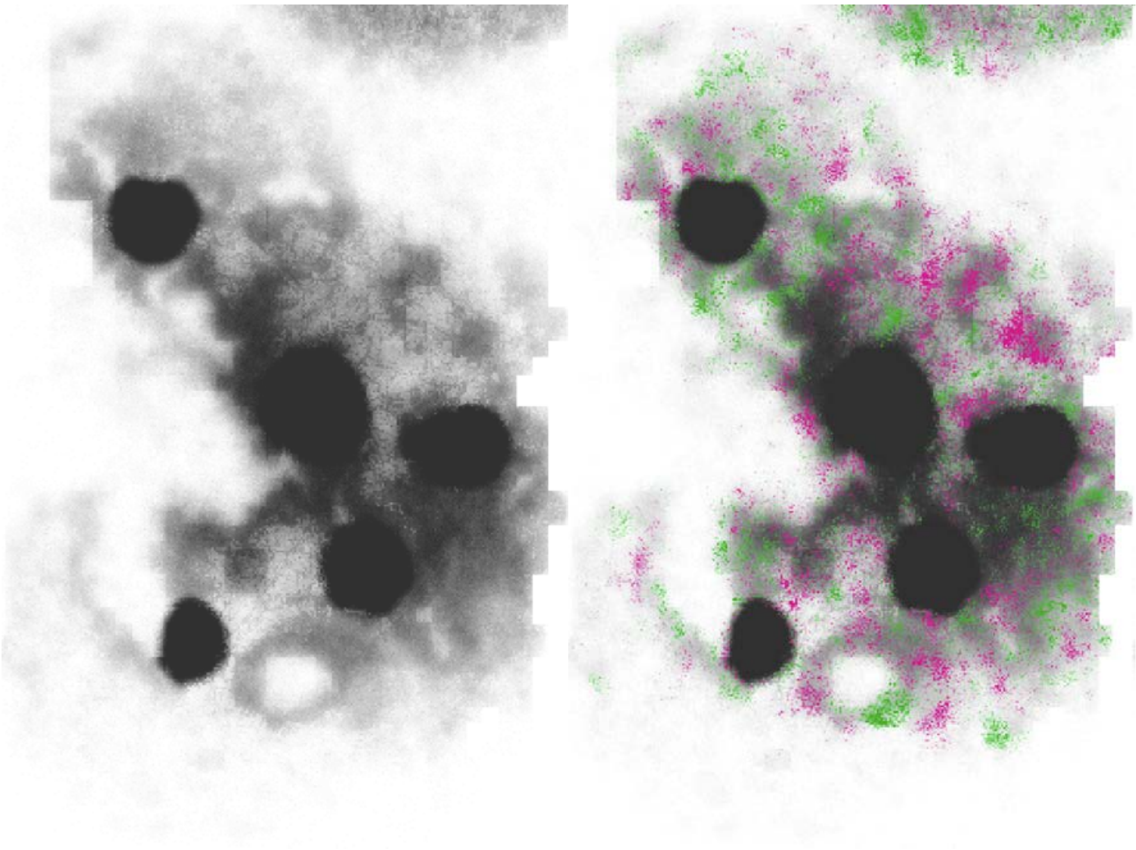

Figure 5.15: Left: Optimised dispersal model aggregate, after 30 years, showing the number of simulations colonising a planning unit. Right: Green and pink denote planning units varying by more than 5% overlayed onto the 100 run aggregate of the optimised dispersal model. Note: The output from the standard MigClim algorithm is not shown as it is visually identical to the optimised version.

on the I Value and observation data, the optimisations did not appear to influence the statistical nature of the model.

There was an improvement in the mean run-time of the standard model compared to the optimised model. A drop in the run-time from 22.43 seconds from the standard model to 5.94 seconds for the optimised model represented an improvement of 3.7x for the tested dataset. Although the improvement in run-time appears rather minor, it is important to retain the attention of the participants and keep the session moving forward as fast as possible. FNQ incorporates a lot of regional towns and it's normal for stakeholders to travel hundred's of kilometers to attend a pest management session. To make these sessions as effective as possible they must plan for multiple species. Furthermore each model run gives them an opportunity to further refine their plans, every second counts.

The improvements of this itteration are further compounded in the second iteration.

5.5 Iteration Two

This iteration focussed on reducing the wait time for the model to run and improving the responsiveness of the user interface from prototype one. The model was adapted to perform several dispersal simulations concurrently and aggregate the output data in memory. Combining multiple runs of the model in memory removed the need for each models' output to be written to disk and aggregated upon the completion of all repetitions. Aggregated rasters could then be written out as soon as the dispersal model had completed that step. Improvements made in this iteration made running and displaying model repetitions feasible for use in planning scenarios and brought the model wait time to below the one minute target (defined in Section 3.3.5 on page 70).

Performance issues with the user interface were identified by the researcher during lab tests of the first prototype. Using the software for more than a few minutes and visualising model runs would result in the user interface becoming unresponsive and eventually crashing. This next iteration focussed on eliminating the crashes caused by Open Layers 2 by moving to the newest version, Open Layers 3. Further improvements were made by developing a new technique for animating raster layers on web-based maps (see Section 5.5.2.2 on page 160). Changing versions required a large portion of the map visualisation code to be re-written to suit the new API, but improved the responsiveness and usability of the user interface.

5.5.1 Multi-threading and Asynchronous Output

MigClim was originally designed to run the same model consecutively multiple times. Model runs were completed independent of each other and produced a separate output file for each step of a run. The model only made use of a single processor core for the entire model run. Although separate models could be run concurrently, the output dispersal steps needed to be aggregated at the conclusion of the model run.

If it was run a large number of times, this generated significant amounts of data on the disk. Using the Miconia dataset of 3248 x 5154 cells, an output grid is produced of typically 40MB for each of the 30 time steps. While the files were typically small, the expected disk usage of the uncompressed AAIGrid files was about 1.2GB per run. The storage space required was fairly insignificant in terms of the ample disk space on modern computers, but it was a concern for processing all the model runs into a single aggregate. Summating all the files required every file to be opened and processed.

A parallel approach could aggregate the model runs in memory and reduce the initial start-up time for independent model runs. To achieve this, the MigClim algorithm was modified to use a shared memory approach to aggregate dispersal steps as they were computed. Each step added its dispersal output to an array in shared memory to avoid the need to write to disk. Instead of running the model process multiple times, the model was modified to fork a process for each run requested by the user. Each model run was forked from MigClim and run in separate processes using a pooled approach to limit the number of jobs running at once.

A writing thread was run in addition to the model threads in order to write out all of the aggregate files as they became ready. The write thread worked concurrently to the model simulation. This concurrency enables writing to disk to take place before all of the dispersal steps had completed. The completion of each time step is stored in shared memory as an array. As each process completed a run it incremented the time step counter for that time. When the counter reached the number of model runs for a time step, the writing process wrote the aggregate file to disk.

When running the modified MigClim, additional parameters were added to allow the user to specify the number of runs required and how many processes the model could use to perform the runs. Parameters can specified on the command line using the following format.

mig <input path> <param file> <output path> <number of runs> <number of processes>

5.5.1.1 Testing Methodology

The parallelisation and use of shared memory is a major change to the architecture of the MigClim model. Testing was undertaken to ensure the changes made during this phase did not impact upon the validity of the model. A systematic approach was performed, identical to that used in section 5.4.2.1 (on page 151). Both the standard and optimised MigClim models were run in the production environment 100 times to establish their performance characteristics.

Any further optimisations to the MigClim algorithm would have to produce dispersal simulations statistically similar to the standard version. Although these changes apply solely to the implementation and not the underlying mathematical model, it would be important to verify that the validity of the model was not changed. To achieve this, the optimised model and standard MigClim were run with identical datasets and configurations and their outputs compared. An optimal result would show that both models, over a large number of runs, produced outputs that could be shown to be statistically the same with a high level of confidence. If the aggregate outputs differed, this would indicate that the modifications had affected the underlying probability of the model.

5.5.1.2 Results

The aggregate datasets were compared using the SDM Tools IStat function. Comparisons were performed across all combinations of the standard MigClim model, optimised model and new threaded version of the model. The results from running IStat are shown in Table 5.5.

Version	*I* value
Standard, Threaded	0.9921221
Optimised, Threaded	0.9920505
Standard, Optimised	0.9920666

Table 5.5: I values, showing the similarity between combinations of the model aggregates.

The *I* value of 0.992 indicated that the two models were not exact copies. This value by itself represented a very high equivalence between the models, however it does indicate that there was some variance. I expected to see this variance in areas only reached by long distance dispersal events with low probabilities of populations being established. This I value alone was enough to verify that the optimisations to the model had not had an influence on the underlying statistical model. However, to build an understanding of where the model aggregates varied, a raster was generated containing the difference between each corresponding pixel.

Figure 5.16 is a visual comparison between the aggregated datasets. Each pixel was compared between the two models and were coloured to indicate a variance of more than 5%. In this visual representation it is evident that the areas varrying between the two models the most were the areas that were not colonised very often. Differing fringe areas appeared to only be small areas on the map.

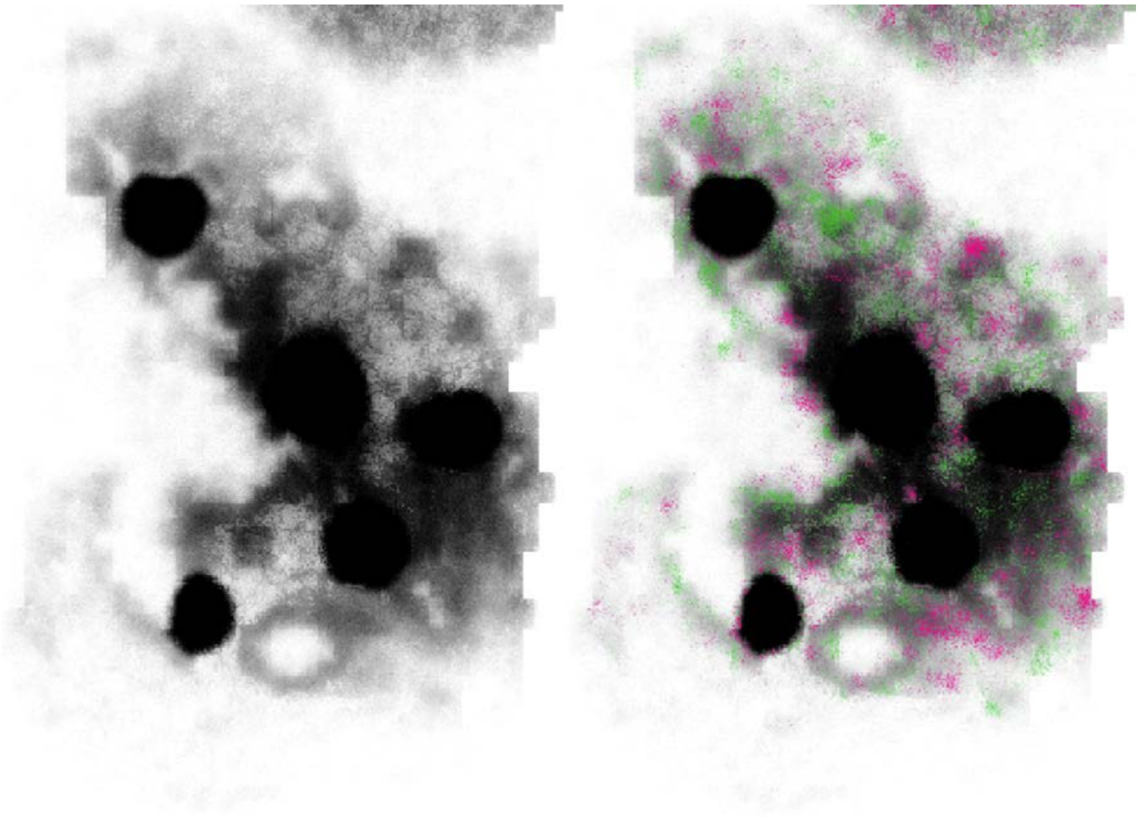

Figure 5.16: Left: Optimised dispersal model (100 run) aggregate, after 30 years, showing the number of simulations colonising a planning unit. Right: Green and pink denote planning units varying by more than 5% overlayed onto the aggregate of the optimised dispersal model. Note: The output from the standard MigClim algorithm is not shown as it is visually identical to the optimised version.

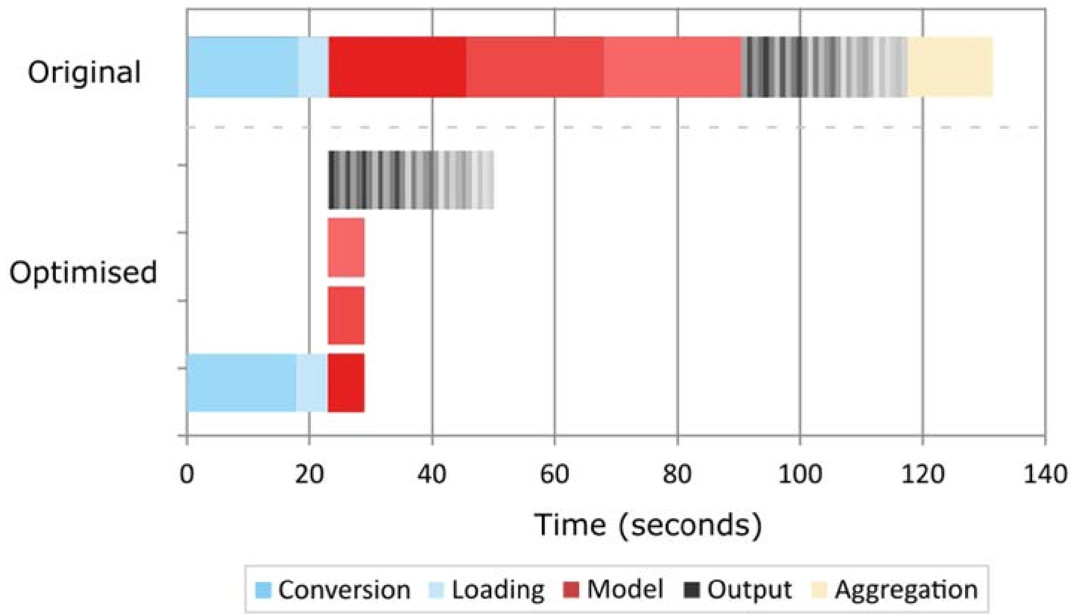

Figure 5.17: The improvement in run-time is visible from the user interface. Blue: data is exported from the database and imported into MigClim. Red: The model is running the 30 dispersal steps. Black/white: The model is exporting each dispersal step. Note: the optimised version starts exporting dispersal steps while the remainder of the model runs.

5.5.1.3 Testing Conclusion

The Multi-Threading of the model represented a major improvement over the original process for running models and aggregating their output into a single file. This process also simplified the generation of aggregate statistics for tracking the impacts of management actions. Figure 5.17 shows the changes to the run-time of the dispersal model made over Iteration One and Iteration Two. The graph shows the time taken to run the dispersal model from the user interface using the test dataset. The dispersal simulation started playing after an average of 22 seconds from the run model button being pressed. This was substantially faster than the original model which took on average 120 seconds before animation started.

5.5.2 User Interface

A graph (Figure 5.18) was added to the user interface to illustrate both the management plan outcomes and the no-action plan outcomes and illustrates the distribution over time.

It provided an easy to interpret graphic representation of how a management plan could reduce the impact of a species over the long term. Due to the limited vertical space on the screen, the scale of the graph has been aligned to the timeline slider on the bottom of the page to negate the need for X-axis values on both components.

The toggle arrow, shown in Figure 5.18 allows the graph panel to be expanded, whereby the graph adds X-axis labels and titles as well as enlarging the canvas the graph is drawn on to show more detail. This allows the graph to transition from small to a large detailed visual comparison of the two management scenarios.

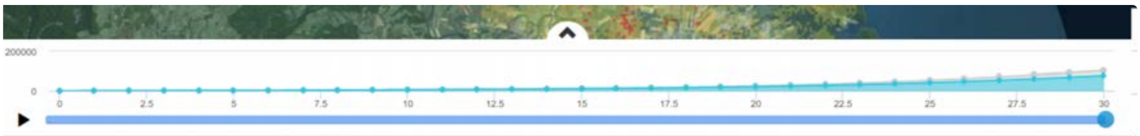

Figure 5.18: Graph showing the no-action management scenario to the currently defined management scenario.

5.5.2.1 Changing to Open Layers 3

In the testing of the first prototype, one of the biggest concerns was the unreliable performance of the user interface. During the first few minutes of use, it would run relatively smoothly. However, over time the animations would slow and panning around the map would become laboured and jerky and after only a few minutes of operation would require the page to be refreshed. All of the methods used for the initial implementation were quite common across other web services and were considered to be best practice. However, it was apparent that the animation between 30 map layers seemed detrimental to the performance of the application. While each of the individual components were tested prior to fully implementing the prototype, when running in combination, it was too much for the web browser to handle. The difference in the implementation scale also hindered the operation.

By switching the animation layers to single tile layers with no overlap, there was a small difference to the performance of the applications in that it would remain usable after several minutes of operation, but the slowed performance still interfered with panning the map and drawing management actions. Although the focus of this research project was on developing a proof of concept, improvement to the front end was necessary to ensure the software was easily usable by participants in the following stages of the research.

To find a solution to the performance problems, I explored alternate web mapping libraries, most notably OpenLayers 3 and Leaflet. Leaflet was a popular choice amongst the development community due to its modern design and lightweight library. While Leaflet supported WMS, drawing tools and time-based playback, it did not offer the WFS-T support necessary for editing distribution maps and management action layers. OpenLayers 3 offered more features out-of-the-box, including WMS, drawing tools and WFS-T. Furthermore, it offered an easier transition away from OpenLayers 2.

The change to OpenLayers 3 took a considerable amount of time. However, it alleviated all of the animation slowdowns and browser performance issues that occurred with OpenLayers 2. It also provided the potential for developing a more efficient strategy for animating the raster map layers discussed in Section 5.5.2.2 (on page 160). The change between libraries made the front end a lot faster and lighter. Drawing, map panning and playback were now all very smooth. Panning during playback, which had been impossible in the previous version, now worked very smoothly. Therefore, the transition to the next major version of OpenLayers made a substantial improvement to the usability of the front end of this pest planning prototype.

5.5.2.2 Smooth Animation of Raster Map Layers

Dispersal maps generated by the model were stored as rasters in the ASCII ESRI grid format. The ASCII version of Esri grid format, which was uncompressed and stores data encoded as ASCII, popularised for its ease of interoperation between multiple programs. The format was not designed for use on the web and is typically rendered as tiled images.

