ADAPTNRM

Weeds and Climate Change:

Supporting weed management adaptation

TECHNICAL GUIDE by John K. Scott[1], Bruce L. Webber[1], Helen Murphy[2], Noboru Ota[3], Darren J. Kriticos[4], and Barton Loechel[5]

Front Cover:
Image: Cat's claw flowers, Source: Burnett-Mary Regional Group (BMRG). Photographer: Lalith Gunasekera

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CLIMATE CHANGE IN AUSTRALIA
IMPACTS & ADAPTATION INFORMATION FOR AUSTRALIA'S NRM REGIONS

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Example Boxes

Bottom: Image: Prickly Acacia, Aramac, Western Queensland. Source: Desert Channels Queensland.

Executive Summary

Weeds are one of the main threats to biodiversity and agriculture but under climate change, management of this threat will be an increasing challenge in two ways.

Firstly, the suite of weed species will change. Secondly, some weeds will become more invasive.

In this Technical Guide we synthesise impacts and adaptation information that is likely to be broadly applicable across much of Australia to assist NRM Groups with regional planning for weed management. The first part of the Technical Guide summarises research on weeds and climate change, while the second part outlines key elements to develop a vision, strategy and weed management plan, and weed management techniques in the context of climate change.

The main drivers for climate change impacts on weeds include increased temperatures, changed rainfall, increased CO_2 levels, more extreme weather, more frequent frosts, changed phenology and changed land use. The rate of response of invasive plants and weeds is expected to be faster than for other plants, including native species and crops. Secondly, climate change is likely to foster the appearance of a new set of weed species.

One of the main effects of climate change is its influence on species' distributions. There is extensive modelling of species distributions for southern Australia, mostly indicating a southern shift. There is a need for increased species modelling for central and northern Australia.

A major adaptation response to climate change is increased landscape connectivity, but this presents a major opportunity for increased weed invasion. Adaptation responses include quarantine and filtering methods to monitor species displacement.

The national level of biosecurity threat is not expected to increase with climate change. Instead, the main threat of species migration is from neighbouring regions in Australia.

Novel ecosystems are already a reality in the Australian environment. The new species assemblages due to changed distributions of both alien and native species will lead to the formation of novel ecosystems. A new management approach will be needed.

The Technical Guide develops an outline of the vision, strategy and weed management plan elements that are required to address climate change adaptation. The plan is also connected to other planning approaches such as asset based and resilience thinking.

Examples are given for adaptation responses for the main weed management techniques of quarantine barriers, eradication and containment, biological control, herbicides and other control methods. Examples are also given of maladaptation, that is, management responses to climate change that may prove to be detrimental.

The Technical Guide concludes with suggestions for strategic, research and communication needs. In addition, the Guide provides an extensive list of information sources, and data repositories of supporting materials and maps of use in developing a weed management plan adapted to climate change.

What to expect in this guide

SECTION 1

Weeds are one of the main threats to Australian agriculture and the environment. Their management remains a significant financial, logistical and research challenge. Climate change will require revisiting what we deem appropriate for weed control to keep current and future management strategies efficient and effective.

Below: *Image: Broom, Source: NRM South.*

1
What to expect in this guide

This module of the national NRM project delivers a summary of knowledge, processes and tools specifically targeted at NRM groups for climate adaptation planning for invasive plant species and weeds. This overview will be useful for guiding the management of existing weeds and likely future weeds as climate change continues to alter the world in which we live.

The module synthesises impacts and adaptation information that is likely to be broadly applicable across much of Australia to assist all NRM Groups. Some issues are likely to affect most if not all regions and those are the ones this Guide focuses on. Further, developing strategy and management approaches that flow from an understanding of national and state responsibilities can help regions better define their role and be more targeted and cost-effective with their own approaches. The module is also intended to complement regionally-focused projects that may address more specific needs for adaptation to weeds and climate change.

This Technical Guide is structured into two main parts: science and management. The first part (Sections 2 to 7) provides a summary of research on climate change and weeds (see Box 1 for information sources and supporting data), including:

- Background context to the weed problem in Australia and definition of terms used in the study of invasive species.
- An outline of the effects of climate change on plant physiology and ecology.
- The effect of important climate change variables for weeds: increased temperature, changed rainfall regimes and higher atmospheric carbon dioxide (CO_2) concentrations. These are linked to other aspects of environmental change, such as land use change, that influence weed management.
- A summary and examples of how weed modelling is done and how best to interpret the results. This is important because modelling the potential current and future distributions of weeds can provide essential guidance for management decisions.
- An outline of key challenges for weed managers considering climate change adaptation decisions in agriculture and biodiversity domains, such as changing agricultural practices, crop rotations and landscape connectivity to help protect native biodiversity.
- To conclude the research summary, we emphasise the importance of considering different temporal and spatial scales for making weed management decisions in a rapidly changing climate.

THIS TECHNICAL GUIDE

delivers a summary of knowledge, processes and tools to help NRM groups manage both existing and potential future weeds under climate change.

THE GUIDE PROVIDES

information broadly applicable across Australia and of value to all NRM regions. It is intended to complement regionally focused projects that address more specific needs.

THE FIRST PART

of this Technical Guide provides a summary of research on climate change and weeds (Sections 2 to 7).

THE SECOND PART

of the Technical Guide develops a framework for planning the management of weeds in the context of climate change (Sections 8 to 10).

BECAUSE THIS IS STILL AN EMERGING AREA OF SCIENCE

It is important to emphasise that, because this is still an emerging area of science and each NRM group's situation is different, this guide cannot provide all the information required to develop a weed strategy and management plan. Rather, it seeks to identify the important building blocks for such plans, raise key issues and questions that need to be considered, and points to some examples for possible answers.