The common strategy for playing back time-series raster data in OpenLayers was to create a layer for each time-step and toggle through layers sequentially. While this method worked effectively to animate through small numbers of steps, it required a high memory overhead for each of the layer objects. In testing the playback of 30 years at a resolution of 1200 x 719 pixels, the following observations were made:

- Playback was jerky
- Tiles would disappear from the cache
- The web browser would start slowing down and eventually crash

A more efficient strategy for playing back raster tiles was needed to improve the user experience of playing back raster tiles. Existing methods for animation in web mapping often relied on small vector datasets that could be streamed and rendered through canvas, SVG or WebGL. One example of this was the Torque Visualisation library developed by CartoDB to enable streaming and animation of vector data. Another example was Cesium, a WebGL based, 3D mapping library. It could take advantage of vector data to animate objects spatially over a timeline. Cesium also enabled video to be aligned and used like a standard map layer. Playback was smooth and made use of the HTML5 video standard to enable fast scrubbing through the timeline.

Video was ideal for creating animated map layers as it could be hardware accelerated and make more of the advantage of compression than individual image tiles could. However, video had major disadvantages when the size, extent or content had to change often. To create high quality visualisations, the video would have to be re-generated every time the map was zoomed or moved and every time the content was updated. The overhead required would be too great for even a single-use, locally connected mapping service.

OpenLayers 3 provided a HTML5 based canvas layer (ol.source.ImageCanvas) that allowed a custom function returning a canvas to be used as a layer source. The canvas layer was often used by other libraries as a method for inserting custom vector-based visualisations into a map layer. For example, D3.js could be used with the image canvas to integrate vector based D3 maps into open layers, allowing a D3 map to be positioned and moved as part of an OpenLayers map. Although the image canvas layer was typically used for vector data, it was a standard HTML5 canvas and could be used in other ways.

To improve both the cost and performance of the layer switching used in the previous prototype, the image canvas layer could be used to avoid accumulation of unnecessary layers and the need to switch between them. This method used a single layer in OpenLayers and updated the content drawn on the layer to reflect the time the map was set to. Map tiles could be loaded from the web server as a single image and drawn to the canvas as required.

The outcome of changing to OpenLayers 3 and using the new method for rendering map tiles, resulted in smooth animation of the dispersal over time, faster scrolling, and the user interface no longer slowed down during extended use.

5.6 Chapter Summary

This chapter developed the findings from the analysis of the existing pest management process (described in Chapter 4) into a prototype pest management planning tool. The findings from the previous chapter were first formed into functional requirements, and then adapted these into a user interface design and implementation. Two iterations of the prototype were described in this chapter that focussed on improving the performance of the MigClim dispersal model. The wait time between pushing the run button and animation beginning with the test dataset was reduced from 120 seconds to 20 seconds.

Chapter 6

Phase 3: Refinement and Evaluation

Chapter Overview

This chapter builds on the implementation from the previous chapter and starts involving first time participants and experts into the development process. Usability testing was conducted in an iterative manner with non-expert planners to refine the workflow and user interface of the pest management tool. A scenario was conducted to evaluate the tool with experienced planners. This chapter is divided into 5 sections, that were conducted in chronological order:

- Usability Analysis of Iteration Two (6.1) describes the findings from the first usability analysis session conducted.
- Developing Iteration Three (6.2) develops the findings from the first usability analysis into the next iteration of the prototype.
- Usability Analysis of Iteration Three (6.4) conducts a second usability analysis with the new iteration of the prototype.
- Developing Iteration Four (6.4) develops the findings from the second usability analysis into the next iteration of the prototype.
- Pest Management Tool Evaluation: A Case Study with a Quasi-Real Species (6.5) conducts an evaluation of the tool using a scenario and focus group consisting of experienced pest managers.

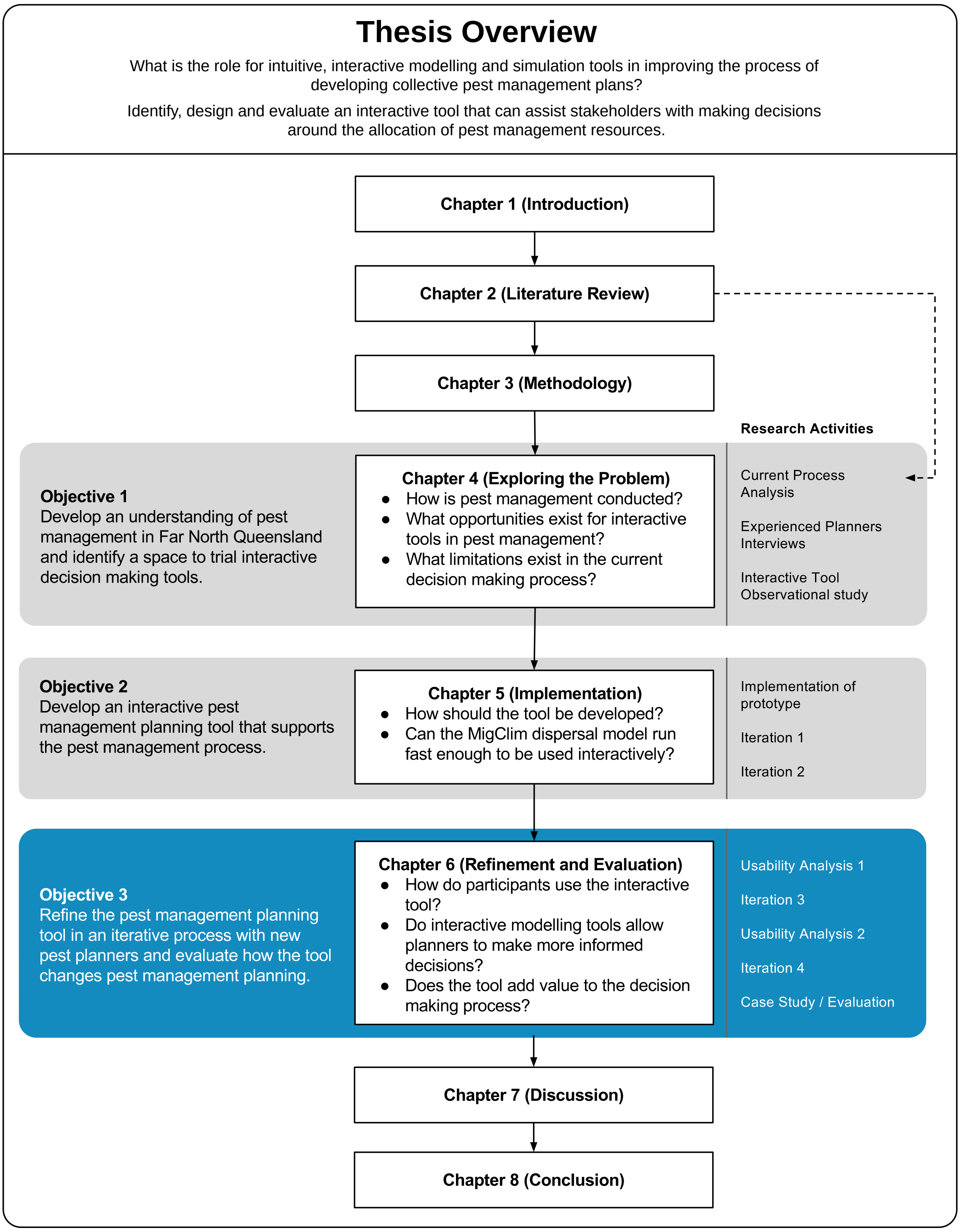

Figure 6.1: Diagram showing the order of research activities presented in this thesis. The blue highlight illustrates the current position in the thesis.

6.1 Usability Analysis of Iteration Two

The previous chapter developed a prototype pest management tool, concluding with the second iteration of the tool. A successful decision support tool must be usable by pest planners and stakeholders and must provide value to the planning process. This section continues from the second iteration, conducting a usability analysis session to understand how this pest management tool is used by actual people. The session was conducted in October 2015 with university staff members. Participants were given an introduction and asked to complete a number of tasks as described in the methodology (see Section 3.3.6 on page 72). An assessment is conducted to evaluate how successful the tool is in supporting pest management planning. The findings are reported below and will be developed into the next iteration.

6.1.1 Results

This usability analysis session uncovered several issues with the user interface and the tools designed workflow. Additional metrics were requested by the participants to assist with their decision-making process. During this usability testing session, there were several instances of the tool performing unexpectedly. While drawing management actions on the map, participants experienced intermittent problems while finishing drawings or the tool, not recording points. Participants also had problems determining which tool was active in the tool palette and would often attempt to draw management objectives but instead perform a different action. The unexpected behaviour was a combination of technical problems, hesitance of the participants and design issues with the tool.

6.1.1.1 Low Resolution Model

The prototype was built to animate dispersal simulations on the map, allowing users to visualise the spread of a pest species over time. To achieve this, an image of the entire planning area would be rendered. The image would become slightly blurry when zoomed in to a scale suitable for viewing at a town level. However, throughout the session participants preferred working at a much larger scale than expected. Working at this scale caused problems with alignment of the rendered images and with the management actions participants were defining.

An example of this was during the process a participant was attempting to remove a small population of the example pest species. The population was one hectare, a single planning unit in the distribution dataset. The participant was verbalising what they were doing and what was expected to happen when the run button was pressed.

> *Participant: "If I set this as eradication, it won't spread any more."*

The participant drew a square around the targeted species using the eradication tool (example in Figure 6.2). However, the square target was drawn very tightly around the population for removal. I had concerns that the drawn target did not select the entire hectare and that the target may not exactly line up correctly with the distribution data when it was processed. The scale at which the user was working was much larger than had been anticipated and the alignment of the rendered data could be out by several planning units. In previous informal testing sessions with different volunteers, it had been common to select areas for eradication that were much wider than the intended target.

As the output of the model loaded, the participant looked slightly concerned at the result showing that the eradication action had no impact on the outcome. I explained that the alignment of the management actions may not be the same as the data shown in the model as it uses a lower resolution image.

Reflecting on the session and the objectives of planning sessions it seems a sensible conclusion that cost minimisation has a large influence on the scale that the participants operate. Cost are largely driven by the amount of work undertaken in the field. Each objective drawn onto the map represents a management objective requiring work to be undertaken. Although eradication work in the model is only applied to infested areas, it is not immediately obvious that is the case.

6.1.1.2 More Information to Make Decisions

During the session, participants were observed having difficulty understanding the financial impact of each management objective. On several occasions, a new objective

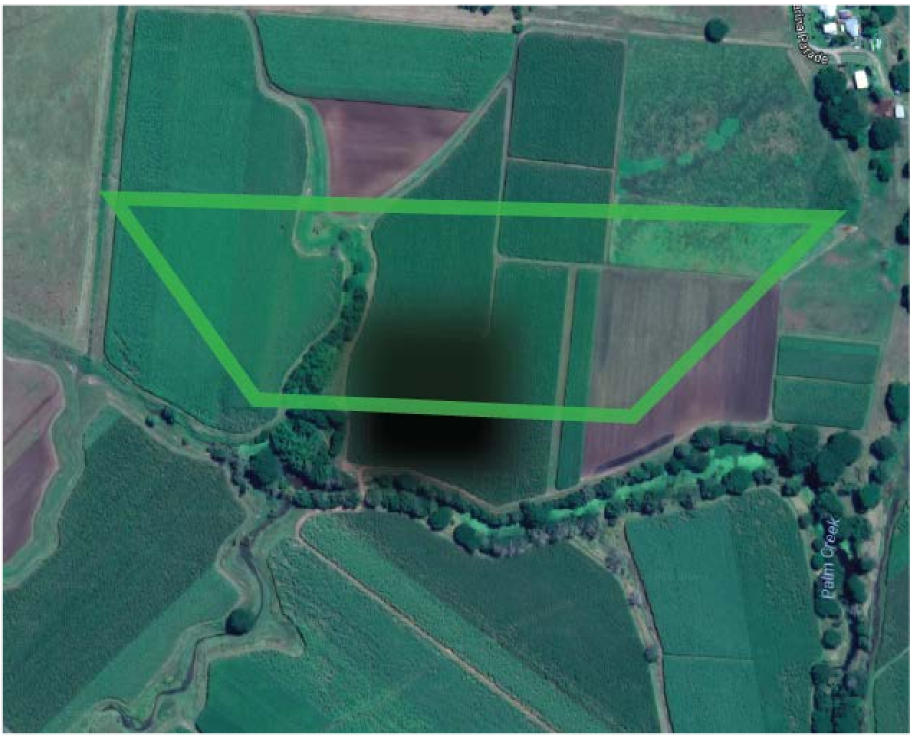

Figure 6.2: Example showing the eradication action (green polygon) the participant drew over the infected planning unit (black square).

was added to the map, and the price would increase sharply and participants would often be surprised by the final cost of running the simulation. The participants were not able to easily see the annual costs and management action required for their various objectives on the map. Although participants did not request more information about the objective costs and work requirements, they did ask why the containment and asset protection objectives became more expensive over time. Additional information needs to be provided, so users of the tool understand the characteristics of each objective.

6.1.1.3 Touch Screen Input Problems

Throughout the session, participants were observed having difficulties using the pens when performing certain tasks. Drawing management actions on the map appeared to become progressively more challenging as users interacted with the tool. The polygons participants were drawing were often being closed and saved before participants had finished defining all of the points. As the session continued, users began having difficulties selecting the objective in the drawing tool palette. Normally, objectives are selected by single tapping the button of the desired objective. I had originally made notes about this issue follow up after the session had completed and suspected a flat battery in the pen as the occurrences seemed to be happening more frequently.

I observed the next person having their first turn. They opened the drawing menu and verbalised the management action they wanted to use. As the participant clicked on a management objective, the toolbar suddenly turned orange. The pen had highlighted a section of the page as though the pen had been depressed and dragged. As the participant drew the management objective on the map, the shape was automatically closed on the second point. It was evident from this that the projector was registering single-clicks as double-clicks. Furthermore, as the session had progressed, it appeared that participants had lost trust in the tool and were not using the pen as confidently, causing more inadvertent double-clicks to be made.

I confirmed the pen was performing double clicks when used in a certain manner and proceeded to reassured the group that pen was malfunctioning and it was not their mistake. I demonstrated that confident and exaggerated motions would reduce the likelihood of management actions being pre-emptively closed. The group proceeded and adapted to the new technique fairly quickly, with only a few slip ups and accidental completions throughout the rest of the session.

The unintentional double clicking was a result of how participants were using the pen on the interactive screen. However, it was not a result of user error. The unexpected responses from the tool likely caused users to be more hesitant in their use of the tool and resulted in more errors being caused.

6.1.1.4 Feedback

In making the tool easy to learn it is important that buttons and responsive components clearly communicate their state and react in an intuitive manner. Participants in the session were observed becoming confused by some of the buttons response. When tools in the tool pallet are activated, they change from black to light blue. Although the active tools were clearly visible on a monitor, discerning the difference between an active and inactive tool was difficult on the projected display. Participants were observed selecting tools, making a perplexed face and re-selecting the tool. If the tool was activated initially, a subsequent press would de-activate it and cause greater confusion when they were unable to perform the expected action.

Similarly, the run model button would change to blue while the model was running and back to black upon completion. Like the other tools, the run button was clicked multiple times and would not give clear feedback to the participants. The model typically takes 30 seconds between the button being pressed and playback to begin on the map. This was originally designed to allow continued editing of the map while models ran in the background. However, in the session, the limited feedback caused multiple clicks of the run button and multiple modelling jobs to be run. The model would play back the outcome and then start the next modelling job in the queue. There would be a 30-second delay between the end of one job and the start of playback of the next. Participants were unaware that another model was running and would become confused when the interface started playing the model back again.

6.1.1.5 Other Notable Findings

Throughout the session many other cases of unexpected behaviour and limitations of the tool were observed, these have been summarised below.

Right Click Menu One person seemed to have issues with the right click menu popping up as they touched the pen on the table. This was caused by a button on the side of the touch pen being pushed while depressing the pen on the table surface. The button was disabled after that session to prevent future issues.

Menu Placement The placement of the navigation toolbar and the zoom buttons at the top of the screen required participants to stretch across the table to change views. The top (back) of the screen was blocked by the projector and prevented participants from standing around that side of the table. In future, moving the menu and tool palette to the bottom edge would allow easier accessibility by all three accessible sides of the interactive screen.

Table Size The table used during the usability testing session was quite large, about 1.5m wide and 4m long. This prevented people from interacting with the touch screen from the sides as observed during the observational study earlier in this thesis.

Run Model Button The run model button, located in the tool pallet, does not deactivate other active tools when it is pressed. All of the other tools except the run button would disable the current tool when selected. Participants would often run models and upon completion forget that the management action drawing tool was still active. As the model played back, participants would attempt to scroll around the map, but would instead draw new management actions. These management actions would then be deleted, or left and forgotten about.

Who Did It? One of the requested features from the participants of the session was the ability to attribute distribution data and management objectives to the person who contributed the data. Population records would be more closely aligned to existing data-collection practices at the local council level and would allow easier vetting of reputable data and ground truthing of new unconfirmed data from the public.

Timeline Incorrectly Aligned During the session, several participants noted that the first point on the timeline and graph was not the current year but was instead one year in the future. This was an oversight in the API. The current year should have been prepended to the results from the model.

6.1.2 Summary

A usability testing session was conducted to evaluate the second iteration of the pest management planning tool. The session consisted of an introduction to using the tool and users being asked to perform tasks. Video was recorded, and notes were taken throughout the process. The results presented in the previous section were summarised from the video analysis and reflection. Findings from this usability analysis will be used to refine the workflow and user interface in the next section.

I intervened once during the session to prevent a feedback loop between the users and tool, causing users to become hesitant which exacerbated the occurrence of the problem. The session was stopped a second time to delete unintended model runs from the queue. Several contradictions between the conceptual design of the tool and its real-world use were identified to be refined in the next iteration.

The identified problems are summarised in bullet points below:

- The low resolution of the rendered model outputs prevented precise management targets from being defined.
- Participants wanted to know how much they were spending on management objectives.
- Hesitance with the touch pen caused unintended double-clicks.
- Activated tools in the tool pallet were not easily visually identifiable.
- Participants could not recall which species occurrence records they had added to the map.
- The timeline comparison page caused confusion among users.
- The zero point on the timeline was one year in the future.

6.2 Developing Iteration Three

The previous section regarding testing the usability of Iteration Two highlighted several interaction problems and contradictions in the intended use of the tool. This section describes how these findings were incorporated into the development of Iteration Three in which user interface and conceptual changes to the software were made. These refinements included improving the accuracy of rendered dispersal models and the addition of summarised data from the model. This section is divided into two categories and several sub-categories:

- Map Rendering (6.2.1) describes the major changes to the backend to increase the resolution of the user interface
- User Interface (6.2.2) describes the changes to the user interface.
  - Preventing Accidental Double-clicks (6.2.2.1) describes how the interaction feedback loop was solved.
  - Who Added This? (6.2.2.2) describes the modal window for adding a participant's name to data.

– Improving The Recognition of Selected Tools (6.2.2.3) describes how the toolbar was modified to assist users in identifying the tools they had selected.

– Simplified Timeline (6.2.2.4) describes how the timeline user interface was replaced with a simpler design.

6.2.1 Map Rendering

One of the major limitations in the previous version was the inability to play the dispersal simulation at the full resolution and extent of the display. Although the target area was rendered out at a sufficient resolution over the entire planning area, as the user would zoom in no additional imagery was available, as would be the case with a tiling strategy, and the browser would expand the image to the point that individual pixels became blurry (see Figure 6.3). This was simply an artefact of the browsers scaling algorithm attempting to substantially scale up the image. Given the participants testing the software wanted to work at a scale smaller than 1 hectare per pixel, the dispersal images must be capable of being loaded at higher resolutions. To allow users to zoom in and work at finer scales, a different strategy for loading the animations had to be implemented.

The ability to load different imagery as the scale changes is a standard feature of Web Map Services (WMS). Common services often serve maps using a tiling strategy at multiple levels. This allows a client to select the tiles most appropriate for the required view extent. A tiled strategy standardises the potential requests, allowing the server to cache and re-serve tiles independent of the client resolution and extent. However, this strategy can become limiting when a client needs to request a large number of different layers from the map service. Animating a time series, such as the dispersal simulations of this pest planning tool, requires a large number of requests and image tiles to be managed by the client. Furthermore, the intent of the dispersal model in this tool is to support changes to the management strategy, causing the dispersal model to be run again. The ephemeral nature of the dispersal data limits any benefits a tile and cache strategy would offer.

The new animation method developed for Iteration Two (Section 5.5.2.2 on page 160) used a single image strategy for requesting map data. This required the WMS to render a

Figure 6.3: Comparison of the rendering methods. Left, original rendering method. Right, new higher resolution rendering method.

new image every time the map was moved or the time was changed. Changing to a real-time map rendering strategy required changes to the modelling back end. In Iteration Two, map tiles were rendered into PNG files as soon as the dispersal model wrote that particular time step. However, the new rendering strategy required the output data from the model to be saved. The model controller was modified to convert the models ASCII Grid file output to GeoTIFF files using compression, to reduce disk space and improve the render time. Output files were then rendered as the browser requested them, either from the ASCII Grid or the GeoTIFF file.

6.2.2 User Interface

During the Software Usability Analysis and Pilot Focus Group, one of the most requested features was more detail on the impact of actions against the pest species. Participants often queried why the costs would vary so much with only small management actions defined. To address this in the software a reporting page was developed that provided statistics on the management actions, work required an approximated cost of putting their management plan into action. Statistics are graphed and shown visually in Figure 6.4 to simplify comparisons between different management actions.

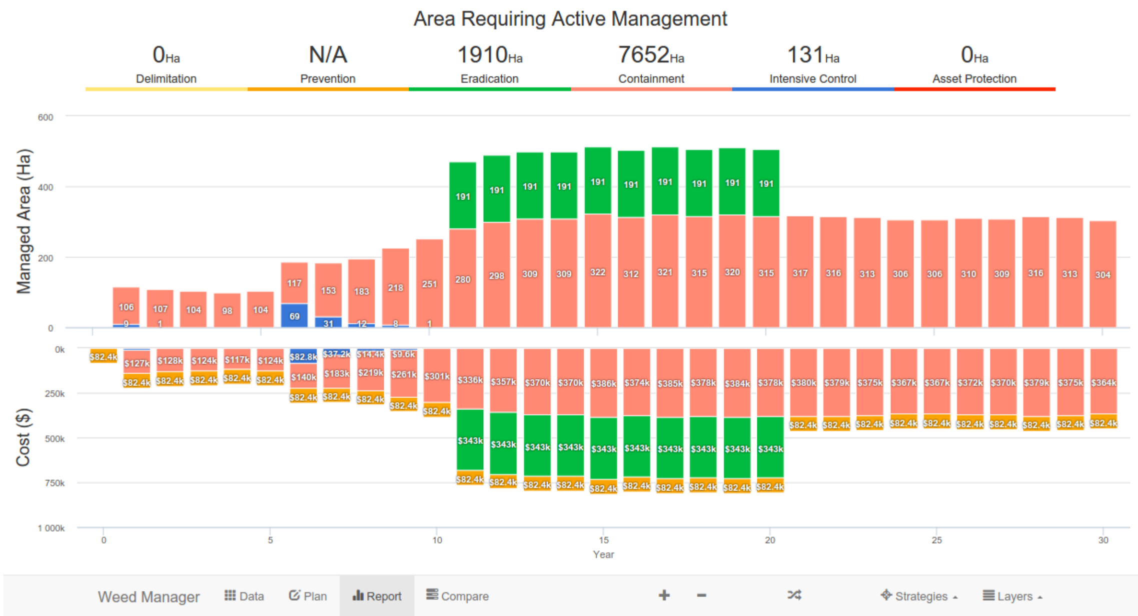

Figure 6.4: Screenshot of the reporting tab showing the statistics generated from a model run. The colour codes for the graph are shown at the top.

6.2.2.1 Preventing Accidental Double-clicks

Users interacting with the software were observed struggling to use the pen to draw management actions onto the map. Participants also reported the program exhibiting strange behaviour during use including adjusting the time slider unprompted. I asked the users to attempt to redraw a management action onto the map. As they tapped out the points of the management actions, at seemingly random taps the polygon would close itself, consistent with a double-click being performed. Even as the participants attempted to make a single-click and exaggerated the motion, it would still occasionally register as a double-click. The participants eventually learned how to reduce the amount of unintended double-clicks, however, they would still occasionally run into problems.

To prevent accidental double-clicking the user interface was modified to ignore any clicks within 150ms of any previous clicks. Double-clicking was not required to use the prototype tool and removing it would help alleviate hesitation in the user when inputting data. The time period between clicks was determined by logging the click times of the pen while drawing management actions. I tested this in the lab by reproducing and recording hesitant click events and replaying them against the software. An additional buffer was added to the maximum time from the logged tasks.

6.2.2.2 Who Added This?

During the usability testing session, after performing other tasks, participants had difficulty remembering who created the different occurrence records. Participants appeared cautious about deleting records they had not created. The prototype tool, however, did not have any mechanism to record the creator of an occurrence record. Reflecting back to the interviews in Chapter 4, local councils verified all of the occurrence records reported by the community before recording them in their databases. Capturing the creator of the record with each occurrence would allow organisations using data collected with the tool to identify occurrences that need verification.

To record a name with each occurrence, user interface components needed to be added to allow users to add, select and change the data entry author details. A modal was designed to appear when the add occurrence button was pressed (see figure 6.5). Users can select their name from the list, and all occurrence records created while the tool was still active would be associated with that person.

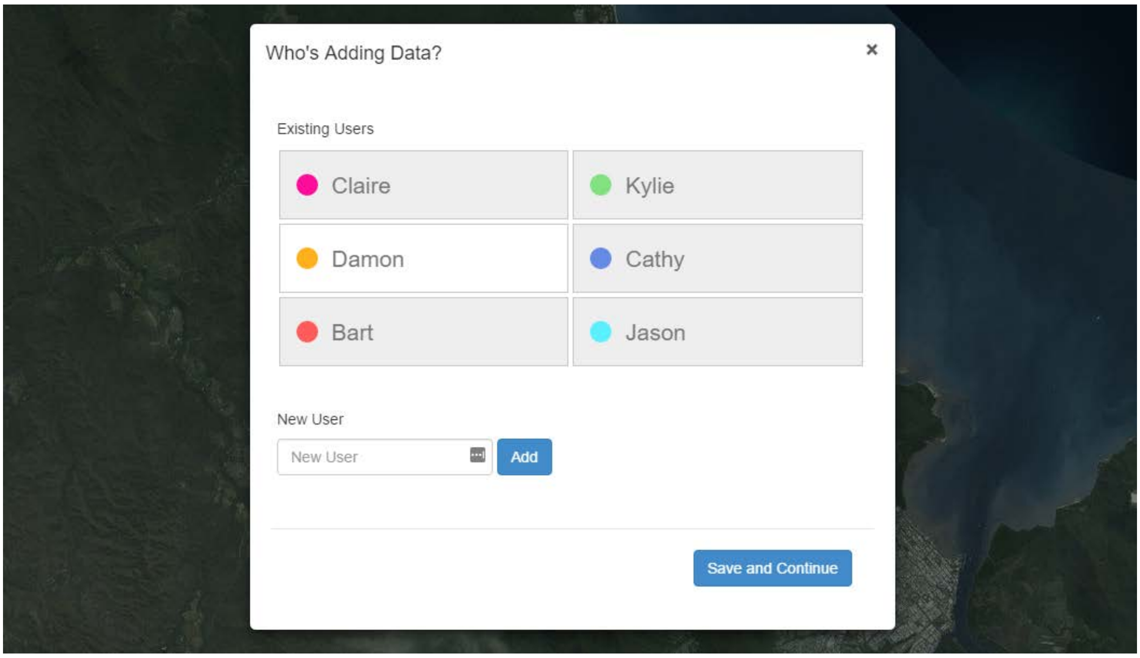

Figure 6.5: Select user dialogue, showing the quick selection for existing users.

6.2.2.3 Improving The Recognition of Selected Tools

Participants were observed having difficulty determining the state of a selected tool. The standard operation when a management action is selected from the tool palette, is for the text and icon to change to a light blue colour. However, during the session, the lower contrast on the interactive projector made it difficult to determine if a management action was selected or not. The contrast between the selected and unselected states was increased to attempt to improve the recognition of tools in the tool palette.

Participants also had difficulty determining when the dispersal model was running. The button would change to a light blue colour while the model was active and was difficult to see. Furthermore, while the model was running the species range graph would expand to show real-time changes from each step of the model. The movement of the graph presented a strong visual cue that the run button had been pressed. However, after the completion of a model run, participants would often leave the graph expanded, make minor changes and then rerun the model. With the graph already expanded, there was no major visual change to indicate the model was still running. To address this the colour change was removed and instead, the run icon would rotate to indicate the model was actively running.

6.2.2.4 Simplified Timeline

The timeline visualisation, used to switch between and compare different management plans, had several limitations that became apparent when used in the tool with real data. It was difficult to make comparisons between layers due to the plot scale and the lack of distinction between the actions taken in each plan.

The plot of each timeline showed the area covered by the pest species at each point in time. The tool was created so that each dot on a row represented the distribution of the species at that point in time, relatively scaled between the minimum and maximum distribution across all management plans. As new management plans were generated, they were displayed in a new row with their associated cost and all of the dots in the visualisation were resized if needed. Typically, the no-action scenario created the largest dots across the map as no management actions defined in this software would improve the dispersal potential of the species. Thus, each new management scenario that was effective would have a lower distribution than the no-action.

The relative scale was effective for comparing management scenarios to the no-action scenario. However, comparisons between two managed scenarios were difficult. Two effective management plans in the visualisation may have appeared as a line of small dots that seemed to be the same size. Although scenarios with smaller points looked identical, they may have in fact been quite different. In many cases, the details in the dispersal of effective management scenarios were lost, making it difficult to gain an understanding of the dynamics of different planning strategies.

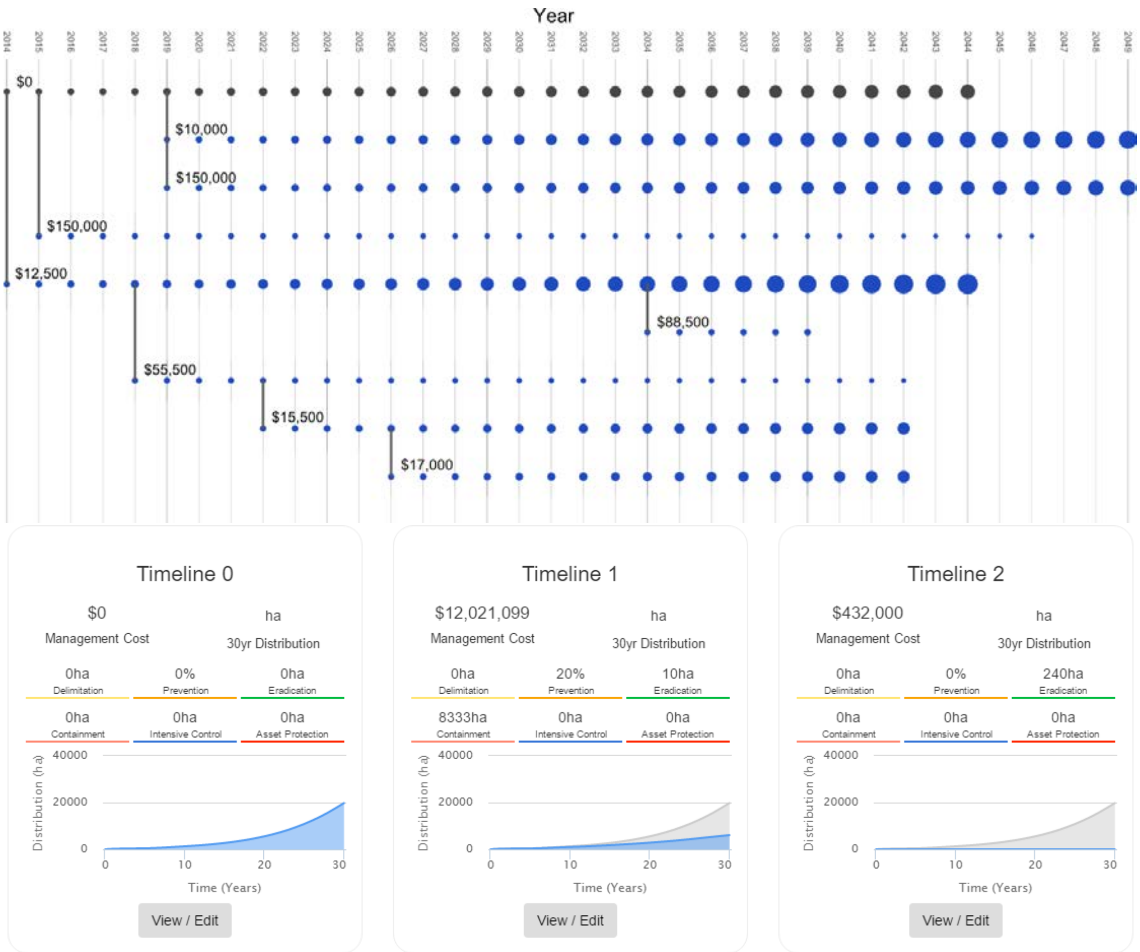

Figure 6.6: Comparison of the first and second version of the timeline for comparing multiple pest management strategies. Top: Original Timeline; Bottom: New Timeline View. Objectives, prices and graphs were more easily compared using the new design.

6.2.3 Summary

This section described the development of the third iteration of the prototype pest management planning tool. Findings from the first usability analysis session were incorporated into the design of the tool to refine the interaction process, reduce unexpected behaviour and fix bugs.

- The rendering process for the dispersal map steps was changed to a just-in-time strategy to increase the resolution of the dispersal simulation animations.
- A click handler was added to prevent unintentional double-clicking.
- A modal was added to allow participants to quickly identify who was adding population data.
- The highlight colour of the toolbar buttons was changed to improve visual recognition of active tools.
- The timeline was changed to an easier to understand comparison page.

6.3 Usability Analysis of Iteration Three

The previous section refined the pest management tool based on the first usability testing session. This section describes the next usability analysis session to evaluate the changes made to the previous tool and to uncover other interaction issues, unexpected behaviour or bugs. This session is conducted in a similar manner to the first usability testing session reported in this chapter, which is described in the methodology chapter (Section 3.3.6 on page 72).

This usability testing session helped identify several technical issues, or 'bugs', within the software, some that were either noticed by participants resulting in unexpected behaviour or not noticed at all. Although the bugs were not interesting from a research perspective, handling them was an important component of the software development process. The usability testing sessions were an ideal way to have the software used in an unanticipated manner by first-time users and also to identify problems related to the technical operation of the program.

6.3.1 Results

The notes and video recordings of the usability testing session were analysed to refine user interface and work flow of the pest management planning tool. This analysis identified usability issues evaluated the performance of the tasks and evaluated refinements made since the previous session. Results from the usability testing session are presented below.

6.3.1.1 Unexpected Behaviour

Newly Added Distributions Do Not Update Model During the session, there were several occasions where participants modified the distribution of the species they were working on. This process involved them switching to the data interface, selecting the draw or edit tool and making changes. When complete participants would switch back to the planning interface to continue planning. However, when participants left the data interface, they would often not press the save button. Although the data was saved irrespective of the button being pressed, the dispersal model was not updated. Participants would then press the play button on the planning interface and observe that their newly added population of pest species would not disperse at all.

Run Model Button Not Clear Enough In the previous usability analysis session, the run model button was one of the user interface components identified that would not correctly exhibit its state, the button had a grey icon and text that would change to a light blue colour when active. The low contrast of the projector made identifying the active button more difficult than on a standard LCD monitor. Participants were often unsure if they had started the dispersal model correctly. To rectify this, the highlight colour was replaced with an icon that rotated when the model was running.

During this usability testing session, I observed a change in participants attitudes towards the run button. Unlike the previous session, participants appeared more confident that their click had been recorded and did not re-click the button. However, at one point while waiting for the first model data to be displayed, after clicking the run button, a participant mentioned that they were unsure if the model was running and re-clicked the run button. Soon after clicking the run button the model started returning new data and animating the distribution visualisation. The participant did not realise they had queued another model job to be run. However, as observed previously, in some cases, multiple model runs would result in the tool behaving in an unexpected manner.

Users had Trouble Deleting Management Actions Participants were observed having difficulty deleting management actions and population records from their plans. Deleting a management action required users to first select the delete tool from the tool palette, and then tap on the management action they wanted to delete. However, when clicking management actions on the map, the delete tool only worked intermittently. This was caused by the pen registering the click actions as a click and drag event.

Identifying Selected Management Action In the previous usability testing session, participants were observed having difficulty discerning the difference between active and inactive tools in the tool palette. The tool icons were changed from light grey to black, and the activated tool colour was changed to a much brighter blue to ensure the active tools were easily identifiable. During that session, the communication of the selected tools was clearer, and participants were not observed having difficulty identifying the active tool. However, participants were observed having difficulty discerning which management action was selected.

On one occasion, a participant selected a management action from the draw menu in the tool palette. Although the management action colour changed, the participant had trouble identifying if the tool had been activated. The participants pressed the button again and looked confused. An excerpt of the interaction is provided, the participant quickly continued afterwards.

> *Participant: (Selecting an objective and looking uncertain.) "Did it work?"*
> *Me: "It looks like it did."*
> *Participant: (Pointing towards the tool palette.) "There should be more feedback when I select things."*

Cumulative Cost This iteration of the pest management planning too showed the total cost for management in the year that had been selected on the timeline. However, participants often wanted to know the cumulative cost of the management objectives up until that point in time.

6.3.1.2 Reviewing the Changes from the Previous Session

The second usability analysis session evaluated the changes to the user interface and work-flow made after the previous focus group in Iteration Three. The changes between the two versions are presented below.

Menu Placement Iteration Two, tested in the first usability testing session, was designed using the Bootstrap web framework. The resulting user interface was very similar to a typical web layout designed for use on a computer or a small touch screen device. However, when scaled onto a table projected touch screen some components became difficult for participants to reach. After participants were observed stretching to reach the primary navigation and tool palette (Section 6.1.1.5 on page 169) they were moved to a place near the bottom of the screen. Moving the toolbar and palette eliminated the need for participants to reach to the other side of the screen to select commonly used tools.

Although the toolbars were moved, the zoom buttons were missed and remained at the top of the screen. These buttons were necessary for zooming in and out of the map, as the pinch to zoom method of touchscreens was unavailable using a single pen. During later analysis, participants moved the map around rather than zooming in when they needed to look at wider areas than the current view. These actions could be attributed to the hard-to-reach positioning of the zoom buttons or because participants had not noticed the zoom buttons at all in the far corner of the screen. This observation is consistent with the literature where participants tended to interact most with components placed nearest to them (Ryall et al., 2004).

Low Resolution Dispersal The model output resolution in the previous iteration caused issues when participants defined small management objectives. Eradication targets that were tightly defined around a population of the pest species could be misaligned and cause the eradication targets to appear to have no impact. A higher resolution visualisation system was developed in Iteration Three (see 6.3 on page 173) to allow more precise alignment of management targets to the dispersal model. Similar to the previous usability testing session participants were observed defining management actions with identical bounding areas to the occurrence records. However, the model in this iteration responded in a manner the participants expected.

Participants also experimented with eradicating different portions of single occurrence records. In all of their attempts, the species would quickly recover, and the partial eradication attempts had negligible impacts over the 30 years modelled. Using a more precise visualisation of the dispersal allowed participants to experiment with the dispersal model in an unanticipated manner. Allowing for experimentation with the model, guided users to understand the characteristics of a pest species and the underlying dispersal model.

Unintentional Double-clicking The unintentional double-clicking with the touch input pen in the previous usability testing session did not occur in this session. Although participants were hesitant at the start of the session, they quickly became more confident as the session progressed. In contrast to the previous session where the hesitation of the participants caused the tool to behave unexpectedly which then caused more hesitation and created a feedback loop. Disabling the double-clicking prevented participant hesitation with the touch input which stopped causing the tool's unexpected behaviour, and thus, did not create a feedback loop.

6.3.2 Summary

This second usability testing session was conducted to evaluate the third iteration of the pest management planning tool. The results presented in the previous section were from observational notes and analysis of the video recordings. This session ran more smoothly than the previous session and participants had less difficulty with the tool behaving unexpectedly. A summary of the findings are listed below:

- Newly added distributions did not update the dispersal model in the 'no action' scenario.

- Participants pressed the run model button multiple times, but not as often as observed in the previous observation session.
- Participants had trouble deleting management objectives from the map. The delete tool was very sensitive to the pen moving slightly when participants tapped the objective to be deleted.
- Participants continued having difficulty identifying the selected management objective in the toolbar. The highlight colour did not have enough visual separation from the normal unselected state.
- The participants requested a cumulative cost of the management actions at the year they were currently looking at on the map.
- The participants could more easily reach the toolbars at the bottom of the screen, compared to the previous usability analysis where participants were observed stretching to reach the toolbar at the top of the screen.
- The unintentional double-clicking observed in the first usability analysis session was successfully fixed in this iteration.

6.4 Developing Iteration Four

The previous section tested the usability of Iteration Three. Several interaction problems and necessary features for conducting pest management planning were identified. This section describes how these findings and input from experienced planners were incorporated into the development of Iteration Four. A number of changes to the user interface and backend of the tool were made in this iteration. The components of this section are presented as bullet points below:

- Management Objective Period and Transitions (6.4.1) describes the limitations of the objectives in the previous prototype and develops a new mechanism to allow objectives to transition over time as they would do in practice.
- Run Model Button (6.4.2) describes the addition of a progress bar to indicate to users when the model is running.

- Additional Features (6.4.3) describes a number of additional features added to the pest management tool, including moving the zoom buttons closer to the users, renaming the tabs on the main toolbar to make them clearer, and easier deletion of objectives after participants previously struggled with deletion.

6.4.1 Management Objective Period and Transitions

Defining management objectives was central to developing pest management plans with this pest management tool. The initial design was based on observations and relevant literature around the existing pest management planning processes. When prioritising pest management efforts against a species only a single management target can be defined for each spatial area for the 30 year period. Both the participants from the second usability testing session and the experienced pest management planners wanted the ability to vary the time periods for management actions. Participants in the usability testing session also requested management targets that could begin at a future point on the timeline. This would enable an objective comparison to be made on the impact of delaying action.

The experienced planners wanted to take this a step further and model the transitions to different management strategies over time. This would closely model the existing process where management objectives, such as intensive control, were designed to support the eventual transition to different management objectives and ideally eventual eradication. Furthermore strategies in the real planning scenarios needed to evolve over time to manage species in a cost-effective manner. Allowing the tool to model changes in management targets and short-term control would help support decisions in regards to long-term funding and management strategies. As the tool was already capable of modelling management actions, it was feasible to model targets transitioning after a user-definable period.

The current modified version of MigClim allows management objectives to be defined through the habitat suitability layer. Each objective represents a human influence that artificially changes the natural suitability of an area. These human influences are interpreted by the model in the same way that natural suitability is. For instance, defining an asset protection objective makes an area unsuitable for pests in the model. To achieve this asset protection objective would require all plants in the specified area to be removed before maturity. This assumes that stakeholders will perfectly meet these requirements to achieve the objective.

To allow management objectives to be defined over user defined periods of time, a method was required that would enable habitat suitability files to be loaded with a time dimension. The model already supported loading new habitat suitability layers at each time step. However, generating and importing additional habitat suitability models would have a significant impact on the run-time of the model. To avoid this, a single spatial layer was used that represented the management objectives with a time dimension. The management objectives layer is a GeoTiff file that the web-service exports from the management objective feature database. Objectives that were over the modelled time period were represented by a 32-bit integer that is spliced when imported into the model (Algorithm 1). The objectives are decoded by the model and are used to change the management objectives without the need for additional layers to be loaded.

Algorithm 1 The objectives layer uses a 32bit integer in each cell representing the year and management objective. This planning unit starts with no objective, at year 9 it switches to objective 1 and at year 20 it switches to objective 3.

```
Position [102,1200]: 0091203
0 | 09 | 1 | 20 | 3
initial action | year | action | year | action
```

During the consultation with the experienced pest management planners, the need for management actions to be defined over variable periods of time and the transition of management objectives was identified as a core feature. This would enable users to easily model and experiment with the timing of intervention with a pest species dispersal. To achieve this each objective needed to be characterised in terms of frequency, human requirements, influence on the model and cost. Table 6.1 detailed the management objectives developed in conjunction with the experienced planners. A brief summary of the objectives and the changes made to them is provided below.

Delimitation The delimitation action is used to define an area for conducting survey work on a particular pest species. Delimitation is simply a search activity and does not always require ongoing work to achieve it. For instance, a delimited area not containing a pest may not require further survey work. However, the detection of a Class 1 pest, being managed by BioSecurity Queensland, would require delimitation to be conducted at regular intervals to ensure eradication (described in Section 4.2 on page 90). Delimitation was removed as an available objective, as it had no impact on the model.

Prevention Humans have been a major contributing factor to the spread of invasive plants and preventing these human factors can help reduce the long distance and unpredictable dispersal of a species. Prevention has been an ongoing task. Methods have included, providing and maintaining wash down bays and running awareness campaigns. The prevention objective was presented in the model as a user-selectable percentage of the pest management expenditure, the chosen percentage influences the long distance dispersal probability. The implementation in the model has not been scientifically validated and was simply an estimate. Users were made aware of this in the user interface. However, future implementations could easily incorporate more accurate models of prevention or simply rely on planners to provide accurate costs.

Eradication The eradication objective is a target used to define an area for the complete removal of a pest. To declare an invasive plant eradicated in an area requires repeated treatment and a commitment of delimitation over the period of the plant's seed viability. For the synthetic species used as part of this project, four treatments a year were required over a period of 10 years. Each new incursion into the area restarted the time required to ensure no viable seeds were remaining in the area. The cost of eradication was calculated from the number of hectares requiring removal multiplied by the seed viability period plus any additional incursions.

Intensive Control Intensive control is a transitional objective used to reduce the size of plant populations to a size that can be targeted for eradication. In terms of the model the Intensive control objective will remove 70% of the mature species each year in an attempt to reduce the seed bank. This objective requires two treatments each year and has no requirement to continue ongoing work. The cost of intensive control operations was calculated from the number of hectares treated each year.

Containment The containment objective is used to prevent a pest plant species from spreading beyond a certain point. This objective requires workers to delimit an area around the boundary of the containment area and treat any occurrences found. The cost is calculated annually from the number of hectares with an incursion. For pest plants species with long dispersal ranges the containment objective can be fairly labour intensive.

Asset Protection Asset protection is often the last resort for an area and serves to prevent pests from entering into high priority areas, for example protecting reserves or endangered species. In the model, asset protection prevents the incursion of a species into the protected area. Each incursion has a cost associated for removing that species from the protected area. Asset protection is generally an ongoing objective but does not have an associated cost if there were no incursions in that year.

Objective	Temporal Context	Frequency per Year	Effect	Cost
Delimitation	Designated Period or one off action. Used for detection of new species incursions	One Off	Survey Only. Does not have any influence over the model.	$314 / ha
Prevention	Perpetual	Perpetual	Represents prevention strategies that may be used in a generic manner. The long distance dispersal probability is reduced to represent the reduced human transport of seeds and improved awareness.	Up to 20% of total budget
Eradication	10 years from last mature	4	Eradication is an objective that assures the removal of a species from an area. This action is assumed 100% effective, but requires a commitment of 4 treatments a year for 10 years, with no new incursions.	$1800 / ha / year
Intensive Control	Transitional	2	The Intensive Control objective is the targeted removal of mature species to reduce the seed bank.	$1200 / ha
Containment	Perpetual or as defined	2	Containment is an objective that prevents a pest species from leaving a defined area.	$1200 / ha
Asset Protection	Perpetual or as defined	1	Asset protection is an objective that prevents the entry of a species into an area.	$600 / ha

Table 6.1: Objectives broken down to characterise their real world use and their influence on the species dispersal model.

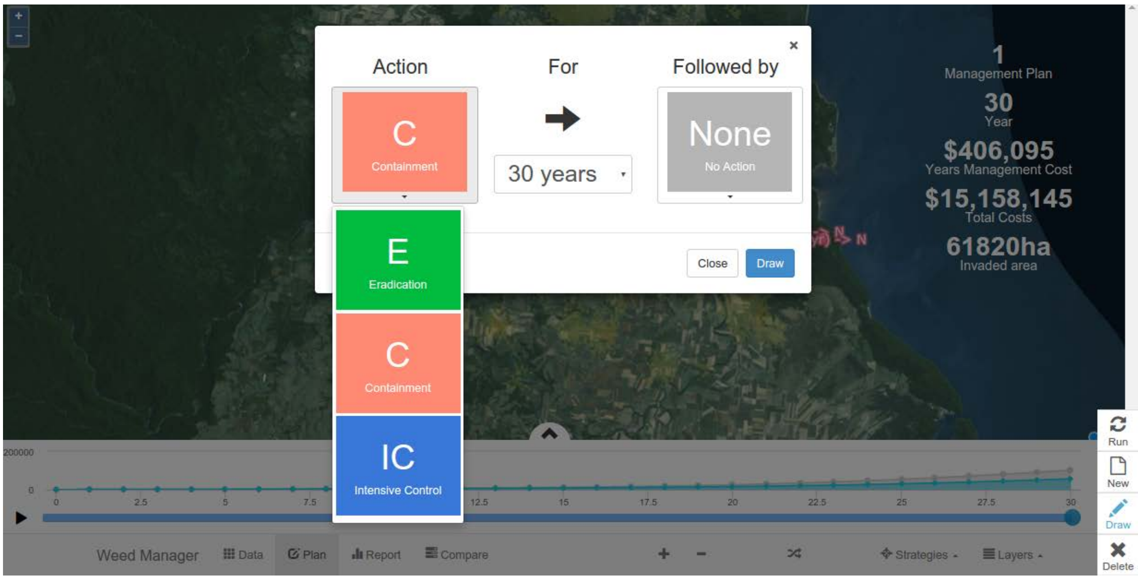

Figure 6.7: Screenshot of the pest management tool showing the selection modal for management objectives.

During the usability testing sessions, participants had trouble identifying which objective was selected from the tool palette. Furthermore, the user interface did not allow for a text description of the objective to be added to the buttons. Although a paper poster was available that referenced the colour and letter to the objective, participants still requested additional guidance. Using the smaller icons without the description underneath would require users of the software to remember the names for all of the objectives.

The draw tool was modified to present a large modal to replace the small tool palette objective selection list (see Figure 6.7). This modal allowed the title of each management action to be shown in the selection list, serving as an additional prompt for users. Furthermore, it allowed the customisation of time-period and transitions to different objectives to be defined. The modal pops up when the draw tool was selected from the tool palette. It was designed with large buttons and text to ensure the legibility of text and to provide large click targets for users.

6.4.2 Run Model Button

One of the issues observed during the testing sessions was users being uncertain of the state the application was in when actions did not provide enough feedback. One of the

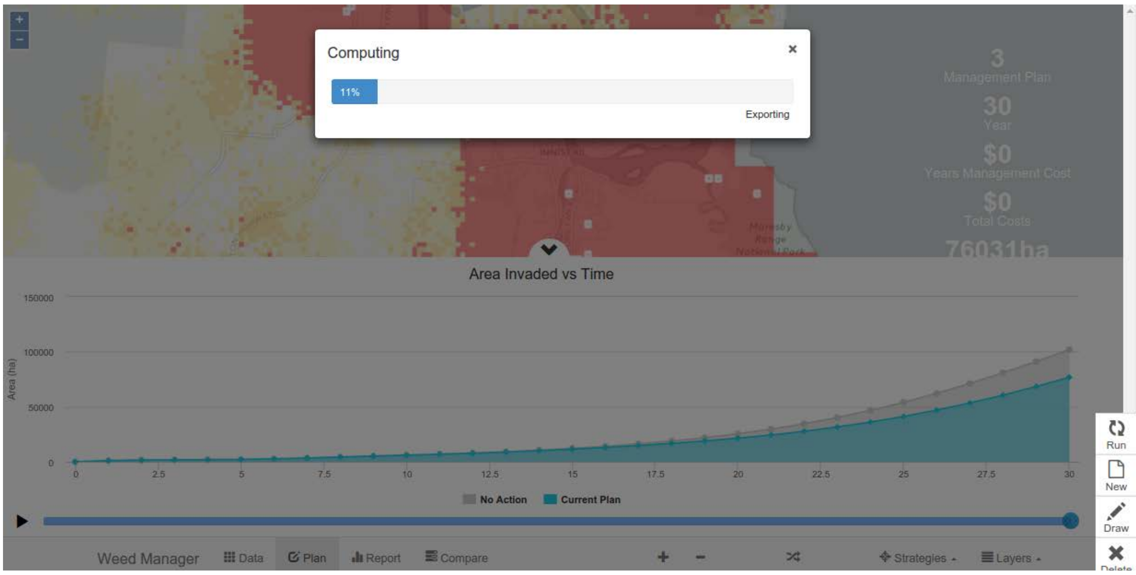

Figure 6.8: Progress indicator showing that the model has currently been started. The run button (bottom right) also rotates while the model is active.

problem areas identified was the run model button located on the right-hand toolbar. When pushed the button slides the distribution graph at the bottom of the page up and dispatches the dispersal model in the background. However, the users only see the distribution graph slide up. This visual feedback was not insufficient and led to confusion in several instances.

To make the visual feedback more obvious a modal box showing a progress bar was added, and the run model icon was made to rotate while the model was running. The modal box was displayed brightly in the centre of the screen, dimming the rest of the screen to show that the model was currently running. The modal box could be dismissed by the user at any point, allowing the users to continue working while the model runs. However, the loading modal would automatically be closed when the first year became available for rendering. Once the modal was closed, the new model layers animate through each year to show the results from the model run.

6.4.3 Additional Features

During the usability testing session, several components of the user interface were identified that participants misidentified or struggled to use. These included the map zoom buttons being out of reach of participants, the names of the navigation tabs being

Figure 6.9: The planning tab of Iteration Four, showing the relocated zoom buttons and the total cost metric.

ambiguous and participants struggling to delete features drawn onto the map. This section details the changes made to the software implementation to solve these problems.

The buttons to zoom in and out of the map were unintentionally left at the top of the display when the navigation and tool palette were moved to the bottom after the first usability testing session. During this session, the zoom buttons required too much effort to reach. An additional set of zoom buttons were added to the centre of the primary navigation bar at the bottom of the screen. The new buttons are illustrated in figure 6.9.

During the second usability testing session, two of the participants mistook the report tab for the review tab. The tabs were renamed in consultation with the experienced planners. A comparison of the changes to the navigation bar is shown in Figure figure 6.10. The Review tab was renamed Report to match the participant's expectations. The Report tab was renamed to Data as the tab was where the species occurrence data could be edited. In pest management planning, the word 'report' is commonly used as a verb such as when a person is reporting a species occurrence to a managing body or authority. In the context of the target audience for this tool - pest managers, the term 'data' would more accurately describe the collection of verified reports and occurrence records. Supporting icons were added to each action to assist people in understanding the purpose of each tab.

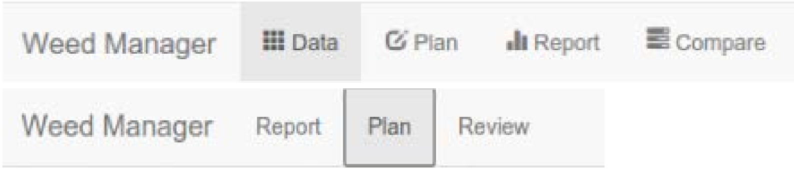

Figure 6.10: Changes to the interface names on the primary navigation bar. Top: Iteration Four, with new icons and renamed buttons. Bottom: Iteration Three.

Participants from the first and second usability testing session had difficulty deleting management actions from the map. This was not identified in the first usability testing session as the participant's hesitation, and inadvertent double-clicks with the touch pen obscured the problem. To address the issue of the pen not correctly registering delete actions a custom click handler was added to the management objectives that would be more less sensitive to slight movements when using the delete tool.

6.4.4 Summary

This section described the development of the fourth iteration of the prototype pest management planning tool. Findings from the second usability analysis session and input from experienced planners was used to refine the pest management planning tool. A number of changes were made to the tool:

- The management objectives were changed to more closely reflect those used in practice in Far North Queensland. Previously management objectives were set for the full 30 year period. In this iteration, management objectives can now be changed at five-year intervals to allow objectives such as Intensive Control to eventually transition to Eradication.
- In both the first and second usability testing sessions, participants had difficulty identifying if the run model button had been pressed. Changes made in the development of iteration three (Section 6.2 on page 171) proved to be ineffective. A dialog including a progress bar was added to more clearly indicate the state of the model and prevent accidental re-runs.
- The zoom buttons were moved from the top of the screen to the main toolbar to make them easier to reach.

- The tabs on the main toolbar were renamed and had icons added to them after one participant mistook the report tab for the timeline tab several times.
- A click even handler was added in attempt to make deletion of management objectives with the interactive pens easier.

6.5 Pest Management Tool Evaluation: A Case Study with a Quasi-Real Species

To evaluate the pest management planning tool developed as part of this project and to answer the research question, a case study was conducted incorporating a quasi-real planning scenario and experienced pest management planners. Six participants from Far North Queensland were involved in the case study and took part in training, a scenario and a focus group. The participants were all experienced in pest management and have taken part in pest management planning sessions previously. The participants are all from surrounding regions and most have worked with each other in the past (more detail 3.7 on page 77). The planners were given a brief training session and asked to work together using the tool to develop a plan that met an annual budget. Observations from the session and feedback from the focus group were used to evaluate the decision support tool. The evaluation aimed to look at the design of the software from a HCI perspective and the value a collaborative tool could provide to pest management planning.

This case study section is broken into two sections:

- Results and Discussion (6.5.2) describes the findings from the scenario and focus group.
- Evaluation (6.5.3) describes the evaluation of the findings conducted using Innes and Booher (1999) consensus building evaluation framework.

The session ran for approximately 1 hour and 30 minutes. It was recorded on video capturing the participants and the user interface. My observations, relevant comments and impressions were also recorded in a notebook. The goal of the case study was to develop a cost-effective and implementable pest management plan for realistic species in the Atherton Tablelands region. Each task performed by the participants was individually analysed from the notes and video. Tasks were annotated on the video timeline and transcribed. The transcripts and raw data were analysed to look for unexpected behaviour and for tasks that hindered or stopped participant's progress or that required participants to find different approaches. Further analysis using the evaluation framework developed by Innes and Booher (1999) explored the process as a whole to identify the value interactive and collaborative decision support tools could provide to the pest management decision-making process.

6.5.1 Process

The session began with me brief introducing myself and what users could expect from the session. This was designed to cement my role as the facilitator and to start building the confidence of participants by outlining the tasks and what could be expected of them throughout the session. I also explained how the software works to point out its limitations and what they can realistically expect out of it. The introduction set the scene for the planning scenario and covered the necessary background information for the species being targeted. I then conducted a short demonstration using the tool which progressed into the planners being asked to complete a series of tasks. A more detailed description of the tutorial is provided in Appendix 9.5 (on page 266). New incursions of the pest species were introduced, and participants were asked to manage them, keeping their expenditure within an annual budget of $100K.

Scenario

The scenario progressed on from the tasks the participants had previously created. A series of new incursions were introduced to the tool, and the participants had been told that recent delimitation activities had uncovered the extent of the newly discovered pest. The participants were allowed to experiment with different objectives for a short period before being given a budget of $100k per annum to work towards. They were asked to attempt to solve the problem using the current budget or to develop a proposal for a larger budget. The existing budget was too restrictive to enable the immediate eradication of the species, so the planners had to prioritise their actions.

Focus Group

The focus group was conducted immediately following the scenario and was used to allow the experienced planners an opportunity to provide feedback and help evaluate the decision support tool. Participants were asked to discuss their experience using the tool, whether they could see it being useful for planning and what would be required for them to use the tool. The questions and topics discussed during the focus group are listed in full in the Appendix (Section 9.4 on page 264).

6.5.2 Results and Discussion

This tool aimed to improve the pest management process by providing more information when decisions about management objectives are made. Better objectives and resource targeting would hopefully result in a more systematic approach and improved on-the-ground outcomes. At the conclusion of the scenario, a focus group was held to gather feedback from the experienced pest planners. This feedback was used to assist in answering the research questions and to evaluate the utility a pest management decision support tool, like the one developed in this thesis, had to them. In this section, an examination of the observation session with the stakeholders using the decision support tool is presented. The data are structured in reference to the research questions for this observational session:

1. How did stakeholders use the tool?
2. How has the usage of the tool changed compared to the previous version?
3. How did the tool change the pest management planning process?
4. Did the tool present value to the stakeholders?

6.5.2.1 How was the tool used?

The session began with participants gathering around the table with the interactive screen but standing back to a certain degree. As the tutorial progressed and people began using the tool and wanting to experiment with new ideas, the group remained some distance from the table. A participant would step forward and interact with the tool while the other group members watched. When encouraged to move forward and join in participants still remained at arm's length from the table. This meant at times, participants would discuss an alternate approach to the person currently interacting with the tool. To facilitate the collaborative planning, these discussions would be most effective when all participants were at the table.

During the previously observed sessions participants had gathered around the table as soon as the demonstration of the tool began. Differences between the sessions may be attributed to the smaller table size in this session and the reduced border around the interactive display. Table 6.2 shows the time taken from the first participant interaction to the point where the group gathered around the table. This dataset is too small to identify the cause of this however it does seem to indicate that the size of the table may have an influence on group collaboration. Although the session started with users standing back from the table, as the session moved into the scenario participants started moving forward and working together.

Session	Time From First Interaction	Elapsed Session Time
Observational Study	during demonstration	25:00
User Testing 2	immediate	8:00
Focus Group	20:00	34:30

Table 6.2: Time from first participant interaction to group gathering around the table.

Throughout the session, the interactive pen was used in a similar manner to a talking stick. The pen was chosen early in the project as the primary method of interaction to reduce the possibility of unintended contact with the device. During the first observational session, participants would inadvertently bump paperwork onto the screen, place coffee cups down, or touch the surface while pointing. These inadvertent actions caused the tool to behave in an erratic manner, often of minor inconvenience but occasionally moving the map a long way from the viewed location. The use of the pen changed the interaction method during the session and eliminated the problems encountered at the start.

Only one interactive pen was available to the participants in the sessions. Participants would often keep the pen after they had finished interacting with the tool so other group members would either wait for the pen to be put down or request the pen from the participant holding it. The pen holder was always happy to hand the pen over when directly asked. However, there were two observed occasions where a participant's request for the pen was not heard. This scenario could hinder the ability for other users to interact with the tool and could limit the participation and engagement of the rest of the group. Although this situation in the group scenario was easily resolved, it could prove more problematic in groups where individuals were more dominant. Future sessions should be conducted with multiple touch pens or with a capacitive multi-touch display that would not detect input from objects on the surface.

Throughout the session, the group seemed fairly relaxed and casual with participants often making jokes and laughing amongst each other. On one occasion one of the participants did not entirely eradicate a small population in the simulation, which broke free after 20 years. The group laughed and the participant happily quipped that this was just like real life. Overall, participants seemed to enjoy the experience and remained engaged even while talking to each other about unrelated topics.

6.5.2.2 How has the usage of the tool changed compared to the previous version?

This section presents data from the scenario and the focus group conducted with the experienced pest managers. The findings presented in this section were used to evaluate the progression of the decision support tool and to direct future work. Through each iteration, the planning tool had been tested to ensure it was easy to use, that it would assist in pest management planning and provide value compared to existing processes.

Finger Talk Throughout this planning, session participants were observed using their hands and fingers near the touch surface to describe spatial areas and support their discussions. This was also observed during the observational study conducted in 4.3 (on page 106), prompting the replacement of the touch sensor with interactive pens to prevent unwanted interaction. In the previous observation session using the finger touch sensor, broken conversations and discussions occurred as participants accidentally interacted with the display. Removal of the sensor during that session allowed participants to start interacting more naturally, however, the pen-only interaction method had not been observed from the beginning of a session.

This session began with the interactive pens as the sole method for participants to interact with the tool. Participants highlighted areas using their hands and objects they were holding. These interactions seemed very natural for participants and allowed them to use the tool as though it was a paper map on the table when it suited them. No interruptions to their discussions occurred as witnessed in the previous session. Further, participants seemed more confident in using the tool as a discussion support tool.

Delete Tool During the second usability analysis session (Section 6.3 on page 178) participants were observed having difficulty deleting the management objectives they had created. Although a workaround was developed for Iteration Four, it did not successfully fix the problem. Participants during this session struggled to delete management objectives with the interactive pen. An example of this is given below.

Mark: "So can I select this?" (gesturing towards an objective previously created)

Christine: "There's a delete."

Dylan: (Gestures towards the toolbar)

Mark: (Selects the delete button.)

Mark: (Clicks on the management objective several times. It doesn't work. Clicks delete button again, deselecting it. Clicks on the objective trying to delete it again.)

Mark: "Yeah, it's like a big pen, it's not working." (laughs)

Travis: "Select the delete thing so it's blue and then push straight down like a button."

Mark: (Selects the delete button and deletes the objective on the first attempt.)

Mark had initially drawn a management objective onto the map to see how it worked when the model was run. He wanted to delete the existing management objective so he could create new management objectives. Mark selected the delete button from the toolbar and attempted to delete the management objective, however, each time he depressed the pen on a management objective he moved it slightly, causing the map to move. The map movement went unnoticed, and Mark had the impression that he had not selected the delete tool. He then clicked on the delete tool again, disabling it and attempted to remove the management objective once more. Travis stepped in and gave a clear instruction that the delete icon should be blue and to ensure the pen was used like a button. Deleting objectives caused problems throughout the rest of the session and was mentioned during the group discussion at the end.

Model Indicator In the previous usability analysis sessions, participants were observed having problems identifying when the model was running resulting in multiple model runs being performed. A dialog was added in the development of Iteration Four that would appear in the centre of the interface and show the progress of the model run. The dialog was highlighted by darkening the rest of the user interface while it was visible. Throughout the session, no participants mistakenly attempted to re-run the model or appeared confused about the state of the program. Although the initial change from the blue model running indicator to the animated icon did reduce the number of unnecessary model runs, it still caused confusion. In this observational session, the addition of the model run dialog successfully communicated the state of the model.

Clear Management Objectives The management objective selection interface was modified between each usability analysis session and the final focus group was based on observations from each session. Throughout this session, participants had no difficulty identifying the management objectives they had selected, as had happened in previous sessions. However, there was a circumstance where a participant did not save the management objective that was selected.

Mark: (Clicks draw.) "Drag that across."... "Nah, you can't can you? Can you move these dialogue boxes?"

Dylan: "Ahh, no."

Christine: "What are you going to do first?"

Mark: (Selects eradication)

Anna: "Yeah, he's going for gold!"

Mark: "We're going to do a bit of eradication around the national parks." (clicks outside the dialogue)

Mark had initially selected the eradication action, however, when he went to draw with the tool he had not saved his changes to the management actions.

Mark: (Draws a polygon, messes it up, hits delete and tries to redraw it but clicks on the toolbar and assumes the draw tool isn't selected. He then clicks the planning mode button, clicks the draw button and clicks outside of dialogue again.)

Mark: (draws polygons) "Ahh, that's 10 years intensive control." (He recognised from colour and description that it's not what he intended to draw, but he seems to go along with it.)

Grace: "So, there's this whole catchment area." (pointing at a different area of the map)

Mark: (Draws a small polygon around the populations in the catchment.)

Grace: "There's one over here." (Points elsewhere.)

Mark: "So... How do we make them eradication? Because they're all IC"

Dylan: "You have to hit the draw button to..."

Mark: "Yeah, yeah, yeah. But these are set to Intensive control down here, how do i get eradication?"

Dylan: "You have to have eradication set here"

Mark: (Reselects eradication and goes to click out of the box.)

Dylan: "And you have to hit the draw button"

Mark: (Presses draw button, and draws eradication successfully.)

Mark had recognised that the polygons he was drawing were intensive control, even though he had previously selected eradication. He asked for help in changing from the intensive control objective to eradication. Although he was aware of the method for changing the objective, he had taken a different approach than had been expected when designing the user interface. Mark assumed changes made in the selection dialog would be applied automatically and therefore thought closing the dialog would be sufficient in selecting the action. However, the tool required users to select the draw button to continue, and the default action was not saving their changes.

There were not any repeats of this situation throughout the remainder of the session. A more effective strategy for the objective selection dialog might have been to save by default and retain a history of objectives for users to quickly select from. This would more closely model the interaction with the dialog observed in this session by assuming the user was more likely to be accepting the changes than cancelling them. Unintended changes could then simply be undone by selecting the previous item in the objective history. Irrespective, more observation of participants was required to determine the optimal default behaviour.

Participants did not experience issues in identifying management objectives or identifying the currently selected management objective as observed in previous sessions. To address the identification issues, the method for selecting management objectives was changed. The new interface appeared to improve recognition of the management objectives and, participants were confidently stating the objective name and selecting it from the drop-down menu. Furthermore, there was no confusion as to the objective selected in the interface beyond Marks case where the objective was not saved. Although the participants in this session were experienced pest managers and were familiar with the management objectives, the observations in this session were a positive sign the tool is becoming easier to use.

6.5.2.3 How did the tool change the pest management planning process?

All of the pest managers involved in the session expressed interest in using the tool to assist them in developing pest management strategies. However, the scenario given to the pest managers in this case study may not have fully represented the work that they most commonly undertake. Although the scenario was a realistic simulation including a wide spread of rapidly dispersing weed species, the participants commented on how difficult and expensive they were to manage. During the feedback session at the conclusion of the scenario, Harry commented that he could not see the tool being useful in a scenario like the one they tackled during the session. Harry commented that their department would be more likely to use the tool in scenarios of new incursions or something that is within an achievable budget. Harry did go on to state that the tool would have merits in large-scale planning. However, they would more often use it for smaller local problems.

> *Harry: "Yeah, so you can spend a lot more time getting in depths, saying we're just going to look after this place, this place and this place."*
>
> *Christine: "So what we were talking about there, being able to define the road corridors and things like that and go well this area we want to keep clean, because it's going to head to wherever..."*

Christine continued that being able to easily predict future sites for incursion meant they could pre-emptively control pests. A pest that was modelled to spread into an undesirable area could be treated well in advance and take action while eradication was still achievable.

The pest managers liked that the tool could provide an explicit simulation of dispersal and an estimated cost of management. Although the managers could build a fair understanding of how species were likely to disperse across the landscape from their existing tools, they were not always able to predict dispersal in a methodological and visual manner. The dispersal model, when configured correctly, could give a reasonably accurate estimate of total dispersal and help managers develop plans. The management cost estimate gave managers the opportunity to make objective comparisons between different scenarios and communicate the need for early intervention to non-experts. It was noted that the pest managers expected the ability to set pricing for their own region.

> *Christine: "To be able to put in real costs, our costs are a lot higher than anywhere else."*

For the outcomes of the scenarios developed in this planning tool to be used for the justification of budgets, they must reflect the true cost of management in a region. Christine also added that the tool reflecting their real costs would allow them to justify their spending on new pest incursions.

The pest managers also expressed interest in using the tool to assist in the development of funding proposals. Pest managers often had trouble communicating the urgency of their need for funding to those who were not heavily involved in the pest management process. The opportunity to successfully eradicate a new incursion is often very limited, and a rapid response is necessary to successful control of the species. Developing multiple scenarios around varying budgets would help demonstrate the necessity of proactive funding.

> *Anna: "These are the different options, if this is the management action you take, this is the consequence."*

The pest managers continued to justify that the response taken to manage a new pest incursion is just as important as the timing. By the time it took to write the grant applications and receive funding approval, it could often be too late to implement affordable control. As the participants observed and commented about during the scenario, delayed or incomplete actions cost far more in the long run than quick responses. These comments were supported by the findings and in the first interviews (Section 4.2) where LC1 commented that getting in and immediately dealing with pests is the best strategy.

6.5.2.4 Did the tool provide value to the process?

This section presents the data from the scenario and the focus group conducted with the experienced planners. The planners were mostly positive when talking about the tool in the focus group. Fostering group collaboration, consensus building and engaging with community members was a major focus of this research project. However, there were a number of necessary features for the tool to be considered a valuable asset to the pest management planning toolkit.

When asked if the participants thought undertaking planning in a similar group was a good idea, they all agreed and each provided examples of how they would undertake similar session in their work scenarios. Anna mentioned their work in Cape York starting to involve indigenous land owners and rangers to bring more local knowledge into their planning. Having a flat surface would allow the indigenous rangers to point and interact in a natural manner. Anna later asked if the tool and interactive projector would work on a bonnet in the middle of the bush. The projector being used outdoors during the day would present some challenges for visibility, however, the tool could just as easily be used on a large touch screen tablet.

Although all of the planners involved in this case study were aware of the impact uncooperative land managers could have on the process, an event unfolded where a small area of the simulated pest invasion had been missed and broke out re-infesting the surrounding landscape.

> *Christine: "So we're never going to get eradication with that." (laughs)*
>
> **The model reaches year 25 of playback and the eradication target missed a tiny area allowing it to spread uncontrolled.**
>
> *Me: "Yeah, you must have missed a little bit."*
>
> *Travis: "And this is eradication done poorly."*
>
> *Peter: "That's a real world scenario."*
>
> *Group: (Laughter and everyone enjoying the situation.)*
>
> *Christine: "We missed a plant."*

The tiny area of Dangleberry, the participants missed during their strategy building, spread uncontrolled over the landscape. The group laughed and quickly re-defined the area. However, this was later referred to in the focus in relation to the ability to demonstrate cause and effect. Christine commented that involving all of the land owners and different agencies in a session like today was a great method for building consensus and working toward co-operative plans.

> *Christine: "The idea of having different agencies that need to do something and to make it all work. It's okay to say we've got asset protection for national parks. But if people outside the national park aren't on board with what they're doing or what's expected of them, this is an issue."*

Christine continued to explain that once agencies understand the expectations of them, they are able to determine budgets and put together well-reasoned funding proposals. The sessions could be used to get all of the agencies together to use the tool and develop a plan that would work for everyone. The agencies could then approach the funding bodies with a unified plan to show that all of the required stakeholders were involved. In the past agencies would often develop strategies to manage their own areas without an overarching regional strategy resulting in ineffective management.

> *Christine: "You end up with this mish-mash and everybody complains and whinges that nothing's happening and being effective."*

Developing a method to allow stakeholders to collaborate and make informed decisions as a group was one of the gaps identified in the literature review and exploration of the problem. A unified approach with all of the stakeholders gathered to develop strategies would allow each party to understand the influence individual actions have on the group. Pests are not contained by property boundaries and a group approach with widespread buy-in was an identified requirement for successful management. Harry expanded on Christine's response giving an example of how the planning tool could be used at a catchment level with local councils trying to foster engagement from their landholders.

> *Harry: "If you take a catchment. Okay, if we get 80% of the landholders on board this is our likely end."*
> *Christine: "Yeah"*
> *Harry: "Recalcitrant catchments we only get 10% of buy in."*
> *Christine: "...and it's much easier to then get people on board, by saying look, this is how we can win it if we do this and this. If you're not going to be part of it then it's not going to work."*

The outcomes from the scenario and the discussions during the focus group show the potential for the decision support tool to be used in collaborative planning. However, for the tool to provide value to the pest management process it must meet a number of requirements expressed by the experienced planners:

- Planners must be able to provide their own costs for the required work to meet a management objective. Throughout the introduction, planning scenario and focus group, the experienced planners voiced their need for adjustment of the underlying cost of works. The costs for each region vary substantially, and the planners already had a good sense of the real costs of different management actions in their region. Realistic costing would enable the planners to take the strategies developed with the tool to their funding bodies to show an informed process to arrive at their budgets.

- Planners must be able to load their existing datasets. During the interviews with stakeholders, it was uncovered that collaboration between different agencies was limited by their ability to share data. Often, small pest management departments did not have the expertise to convert data stored in different formats or databases. In the focus group, the experienced planners asked about the underlying software, and its compatibility with their data. The ability to load external distribution data was a necessity to ensure a full and complete picture of a pest species' range.

- Planners needed to be able to load supporting layers and cadastre. The planning process required the planners and stakeholders to have access to property boundaries, road corridors, catchments and a variety of other datasets. These datasets supported the decision-making process and helped stakeholders and landholders incorporate their local knowledge and understanding into the process. During the first planning session, I sat in on, catchments and property boundaries were used to determine new areas to undertake delimitation exercises and also areas that were most effective to control.

6.5.3 Evaluation

Developing effective pest management plans requires multiple stakeholders with varying objectives, uncertain funding and unique interest in the process to reach a consensus. Currently, decisions are made in a manner that does not always incorporate the full picture across multiple regions. This research project developed a tool that aimed to assist planners and stakeholders in informing their decisions and encouraging collaboration. Evaluation of this tool was required to understand the wider implications on pest management planning.

Innes and Booher (1999) laid out a framework to evaluate collaborative decision-making processes. Although many numerical and quantitative approaches exist for evaluating these types of collaborative systems (McGrath and Hollingshead, 1993; Steves and Scholtz, 2005) they often do not work effectively with systems where there are no easily comparable outcomes. Quality plans in pest management and conservation planning are often a compromise between the optimal allocation of resources and the allocation accepted by the stakeholders . Evaluation of a pest management plan relies on many measures that cannot be objectively quantified. The framework developed by Innes and Booher (1999) describes seven criteria useful for evaluating the quality of a consensus building tool. An evaluation using each of the criteria is established below.

6.5.3.1 Is self-organizing, allowing participants to decide on ground rules, objectives, tasks, working groups, and discussion topics.

The pest management decision support tool developed throughout this thesis provides a structured approach for simulating and evaluating pest management plan objectives. Simulations provide objective feedback to allow the refinement of strategies developed throughout planning sessions. However, the decisions around the allocation of resources, priorities and approaches the group decides to try are made by the participants. The tool enables more information to be incorporated into the planning process, but ultimately, decisions about the objectives and resource allocation are made by the stakeholders involved in the session.

6.5.3.2 Engages participants, keeping them at the table, interested, and learning through in-depth discussion, drama, humour, and informal interaction.

An important aspect of consensus building is keeping all of the stakeholders engaged throughout the process to ensure the outcomes are respected and adhered to in the long term Richards et al. (2004). Throughout the research project, participants were observed using interactive tools. Participants from the observational study (Section 4.3 on page 106), usability analyses (Section 6.1 on page 165) and evaluation (Section 6.5 on page 193) were observed stepping back from the table to engage in discussion that was not related to the main dialogue happening at the table. During these off-topic discussions, participants would remain attentive to the tasks and debate taking place at the table. Participants who had stepped back would often comment or re-engage when strategies were run through the model or the discussion advanced into an area they were more interested in. These informal discussions were often based around recent experiences and in several cases contributed to the progression of the planning or the focus group at the end of the evaluation.

Throughout these sessions, participants used humour to help progress the planning scenario forward. When participants attempted strategies that resulted in an unexpected or unsuitable result, they would often make jokes about the cost. In one instance a participant exclaimed “That’s a real world scenario”, when a tiny area of a species was missed and broke out.

6.5.3.3 Incorporates high-quality information of many types and assures agreement on its meaning.

The quality of information available to stakeholders when building pest management plans influences how well the plan reflects the real world and ultimately how successful it can be Norton (1982). Typically species dispersal models can be used to provide additional information about the future range of species in working groups. MigClim, a widely used dispersal model, is used by researchers to help understand how the species distribution is likely to change over time. However, MigClim and other similar dispersal models are used before the planning sessions with stakeholders, and simulations are saved and viewed as static outputs. New incursions presented during these working groups are not easily incorporated into the decision-making process. The dispersal modelling tools also do not provide the opportunity for stakeholders to interact in a meaningful way, to experiment with different management strategies or provide new insights into the process.

The tool developed in this thesis simplified the process of running the MigClim dispersal model, making it accessible to stakeholder groups without experience using modelling tools. New incursions and populations of the target pest species could be defined by simply drawing them onto the map, and their dispersal could be simulated over a period of 30 years in one press of a button. The output from the dispersal model was animated, and stakeholders could step backwards and forwards in time while moving and zooming the map to focus in at larger scales. By incorporating the dispersal simulation into the planning session, stakeholders now had the ability to quickly add their own knowledge of local populations to the simulations. Further management objectives could be defined in the tool which would influence the dispersal of species in the model over time. These objectives reflect real-world actions and could provide more information to the decision makers than possible with traditional tools.

6.5.3.4 Encourages challenges to the status quo and fosters creative thinking.

Challenging the current pest management actions taken by stakeholders is an important path to improving the effectiveness of pest management plans. Regions with large proportions of recalcitrant, uncooperative or unaware land managers often struggle to implement control mechanisms successfully. Pests are not contained within land tenure boundaries, so collaboration from a variety of different stakeholder groups is necessary. Complementary, or shared plans for the control of pests must be developed for processes to be successful. Challenging those stakeholders who prefer to run their own operations could potentially improve the quality of outcomes from pest management activities.

The tool in this thesis could challenge the current methods stakeholders use by presenting them with a mechanism to test and compare their current strategies. Participants can easily define management objectives to be used against the target species on the map and visualise how they influence a pest across the broader landscape. Management costs are calculated to achieve each strategy defined on the map. These strategies and their associated costs can then be compared to demonstrate how land managers and stakeholders that do not build co-operative plans, can influence an entire region. This ability to compare different management objectives encourages participants to experiment with and test different approaches to reduce the costs and impacts of a pest species.

6.5.3.5 Seeks consensus only after discussions have fully explored the issues and interests and significant effort has been made to find creative responses to differences.

Consensus building is required to build effective pest management plans that represent the needs and interests of stakeholders. The planning process currently incorporates multiple views to develop an approach to managing pests across large regions. However, these approaches generally make it difficult to explore and validate the outcome of the planning strategy. Suitable environments can significantly influence the dispersal of a species across a landscape. Some areas may form natural barriers and adequately contain a pest without the need for human intervention. These areas can be set aside to focus funding on areas with pests that have a greater potential to cause damage. Identifying these areas prior to sessions is possible, but new incursions presented throughout the process cannot be included in dispersal simulations.

The tool developed here allows new incursions to be included in the pest dispersal simulations. Differences in stakeholder expectations can be explored by comparing multiple strategies and refining them using an iterative process of designing and testing. Previously unheard or inexperienced participants are now capable of demonstrating their ideas and concepts without the need for domain-specific knowledge. The tool shows the impacts of individual strategies and helps guide the participants to reaching a consensus.

6.5.3.6 Includes representatives of all relevant and significantly different interests.

The tool can incorporate ideas, knowledge and expertise from people with a diverse set of backgrounds. The easy to use nature of the tool allows those that may not be experienced in using scientific modelling software or even contributing to pest management planning, to contribute to the process. However, the approach taken with the design of this interactive tool did not seek to ensure all representatives and stakeholders from a region are invited to the discussions in the process. Ensuring diversity of opinion and representation is a task required of the manager organising and facilitating the planning session. Once stakeholders with differing interests are at the table, the tool empowers them to demonstrate their ideas and experience without the need for domain-specific knowledge. During the case study and previous usability testing sessions participants were observed using the tool to support their talking points and engage with others around the table.

6.5.3.7 Is driven by a purpose and task that are real, practical, and shared by the group.

A limitation of this case study was the use of a quasi-real pest species. The fake species allowed an understanding of how an interactive pest management tool, like the one trialled, could support the decision-making process. Had a real species been used the experienced planners would have brought their existing strategies forward and the associated internal politics of the planning. Although an evaluation with a real species is an important step in the research process, it was important to develop an understanding of how interactive tools change the pest management process. Further research should investigate their use on real, existing pests in a cautious manner, to ensure existing divides or difficulties between planners are not exacerbated. The scenario used, however, was based on the new incursions of Miconia calvescens and helped develop an understanding of how interactive tools can change the pest planning process.

6.5.4 Future Works

The experienced planners expressed that this interactive tool could provide substantial value to their decision-making processes. They identified that the tool would serve to assist them in building consensus amongst participants, engaging uncooperative landholders and educating people on the importance of early intervention. A number of design components were identified for further work, to prepare the tool for use in real scenarios and extend into broader land management scenarios. A list of the future work identified throughout this session is presented as bullet points below.

- Allowing planners to modify the costs associated with different actions in their local region.
- Allowing experts/planning managers to tweak model parameters, that would enable validation of the model to be conducted and shorter periods used for planning.
- Allowing stakeholders to easily import their own datasets.
- Creating reports and easy export of simulations and data.
- Deleting and modifying management objectives on the map has consistently been a problem and needs to be streamlined.
- More interactive pens or a capacitive touch screen to prevent the interaction device being a means of group members maintaining power.

6.5.5 Summary

This section reported the findings of a case study looking at the pest management planning tool developed in this thesis. A group of six experienced pest management planners were given training and tasked with planning around a pest management scenario. The scenario had a restrictive budget and challenged the participants to develop a strategy for managing the pests. A focus group was conducted with the experienced planners after the scenario was completed. Planners expressed that the tool would be beneficial in supporting their pest management planning process provided it worked with their existing data, and the dispersal model could be validated with past observations.

An evaluation of the pest management planning tool was conducted using the framework for the evaluation of consensus building tools developed by Innes and Booher (1999). The evaluation showed that tools like this would provide advantages over the existing pest management planning process in six of the seven categories. The remaining category was not improved upon and relied on the quality of the manager involved in the process. This section has shown that interactive decision support tools do have a place in pest management planning and offer the potential for improving the consensus building process.

6.6 Chapter Summary

This chapter continued the development of the pest management planning tool started in Chapter 5. A series of usability testing sessions were conducted to observe the prototype being used by potential end users. Findings from the usability testing sessions were integrated back into the prototype to improve its reliability and ensure it would support the pest management planning process. A case study was conducted with a group of experienced pest managers, who were excited to conduct a scenario around a quasi-real species. A summary of the findings are presented below:

- The usability analysis sessions found a series of cases where the tool would behave unexpectedly or did not provide the specific information planners needed. These were addressed in the next iterations of the prototype.

- Throughout each of the sessions the participants successfully defined management objectives, ran the dispersal simulation and continued in an iterative manner to improve their initial strategies.
- The experienced pest management planners successfully used the tool to develop and refine a pest management plan around an emerging quasi-real pest.
- The planners expressed their interest in using an interactive tool like this to conduct their day-to-day planning. However, a series of requirements must be met (described in Section 6.5.2.4 on page 205).
- The interactive planning tool developed in this research project improved upon six of the seven criteria for consensus building tools defined by (Innes and Booher, 1999) when compared to the existing planning process (described in Section 6.5.3 on page 206).

Chapter 7

Discussion

Chapter Overview

This chapter provides a summary of the findings of this thesis and explores the implications of these findings to pest management.

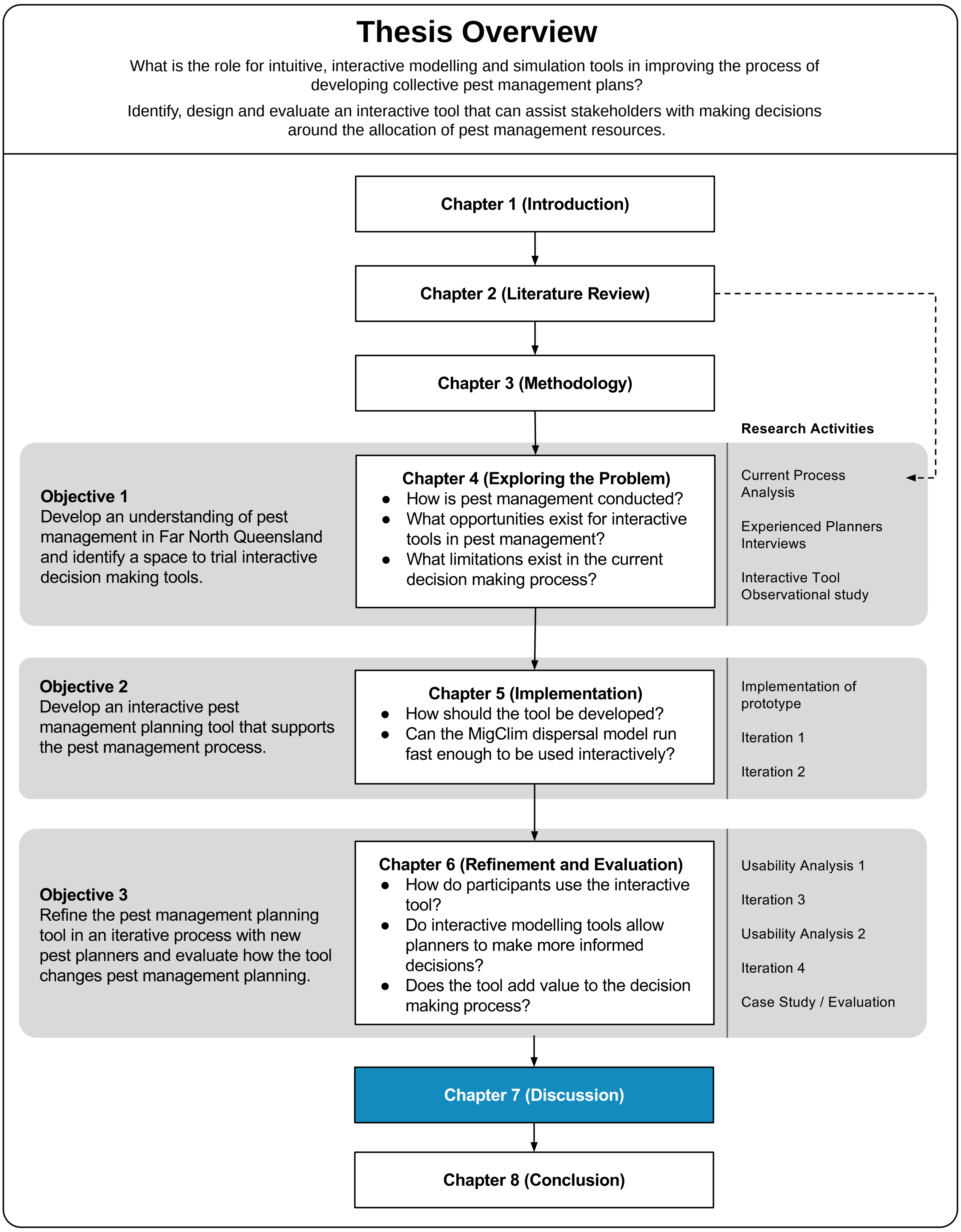

Figure 7.1: Diagram showing the order of research activities presented in this thesis. The blue highlight illustrates the current position in the thesis.

7.1 Introduction

This thesis sought to explore the opportunity for collaborative and interactive technology to assist pest managers in making informed decisions about allocation of their resources. Experienced pest managers were interviewed to uncover their experiences with pest management planning and help shape the design of the tool. An interactive decision support tool was developed that enabled stakeholders to simulate and compare the effectiveness of different management objectives. To establish the feasibility of applying collaborative and interactive tools to pest management planning an evaluation was conducted with experienced planners from the region using a case study based on a quasi-real species. The evaluation of the decision support tool, presented in Chapter 6, shows that interactive tools can facilitate decision making by providing estimates of work and costs, by showing cause and effect, and by encouraging collaboration amongst stakeholders. In this chapter, a summary of the findings is presented highlighting the benefits of using interactive tools for pest management planning. Finally, I discuss the implications of the findings of this study for pest managers and interactive decision support tool designers.

7.2 Summary of Findings

There were a number of findings throughout the development and evaluation of the interactive pest management tool. This section highlights the key findings of this thesis.

- Interactive decision support tools in pest management planning allow stakeholders to ask questions and experiment with different ideas.
- Interactive decision support tools encourage users to reach a consensus before moving forward. The simulations inspire participants to consider the larger picture by showing the consequences of inaction.
- Interactive decision support tools can enable the use of scientific modelling where it may have previously been difficult too use. The reduced complexity of using the models with an intuitive user interface makes it ideal for use in day-to-day pest management decision making.

- Approaches to pest management planning can use interactive decision support tools in their existing working groups and forums.
- Planners wanted to use the decision support tool for additional activities, such as: engaging uninformed or uninterested landholders; demonstrating different management approaches to the community; collecting local knowledge from remote locations; and developing budget proposals.
- New audiences for participation can be reached with persuasive and interactive visualisation.
  - Inexperienced participants are able to interact with a scientific model that would have previously been too technically challenging for them to use.
  - Inexperienced participants are able to understand the consequences of their actions and quickly find new strategies for controlling pests.
- Experienced pest management planners who had not previously used dispersal modelling were able to start running dispersal models within a few minutes.

7.3 Implications of the Findings

The findings above have a number of implications for pest management planning which are discussed below.

7.3.1 Enables Non-Experts to Use Scientific Models

This thesis has effectively demonstrated that scientific modelling of invasive pest species can be used by experienced pest planners with no previous modelling experience as well as non-expert stakeholders (see Section 6.1 on page 165 and 6.3 on page 178). One of the drawbacks of conventional species modelling is that domain expertise is often required to configure and visualise the outputs of the model. In the approach presented here, the software automates all of the visualisation and analysis of the model outputs. Furthermore, the model can easily be pre-configured for the specific species the planners wish to explore in their working groups. Persuasive tools like this will be useful for planners in engaging previously uninformed or uninterested stakeholders. This approach will enable planners to more readily conduct dispersal simulations in pest management working groups.

However, it is important that the application of interactive modelling and decision support tools communicate the correct message to the non-expert users. In the past, the uses of distribution and dispersal models have received criticism for the way conclusions were drawn from data that did not represent the initial questions being asked (Araújo and Peterson, 2012). Distribution models can misrepresent a species by over or under-predicting its range when limited or incorrect data is provided. Therefore, the outputs must be viewed in the context of the data used to build the model. Furthermore, dispersal models are based on probabilities and often do not account for freak weather events, natural disasters or unexpected human activity. For interactive models to be used effectively, it is key that non-experienced users understand the outcome of the model presents a probable scenario and not a certain future reality.

7.3.2 Reducing the Time for Scientific Models to Inform Pest Management Planning

During the development of the pest management decision support tool, several optimisations were made to improve the MigClim dispersal model. The modifications to the model have made it substantially faster when running simulations with a single habitat suitability layer. Additionally, dispersal simulations could be run in parallel aggregating the dispersal steps in memory. This reduced the time required to manually combine all of the written dispersal steps at the completion of the model run. Furthermore, the model now supports the use of compressed GeoTIFF files for reading in and writing out data. This substantially reduced the disk space required for large modelling jobs. Optimisations made in this thesis can be contributed back to the open-source community and incorporated into the production MigClim dispersal model.

One of the major limitations to running dispersal modelling in pest management planning sessions is the time it takes for the input files to be created, converted, run through the model and then visualised. The interactive tool developed in this thesis automates all of this process. The participants simply define and modify the pest populations and the management objectives and hit the run button. The data defined by the participants is converted modelled and then visualised as an animation that can be played back like a video.

Improvements to the model and automation of the modelling and visualisation process substantially reduced the time it would conventionally take to run modelling in planning workshops. During the case study (see Section 6.5 on page 193) and earlier usability testing sessions participants were observed performing new model runs every few minutes to test new approaches and strategies they had come up with. This improvement will enable planners and stakeholders to spend more time focussing on discussions around pest strategies and the incorporation of local knowledge into the process instead of waiting for models to be configured and run. Furthermore, this tool provides an analytical method, which has not previously been available, for assessing strategies during the working groups.

7.3.3 Increases the Effectiveness of Integrated Pest Management Planning

Pest management planning relies on planners and stakeholders being able to prioritise and target their resources. These decisions are often made without full regard for the broader implications across the region. Pests are often constrained to their suitable habitat which may be made up of large patches connected by corridors. These corridors present opportunities for pest managers to contain species with the support of natural barriers. The decision support tool developed in this thesis allows planners to gain an understanding of how pest species disperse across the landscape. Visualising the dispersal of a species enables planners to identify areas that intervention could be most effective. Furthermore, planners can experiment with different strategies and visualise how these strategies are likely to affect the pest species before implementing them in the real world.

Pest weeds can disperse long distances by wind, animals or human activity. Similarly, some pest animals can cover large distances in short spaces of time. The prevention of these species from invading an area is often reliant on the prevention efforts were undertaken in the surrounding areas. Burnett (2006) explored the financial incentives of collaboration between regions, arguing that transparent prevention costs would encourage other areas to invest in their own prevention actions. The decision support tool developed in this project can be used not only to highlight costs of prevention in particular regions but also to demonstrate the consequence of in-action in regions that are failing to invest in control efforts. The landholder or representative from each property or area can experiment with different strategies and understand how control actions on their properties influence the wider region.

7.3.4 Increase the Planning Capabilities for Areawide Pest Management

Areawide pest management is conducted across large areas that are often owned by numerous landholders and organisations. Frequently, uninterested or uninformed landholders will be involved in the pest management planning processes. By using interactive decision support tools, planners can engage those landholders that may not have previously been involved. The tool developed in this thesis demonstrated the ability for pest species to be modelled across large areas in during working groups without the need to reconvene. First-time planners were observed during the usability analysis sessions (see Section 6.1 on page 165 and 6.3 on page 178) defining their own plans and adapting them as they progressed. This approach enables participants, who may have no experience with pest management, to experiment and learn at their own pace. These types of interactive decisions support tools present an opportunity for planners to educate and engage more people in the management process.

7.3.5 Collecting and Working With Local Knowledge

Collectively landholders have a wealth of knowledge and firsthand experience about their properties and the surrounding environment (Bosch, 1996). This knowledge is invaluable to pest management planning and ensures plans accurately reflect both local values and the local environment. Interactive pest management decision support tools, like the one developed in this thesis, can help achieve the aim of incorporating local knowledge into the pest management planning process. The design of the tool allows local residents to include known pest populations into the modelling process during the session. New populations (along with the persons name) can sipmly be drawn onto the map to be incorporated into the planning session. Up until now, working groups have used pre-run models that are not capable of incorporating new information during the session. These working groups are then forced to either develop strategies around information that does not fully reflect the knowledge or re-convene at a later date once models have been updated with local knowledge collected during the previous session. This new approach ensures that local views, values and knowledge is captured and involved instantaneously in the planning process which will help ensure pest management plans reflect these local values and increase the probability of success over the long term Knight et al. (2008).

7.3.6 Engaging Those Who Implement Plans

Developing effective pest management plans is only a small part of the pest management problem. Plans must be implemented for them to have any impact. In areawide pest management, plans are implemented by large groups of stakeholders made up of landholders and organisations. The planner's role in the pest management process is to encourage the majority of stakeholders to undertake recommended the control techniques (Allen et al., 2001). Weak links in the management chain can quickly render control programs ineffective (Florec et al., 2013). The interactive tool developed in this thesis demonstrated to stakeholders the consequences of inaction in regards to a pest species. The visualisation clearly showed how one landowner's problem could quickly become the whole region's problem. Interactive decision support tools can play an important role in educating stakeholders and encouraging engagement of previously uncommitted stakeholders. Furthermore, the visualisation of consequences of inaction may encourage communities to cooperate with each other, before their neighbour's problem becomes their problem.

7.3.7 Encourages Consensus Building

Areawide pest management requires the input and contribution of a number of different stakeholders. Each stakeholder is an integral part of the implementation of pest management plans. Once stakeholders are engaged in the pest management process, it is important they form a consensus regarding pest management actions. This consensus ensures that the control mechanisms are as effective as possible and any disagreements on methods and timing do not cause gaps in the plan. During the case study (see Section 6.5.2.4 on page 203) the experienced planners highlighted their past experiences where groups had not built shared plans and thus rendering their control mechanisms ineffective. They wanted to include this decision support tool into their working groups to demonstrate to other collaborators the importance of a collective shared plan. Future tools could assign specific management actions to stakeholders in the planning meeting and allow them to directly watch the impact their actions could have on the other stakeholders present in the group. This approach would help ensure that all stakeholders have a clear picture of the work required of them and the benefits of working as a collective group.

7.3.8 Engaging Remote Stakeholders

Effective pest management requires the participation and consensus-building of multiple neighbouring stakeholders and planners. Organising these groups between busy stakeholders and planners is a complex process, especially when stakeholders may have other duties or need to travel large distances to participate. The pest management tool described in this thesis was developed as a web tool that can be remotely accessed. Planners can use this tool to remotely conduct pest management planning. This would enable busy or uninterested stakeholders who may not have taken the time to be involved in the process to contribute to the planning in their own time. The approach developed in this thesis could extend beyond large planning activities into day-to-day pest management decision making.

7.3.9 Demonstrating a Need for Funding

Pest management is an expensive and time-consuming process. Often many of the relevant pest management organisations and sections of local councils need to either apply for funding or seek funds within their own organisation's budgets. Justifying expenditure for pest management can be difficult for a species with a limited range and/or population that may not be presently impacting the local community. However, these early stages of new incursions are when pest control techniques can be most effective and most economical. During the case study (see Section 6.5.2.3 on page 201), the participants highlighted the need for new tools, like the prototype developed in this thesis, to help them justify their management actions and their spending. The tool developed in this thesis could enable pest managers to develop budget proposals based on required management actions for a species. A number of strategies could then be compiled that demonstrate the positive outcomes of various management actions within thier required funding.

Chapter 8

Conclusion

Decision support tools and collaborative approaches for pest management planning have been evolving over a long time. Current and previous methods have used paper maps, pens, complicated GIS software and models that are often only used by researchers. These approaches have sought to empower stakeholders and democratise the process to improve the quality and acceptance of pest management plans. However, these approaches do not always allow the vast majority of non expert stakeholders to contribute in a meaningful way. Furthermore, decisions are often limited by the knowledge of the stakeholders in a particular planning meeting. To improve the analytical ability of pest management working groups and empower non-expert stakeholders this thesis asked, "*What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?*".

To solve this problem, this thesis proposed the use of interactive decision support software and collaborative technology to pest management decision making to enhance the existing processes and tools available to planners. Experienced planners and operators in the pest management arena were engaged to develop an understanding of the problems they faced - described in Chapter 4. The budget available to stakeholders, cooperation with other stakeholders and resource targeting were identified as the major limitations in the existing process. Relationships between neighbouring stakeholder groups are often tense, each with their own objectives and often with little respect for other groups. A new interactive tool was devised based around a dispersal model that could simulate different management strategies. The proposed tool could integrate into the existing pest working group setting to support stakeholders in developing a consensus through an informed decision-making process.

To demonstrate the feasibility of the tool proposed in Chapter 4, an implementation was developed - described in Chapter 5. The pest management tool was designed to be used on a large collaborative touch sensitive displays and allows users to define management objectives onto a map. This pest management strategy could be run through an enhanced version of the MigClim dispersal model. Management objectives interact with the dispersal of the species, as they would in the real world, allowing simulations of different pest management strategies to be developed. The associated work and costs to implement a strategy were calculated from the dispersal model to assist planners in their allocation of resources.

The implementation was refined over five iterations of the pest planning tool. Usability analyses were conducted with the second and third prototype to identify unexpected behaviour, bugs and conceptual problems. Participants that were observed interacting with the planning tool were hesitant at first, and any confidence they gained was easily damaged by any unanticipated behaviour of the tool. A number of interaction issues were discovered that made the software difficult to use and in some cases impossible to complete tasks with. All of the identified interaction issues, unexpected behaviour and conceptual problems were addressed and corrected throughout this process.

To assess the value and utility of an interactive, collaborative decision support tool in the pest management arena a scenario and focus group was conducted with experienced planners from the study region of Far North Queensland - described in Chapter 6. Participants were given 20 minutes of training and asked to develop a pest management plan based on a scenario of an artificial species with the same dispersal mechanism, characteristics and initial distribution as *Miconia calvescens*. The group worked together making jokes along the way and supporting each other with light-hearted humour when mistakes were made. Some members were more dominant and vocal than others. However, this did not impede the more introverted members from expressing their views. A focus group was conducted immediately after the scenario to gather additional comments and feedback. The group could see this tool being used as a part of their pest management tool-kit as long as it functioned well with their existing data, allowed easy modification of the costs of work and could export the outcomes.

8.1 Contributions

Due to their difficulty of use and time-consuming nature, model-based decision support tools are not a regular part of most pest management decisions. This thesis detailed the experimental work that was undertaken to answer the overarching research question: *"What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?"*. This thesis made four main contributions to the body of pest management literature.

8.1.1 Demonstrated that Interactive Tools Can Provide Value to the Planning Process

An interactive pest management decision support tool was developed to assist planers in allocating resources in collaborative groups. An interactive visualisation tool was built around the MigClim dispersal model and used an interactive projector for participants to collaborate on building strategies. The tool was designed to operate in conventional pest management working groups and support the decision-making process by enabling stakeholders to define, test, evaluate and redefine their strategies. Two Usability testing sessions were conducted to evaluate the tool with first-time planners, and a third session involving a scenario with experienced pest planners was conducted to evaluate the tool. Participants defined the pest management objectives in the same manner as observed in conventional working groups. However, the participants actively used the dispersal model to test the objectives they had defined on the map. These findings showed that interactive decision support tools can be applied to the pest management planning processes and enable pest planners to evaluate their strategies against scientific models.

One of the limitations in the findings of this thesis was that the value interactive planning provides was unknown. Assessing the true impact of a new pest management approach typically requires a long term study to fully understand the social, economic, agricultural and environmental implications. However, the evaluation conducted at the conclusion of the focus group did in fact demonstrate that the interactive planning approach does improve on a number of key attributes that make good consensus building and decision support tools. Some of these findings include: participants actively engaged in the modelling of their strategies; poor or biased strategies became very evident to the group; it encouraged engagement and demonstrated the benefits of collaboration; and it incorporated scientific models into the planning that would not normally be used.

The results from these research activities showed that interactive planning tools do have potential in the future of pest management planning. Furthermore, all of the experienced planners involved in the development and evaluation of the tool highlighted that there was a real need for new tools to better inform the decision-making process and incorporate more local knowledge. Tools were also required that could demonstrate the need for engagement of uninterested and uninformed stakeholders. This research has clearly demonstrated that interactive planning tools have a role to play in improving the decision-making capabilities of pest management planners.

8.1.2 Showed Interactive and Collaborative Decision Support Tools can be Easily Applied to Pest Management Planning

The interactive pest management planning tool developed in this thesis demonstrated how interactive technology can be applied pest management decision making. A large number of scientific models and tools already exist that have huge potential when applied to pest management. However, the majority of these tools are not designed to be used by non-experts. Often, the only limitation in using these tools in pest management is the user interface. Planners need tools that are automated so they can focus on running the working groups and solving pest management problems. Large amounts of local knowledge, ideas and perspectives needs to be incorporated by planners and is often only manually recorded. Any tools that add value to pest working groups, forums or education sessions and can be applied to assist with decision making are desperately needed by pest managers.

This thesis has shown how an intuitive pest management planning tool can be easily applied to pest management planning. The tool was designed with a thorough understanding of the theoretical and practical pest management planning process. Potential end users were engaged in the development process to ensure it was practical and it supported their problem-solving processes and planning strategies. The solid focus on assisting planners in solving pest problems while designing the tool, allowed the prototype to easily integrate into the existing working groups. New tools are needed and if they support the problem solving they will be quickly adopted by pest management planners.

8.1.3 Implications and Design Considerations

This thesis identified and collected information on the potential implications for new interactive decision support tools in pest management planning. Authors identified in the literature have advocated for a new range of pest management planning tools that engaged stakeholders, sought out new information, and informed decision making (Sydes and Murphy, 2014; Furst et al., 2014). This thesis extended on some of these ideas and found new implications in the development of this tool. For instance, the evaluation of this tool highlighted that interactive visualisation approaches could assist in building consensus by demonstrating the consequence of inaction (see Section 6.5 on page 193). Furthermore, these tools could help everyday planners identify existing corridors between areas of suitable habitat of pest species, which could be exploited.

Beyond the implications for pest management, this thesis described a number of design considerations that need to be made when developing interactive pest management planning tools. The tool developed in this thesis went through five iterations, each a major improvement over the last regarding usability and ease of use. These insights into the design can be applied to improve the usability of new interactive land management tools.

8.1.4 Improved the Runtime of a Widely Used Dispersal Model

During the development of the pest management decision support tool, a number of optimisations were made to the MigClim dispersal model. These contributions improved the run time of the model, allowed the model to aggregate dispersal steps in parallel and use compressed GeoTIFF files as source and output datasets. The modifications were evaluated in Chapter 5 to verify that they did not break the statistical nature of the model.

The improved model can now be contributed back to the community to be of benefit to other projects.

8.2 Future Work

Throughout this research project, additional needs of pest management planners were identified. To help advance improved working solutions within the pest management framework and extend or complement the work completed in this thesis, a number of features still require development or further research, as outlined below.

8.2.1 Community Engagement and Education

Within the pest management arena, there are only a few examples of easy to use public education and communication tools. There are, however, a number of existing tools in similar fields such as climate change impacts, disaster preparation (Mathiesen et al., 2016), landscape planning and conservation. Applying similar interactive concepts to pest management could enable stakeholders and the community to develop a better understanding of pests.

8.2.2 Connected Ecosystem

There are numerous data collection and reporting tools available in the iOS and Android app stores for pest management planning. New methods for easy digital data collection are appearing everyday, including drones, connected farm vehicles, and IoT sensors. Collection tools that allow data access via APIs could allow new pest population reports to stream into the system in real time. Data could be imported seamlessly from the users perspective, alleviating the challenges participants already have in combining datasets (See 4.2.4.2 on page 101).. A future planning tool could integrate with autonomous drones to remotely survey areas during pest planning sessions, which would enable planners to determine survey areas and respond to findings in as single session. The automation of this process could massively simplify the current challenges in invasive species management.

8.2.3 Multiple Species

This thesis focussed on the prioritisation and allocation of resources for a single species. However, rarely do managers have the luxury of dealing with only one species. Pest species often have overlapping distributions and habitats which present opportunities for combined strategies that could reduce the costly expense of time spent travelling to and accessing remote areas for one weed at a time. However, management of additional species can also present a more complex challenge in resource allocation. Communicating the potential benefits and related costs to stakeholders tasked with making the final decisions can often be a challenging task. One approach could be to use an optimisation algorithm which could make spatial decisions for the stakeholder based on economic objectives agreed upon by all parties.

8.2.4 Integrating Optimisation Model with Human Stakeholders

Decisions about the allocation of resources using the tool developed in this project rely solely on the judgement of the stakeholders involved in the process. This thesis focussed on communication and assisting stakeholders in reaching consensus and making more informed decisions. The future of interactive planning tools like the one developed here lies in the merging of optimisation algorithms and the knowledge and creative thinking skills of people. Fields using computational fluid dynamics (see 2.5.1.5 on page 42) to develop aerodynamic vehicles, aeroplanes and housing have excelled in the merger of the two, integrating scientific principles with design. Models of scientific principles help shape the designs of the car, but ultimately, the designer has final control over the shape, making compromises between aesthetic form and fuel economy. Further work could investigate how existing optimisation algorithms can be integrated into the pest management planning process while still allowing stakeholders to control the outcome.

8.2.5 Just Ship it and Improve it Later

There is much research potential in continuing the work started in this thesis, as suggested by the findings of Chapter 4, which established that planners are desperate for new interactive and collaborative tools in the pest management planning in order assist them to engage communities and to incorporate large volumes of data. Although research projects into interactive decision support tools often result in the outcome of new tools for problem-solving, development often does not continue beyond the conclusion of the project. Without ongoing maintenance and development to keep up with ever-changing standards, in a short space of time a large number of these tools cannot solve the problems they sought to. The tool built in this thesis needs to transition from a research prototype to a commercial or open source project to have any impact on pest management planning. By transitioning into a product, further evaluation, research and improvement of the tool could be simplified with a much larger user base capable of contributing vast amounts of usability feedback and project outcomes.

8.3 Summary

This thesis contributes to advancing the field of pest management and the design of interactive decision support tools for making decisions about land use management. It answered the question, "*What is the role for intuitive, interactive modelling and simulation tools in improving the process of developing collective pest management plans?*". A new type of pest management decision support tool was built to evaluate this question giving stakeholders the ability to spatially define, review and improve their management objectives in a collaborative space. It demonstrated that scientific modelling for spatial decision making does not have to be difficult to use or require domain specific knowledge. Furthermore throughout the usability testing sessions and final case study the inexperienced and experienced planners were observed experimenting and revising their objectives.

A further finding throughout this project was that the interactive decision support tool had applications beyond those initially envisioned. Experienced planners involved in case study noted the potential for these types of tools to be used for engaging their communities, demonstrating the consequence of inaction, creating budget proposals and incorporating vast amounts of local knowledge. These findings clearly demonstrate a need for new tools to assist pest managers in developing pest management plans.

This thesis shows that interactive modelling and simulation tools do have a role to play in improving the process of collective pest management planning. The findings contribute to advancing the field of pest management and the design of interactive decision support tools for enhancing the quality of decisions, developing funding proposals, engaging community members and communicating the significance of taking action. In general, this thesis has shown that the modelling tools previously only used by researchers and experts can be made more accessible to the wider community.

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Legislation

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Chapter 9

Appendices

9.1 Iteration 5 - Post Real World Testing Improvements

The fifth iteration is an addendum to the research project based on a hunch while preparing for the final focus group. This iteration was simply a change to the file format the MigClim was using to read and write data. It reduced the dispersal model wait time substantially and was thus included in the thesis. This iteration used GeoTIFF as the data format for MigClim instead of ASCI Grid files. The implementation of the GeoTIFF format improved the write performance and reduced the storage space requirements by using compression.

9.1.1 Changing Data Formats to Increase Performance

One of the largest bottlenecks in the model running is the need to read and write input data and output data to disk. This limitation is a result of the different software packages being used to store, process model and render the data being unable to communicate directly with one another. Ideally all of the services would perform operations on data in memory and pass them off to the next stage. However not all of the software used in this process would allow this to take place and would require a custom implementation. Given the time constraints in this research project this is not feasible and as this section will show unnecessary.

MigClim uses AAIGrid files or R Data Frames as its input and output data formats. As this project has deviated from using R to run the model and is instead using a standalone executable, it is impractical to use the dataframes as an input format. This leaves AAIGrid as the only format available for use in the modified version of MigClim with this project.

While AAIGrid has advantages as a data format in its simplicity of implementation, it does not support compression in the file. The lack of compression results in the AAIGrid files being up to several orders of magnitude larger stored on disk compared to formats supporting compression. File size also limits the speed at which the AAIGrid files can be read and written to disk.

GeoTIFF is a descendant of TIFF, containing geographic parameters in the TIFF metadata. The GDAL libraries support the GeoTIFF format with several types of in file compression and non sequential file writing. The compression.

Preparing data to load into the model is expensive due to the required conversion between file formats. When the user clicks the run button the management actions are exported from the database into a GeoTIFF file. It can't be written directly to an AAIgrid file with GDAL as the gdal command requires a data format that supports... The GeoTIFF file is then translated to an ASCII grid file to be imported into the model.

To get data from the model to the user interface, it has to be rendered into a format supported by open layers using map server (see section). Dispersal model output is saved out to disk as an AAIGrid file and rendered by Map Server as it is requested by the user interface. While we would typically see each dispersal step being complete in 0.5s it would take an additional ~0.9s for the write thread to write the output AAIGrid file to ram disk. This represents a significant proportion of the time spent running the model. To improve this the model was setup to write GeoTIFF files out.

GeoTIFF support was added to the model for reading and writing raster layers. It reduced the pre-processing time from 11 seconds down to 1.5 seconds. The write time was also improved from an average of 0.9s to 0.1s. The improvements in run-time of the model made a substantial difference to the load time in the front end. When the run button is pressed, the loading bar is shown for a much shorter period before data starts streaming back. Due to the improvements in write performance, the new model outputs were ready faster than the user interface could handle them.

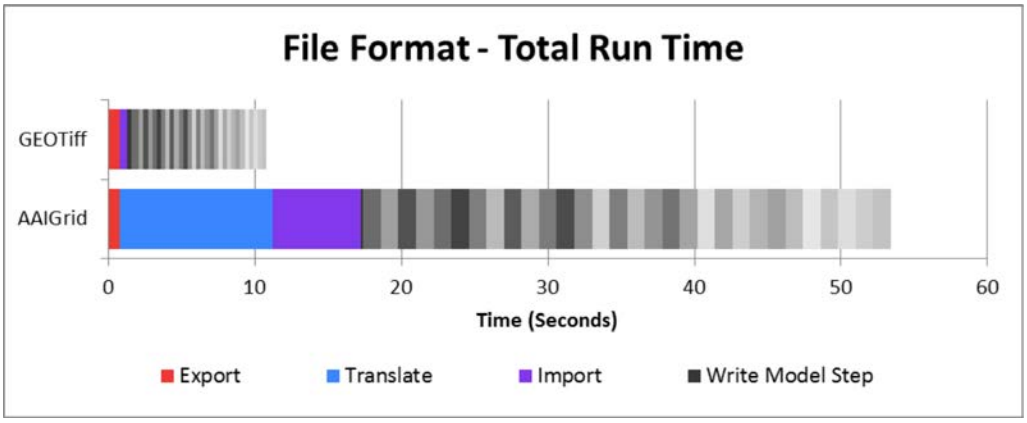

Figure 9.1: AAIGrid vs GeoTIFF total modelling time. The grey stripes represent each frame of the dispersal simulation being displayed in the user interface.

9.2 Information Sheets

9.2.1 Interview Recruitment

Hi <name>,

I was directed to you as suitable candidate for my research project looking at building interactive easy-to-use technology to assist with weed and pest management. If you are available, I'd like to sit down and conduct a short interview in the next few weeks to understand your perspective and involvement in the process of managing pests and weeds. It won't involve anything technical and will just be a discussion around your experiences with the management of pests and weeds.

I've attached more details below about the project.
To take part, you can just respond to this email and we can organise a time.

Thanks!

Kind Regards,
Dylan Mathiesen

Your Help Required - JCU Research Project

We are looking for farmers, land owners, industry representatives and managers engaged in pest and weed management in North Queensland to help us develop a new type of decision support tool.

Designing a Pest Management Tool

This tool will assist in prioritising resource allocation for the management of pests and weeds. It follows the same principles that are used when designing a household budget, targeting resources to essentials and preventative maintenance to minimise expenditure and maximise the benefit over the long term. We need your help in identifying the priorities and understanding how you go about managing pests and weeds on your property, in your community and across the region. With this we will be able to start developing a tool that can capture your knowledge and give you more say in the planning and management process.

Take part in the study
You don’t need to be technically inclined and all we need is an hour of your time to have a chat. Count me in! »

Things we are interested in

- Do you manage pests and weeds as part of your business, lifestyle or community?
- How do you plan what to do and when to do it?
- Are you involved with any groups that tackle weed or pest management?
- Are there ways easy-to-use technology can help you plan and communicate?

The Researcher

My name is Dylan Mathiesen, I'm in the third year of my PhD undertaking research to improve the communication between policy makers and stakeholders looking at weed and pest management through technology.

The Research Project

The major outcome of this project is the development of a software tool that captures local knowledge from different stakeholder groups around the management of pests and weeds. I have developed new software that allows community members, who may not be experts in pests and weeds or modelling tools, to run simulations identical to those that researchers use to experiment with different management strategies. This is all done in a fully immersive and interactive experience, combining new technologies in a simple and easy to use manner. The end result will be increased community involvement, and more informed pest and weed management strategies for you and the community.

Your insights are needed to ensure we develop a decision support tool that is easy to use and can represent the needs of all the different stakeholder groups involved.

Requirements

- Involved or interested in managing Pests (on your property or in your community)
- Are a farmer, land owner, industry representative, manager involved in pest management, conservationist, or hold any other stake in the process

Interview Details

Duration: <1hr

Date: 14th July - 18th July

The interviews will run for no more than an hour and involve you having a discussion with the researcher around your experiences with pests and the management processes around them. The interviews will be audio taped to ensure I fully understand your views and opinions. Recordings will not be made available to any other party. Findings from these interviews will be de-identified and used as part of my PhD Thesis.

Help us out - Take part in the study
You don't need to be technically inclined and all we need is an hour of your time to have a chat. Count me in! »

Contact Info

Dylan Mathiesen

Information Technology, College of Law, Business and Governance, James Cook University

Phone: 04**xxxxxxxx**
Email: dylan.mathiesen@my .jcu.edu.au

9.2.2 Interview, Usability Analysis and Focus Group Information Sheet

(Next Page)

INFORMATION SHEET

Pest Management Strategy planning Tool

You are invited to take part in a research project that aims to build a tool to aid in building pest management strategies. The study is being conducted by **Dylan Mathiesen** and will contribute towards his PhD project at James Cook University.

If you agree to be involved in the study, you will be invited to take part in one or more of:

Pest management Interviews – The interviews will run for approximately one hour and involve you being involved in a discussion with the researcher around your experiences with the pest management process. The interviews will be recorded (audio only) for later analysis.

Weed strategy planning sessions – The sessions will run for 2-4 hours and involve you working as a group to develop a strategy for managing pests in the Tablelands region. During the planning sessions you will be invited to give feedback on any parts of the process. Video recordings and recording of how you interact with the computer will be made during the sessions for further analysis of how you interact with the tool.

This study aims to

- Develop a system for capturing new information and to help inform management strategies in the design of pest management plans.
- To develop a technique for immediately integrating stakeholder knowledge into the planning process.
- To investigate different techniques of engaging users in the planning process.
- Establish a planning process that directly incorporates invasive modelling software to assist with decision making.

If you are prone to motion sickness or have any other medical issues that can be triggered by electronic displays you **must not** participate in this study.

Taking part in this study is completely voluntary and you can stop taking part in the study at any time without explanation or prejudice. You may also withdraw any unprocessed data from the study at any time.

If you know of others that might be interested in this study, please pass on this information sheet to them so they may contact me to volunteer for the study.

Your responses and contact details will be strictly confidential. The de-identified data from the study will be used, in the PhD thesis of Dylan Mathiesen to partially satisfy the criteria for receiving a PhD, and for publication in academic journals or academic conference proceedings. You will not be identified or have any identifiable information published in the results of this research.

Data collected, including video, audio and notes will be retained, for a minimum of 5 years from collection. Photographs may be taken to document how the system is setup and how users interact with it to ensure consistency in future studies and to develop better processes around the participants needs.

If you have any questions or concerns about this study, please contact Dylan Mathiesen**.**

Principal Investigator:
Dylan Mathiesen
School of Business
Discipline of IT
James Cook University
Email: dylan.mathiesen@my.jcu.edu.au

Supervisor:
Name: Dr Trina Myers
School of Business
Discipline of IT
James Cook University
Phone: 07 4781 6908
Mobile:
Email: trina.myers@jcu.edu.au

If you have any concerns regarding the ethical conduct of the study, please contact:
Human Ethics, Research Office
James Cook University, Townsville, Qld, 4811
Phone: (07) 4781 5011 (ethics@jcu.edu.au)

9.3 Interview Questions

9.3.1 Activity Notation Research Questions

- How does the Power to Enforce management support the management of pests by Council Pest Management Officers?
- How does the Pest Management Act influence the way the Pest Management Officers conduct the management of pests?
- How do the Landholders influence the way Council Pest Management Officers Manage pests?
- How does the Power to Enforce management affect the way Local Councils Manage Pests?
- How does the Pest Management Act affect the way the Local Council Manage Pests?
- How does the Landholders Responsibility affect the way the Local Council effectively Manages Pests?
- How do the Prioritisation tools influence the way the Pest Management Officers conduct the management of pests?
- How do Modelling tools influence the way Pest Management Officers conduct the management of pests?
- How does the use of non-expert input affect the way Local Council effectively manage pests?
- How does pest management information support the management of pests by land owners?
- How does the Pest Management Act influence the management of pests by landholders?
- How does the Council influence the way Landholders manage pests?

- How does the use of pest management information influence the way organisations / representative bodies manage pests?
- How does modelling support the management of pests by management officers?
- How does organisational objective and policy affect the management of pests by management officers?
- How does the focus on high value pests affect the way pests are managed by pest management officers?
- How does the use of the pest management act affect the way government organisations manage pests?

9.4 Focus Group Questions

These are the questions that to be asked in the focus group. The focus group took a semi structured approach and not all of the questions were asked directly as those topics naturally came up in discussion. These questions were simply areas to be explored and the questions served as follow up questions to probe with if topics weren't naturally discussed.

- Do you think the software would be useful in helping you plan to manage invasive species at your current scale?
  - Do you think this would help you coordinate with other local organisations or individuals?
  - Can people comment on areas they could see this tool used?
  - Would spin-off's of this targeting different areas be useful?
  - Did you feel that the tool accurately captured your thoughts and intentions?
  - Do you feel that the information it gave you was accurate or inaccurate?
  - Do you feel that the results from each simulation provided useful insights for planning around this species?

  - Did you feel that the costs accurately represent what you would see on the ground?
  - Did anyone learn anything new about the decision making process for pest management?

Technology

- How easy did you find it to use the technology?
  - Did you understand how to perform actions that you had in mind?
  - Did any parts of the processes seem more difficult than it should have been?
  - Were any parts of your thought process not captured by the tool?
  - Did anyone identify areas where they wanted information that they could not find?
  - Were there any stages that you felt frustrated at the tool?
- Were there times when the information presented was not useful?
- Were there areas that come to mind where information presented was useful?
- Was the tool missing anything that you think is essential to the process?
- Did the tool seem responsive enough for you to plan?

Technology Issues / Improvements

- Did anything seem broken in the tool or not function as you expected?
  - Did you have any issues clicking particular buttons or performing particular functions?
- Did anything seem to work particularly well?
- More broadly I'd like to ask if there were any further things people would like to add that I may have missed.
- Did anyone have any questions for me?

9.5 Focus Group Order

Teaching the participants to use the software was vital to ensuring engagement throughout the session and building user-comfort with the tool. A live demonstration of the software was undertaken to show how different functions of the tool worked. Each feature that would be used by the group was run through quickly in a scenario to show how they should be used within the context of a real planning situation.

- Ran through a pre-set scenario to familiarise the participants in the use of the software
- Ran through the reporting of a particular species:
  - Drawing new occurrences
  - Deleting occurrences
  - Modifying occurrences
  - Have group members report the presence of a species
  - Saving the changed species data
- Ran through implementing management actions:
  - Have group members implement a few different actions on different patches
  - Drawing actions
  - Deleting actions
- Ran the model:
  - How to run the model
  - Go through looking at the outcomes and costs of the model
  - Go through saving and running a new model
- Run through the Analysis page:
  - Describe the graphs and what they mean

9.6 Software

All of the software developed in this thesis is available under the Creative Commons 3.0 license. The software is available on GitHub and is archived on the Zenodo scientific data archive. The prototypes are tagged and marked as releases on GitHub to make them easier to identify. Each release has it's own associated DOI that can be used to reference the software developed in this thesis. The software uses a micro-architecture pattern and is developed across two different repositories. Each repository contains several services and components required to run the software. Although all of the code is available, I would recommend starting with the vagrant machine image of the latest version. If you wish to run older versions, downgrading the git repositories to previous release tags in the vagrant image should work as all the environmental dependencies are backwards compatible. However, setup and operation instructions for prior versions are non existent as the software was continually evolving.

To run the software out of the box, it is expected that your computer meets the following requirements. Although it may run on a computer that doesn't meet these requirements, it probably won't work well.

- Quad Core Processor
- 16GB Ram
- Running Virtual Box 3.x or later

9.6.1 Prototype 5

Although the past versions are available to be built form source, I suggest you just run it from this Vagrant image. The Prototype 5 Vagrant image with sample data is available on ...

The dispersal model and back-end code is available on GitHub and archived on Zenodo.

- https://github.com/pumped/dispm/releases/tag/v0.5
- https://doi.org/10.5281/zenodo.154135.

The user interface and front-end code is available on GitHub and archived on Zenodo.

- https://github.com/pumped/wema/releases/tag/v0.5
- https://doi.org/10.5281/zenodo.155252.

9.6.2 Prototype 4

The dispersal model and back-end code is available on GitHub and archived on Zenodo.

- https://github.com/pumped/dispm/releases/tag/v0.4
- https://doi.org/10.5281/zenodo.154136.

The user interface and front-end code is available on GitHub and archived on Zenodo.

- https://github.com/pumped/wema/releases/tag/v0.4
- https://doi.org/10.5281/zenodo.155253.

9.7 Testing Scripts

9.7.1 MigClim run-time comparison scripts

```
for i in {1..100}
do
  ./migOpt >> opt.csv
  echo "$i"
done

echo "Finished optimised";

for i in {1..100}
do
  ./migRegular >> regular.csv
  echo "$i"
done

echo "Finished regular";
```

9.7.2 MigClim raster comparison script

```
#generate initial manually
./migOpt
for j in {1..30}
do
  #add b -> a
  gdal_merge.py -o mig_mic_curr/$j.tif -createonly -init 0 mig_mic_curr/mig_mic_curr_step_101.asc -n 0 -co COMPRESS=DEFLATE
done

echo "completed setup"

#convert initial to tif

#for 1..100
for i in {1..100}
do
  echo "Run $i"
  #generate b
  ./migOpt

  echo "Compacting"
  for j in {1..30}
  do
    #add b -> a
    if [ 10 -gt $j ]
    then
      gdal_calc.py -A mig_mic_curr/$j.tif -B mig_mic_curr/mig_mic_curr_step_10$j.asc --outfile=mig_mic_curr/$j.tif --calc="A + (1 * (B>0))" --overwrite --co="COMPRESS=DEFLATE"
      rm mig_mic_curr/mig_mic_curr_step_10$j.asc
    else
      gdal_calc.py -A mig_mic_curr/$j.tif -B mig_mic_curr/mig_mic_curr_step_1$j.asc --outfile=mig_mic_curr/$j.tif --calc="A + (1 * (B>0))" --overwrite --co="COMPRESS=DEFLATE"
      rm mig_mic_curr/mig_mic_curr_step_1$j.asc
    fi

  done
done
```

9.7.3 MigClim Testing Configuration

```
nrRows 5045
nrCols 3084
iniDist dist_p
hsMap max_pre
rcThreshold 0
envChgSteps 1
dispSteps 30
dispDist 8
dispKernel 1 0.8 0.5 0.2 0.1 0.05 0.01 0.005
iniMatAge 5
fullMatAge 11
propaguleProd 0.1 0.2 0.3 0.5 0.7 0.9
lddFreq 0.1
lddMinDist 20
lddMaxDist 100
fullOutput false
replicateNb 1
simulName mig_mic_curr
```

Listing 9.1: MigClim Paramaters File

9.7.3