HOW TO USE THIS GUIDE

The main body of text in the Guide provides the detailed information to inform and support adaptive weed planning.

THE SIDEBARS

(here) are useful in a number of ways. First, to provide quick summary points of ideas located in the main body of text. This is the main way the sidebars are used in the first (science/ research) part of the document.

Second, the sidebars are used to highlight key questions for NRM planners ('decision points') or suggested actions for planning ('action points') relevant to the information in the main body of text. This is the main way the sidebars are used in the second (management) sections of the document.

THE BREAKOUT BOXES

in this document are used to provide supporting information, such as definitions of key terms, links to useful resources such as weed distribution maps or weed plans produced by government agencies or other NRM groups, and practical examples of weed issues related to climate change.

THIS GUIDE

follows the AdaptNRM *'NRM Adaptation Checklist'*, which would also be helpful to read, as it provides a general framework for climate adaptation planning and decision-making for regional NRM groups.

The second part of the Technical Guide (Sections 8 to 10) develops a framework for planning the management of weeds in the context of climate change:

- We emphasise the requirement of a clear vision and strategy as the starting point to guide the development of a weed management plan.
- Options for adaptation of weed control methods are discussed followed by examples of 'maladaptation' (i.e. responses to climate change that may have unintended detrimental effects).
- We provide an example of a weed management planning framework and examples to illustrate relevant concepts, such as adaptation options for different levels of quarantine, eradication and containment.
- The management section concludes by identifying major gaps in our knowledge.

It is important to emphasise that there are a number of ways in which this guide can be used depending on where your NRM group sits on the journey of climate adapted weed management planning. For example, groups with a weed strategy that already includes climate change adaptation could use it to check that it covers core issues and aligns with your management options. Groups with a weed strategy that doesn't yet incorporate adaptation can use it to modify what you already do in terms of key planning steps such as assessment, planning, monitoring, etc. Groups who have not yet developed an explicit weed management strategy could use it to build one that incorporates climate change adaptation.

Good planning is iterative and flexible: while it's unlikely that you will produce the perfect plan the first time around, the key is to build on available knowledge, including the experiences of others, to produce something better the next time around. This guide, particularly the 'weed management planning' sections (8, 9 & 10), point to some key strategic and practical elements that if incorporated in your planning, will help you make a much greater impact than would otherwise be the case.

BOX 1

Supporting information on invasive plants and climate change

The supporting materials and information on invasive plants and climate change has been placed in the CSIRO data access portal *data.csiro.au/dap/*. Once logged into the site use the search facility to locate information ("invasive plant" works well). The data access site has the following information:

- Models of the potential distribution of weeds projected to current climates and future (2070) climate scenarios for Australia and the world. These projections were generated by the mechanistic modelling software, CLIMEX, using previously published parameters and were run with data for the CSIRO Mk3.5 GCM sourced from the CliMond archive (*www.climond.org/*). Individual model parameters, GIS data for the projections and relevant modelling technique references are provided. We encourage readers to consult the cited primary resources to understand more about the maps presented.

Further information sources, including distribution models for weeds, are listed in the supporting materials at the end of this Technical Guide.

Figure 1.
General components of weed management planning through an adaptation lens.

Step 1
Assessment

Under climate change, assessment may need to include:

- new weed threats from outside the region
- existing weed threats that may get worse
- new weed threats from changing land uses and other adaptation responses

Step 2
Strategy & Priorities

Under climate change, strategic planning and prioritisation may be different because:

- increasing number of potential weed problems may require stricter prioritisation to focus on weeds that impact what communities value
- priorities may need to shift substantially over time as new threats emerge
- increased coordination with national and state level strategies will be helpful for minimising regional effort

Step 3
Implementation Planning & Action

Under climate change, implementing weed management may need to be different because:

- the effectiveness of some forms of weed control is expected to decrease
- new weeds may need new forms of control
- control measures suitable for extreme events rather than average conditions may be a robust approach

Step 4
Monitoring

Under climate change, monitoring may need to be different because:

- a cost-effective approach may involve lots of monitoring for new threats rather than immediate management of any new species detected
- widespread monitoring for new threats could involve high levels of community engagement

Step 5
Reflection

Under climate change, reflection may need to be different because:

- it may need to happen more frequently to ensure new threats detected by monitoring can be acted on quickly

Right:
Image: Parthenium
Source: BMRG
Photographer: Lalith Gunasekera

Weeds and Climate Change

SECTION 2

Weeds are considered one of the main threats to biodiversity in Australia, second only to land clearing. They are widespread, competing against native species and transforming ecosystems. Weed control is also a critical factor in Australian agricultural production. One estimate puts agricultural losses due to weeds at over $4B per year.

***Below:** Rubber vine, Townsville area, Source: BMRG.*

2
Weeds and Climate Change

Weeds have a long legacy of negative impacts in Australia, but the weeds of today are not necessarily the weeds we will be worrying about in the future. At least 2,700 plant species introduced from other countries are already naturalised in Australia, with the rate of naturalisation of further species is estimated at about 12 per year. Some 30% (798) of these alien species are regarded as significant issues for the environment or agriculture.

Unfortunately, a major source of potential new weeds is already present in Australia. Some 26,000 alien species, mainly garden plants, have already been introduced into Australia. In comparison, Australia's native flora numbers about 20,000 species. These introduced plants are likely to be the pool from which many of our new weeds emerge. With such a large threat already in Australia and global trade representing an increased risk for further introductions, weed management is going to increase in importance and change in the future. One of the main drivers of this change will be climate change.

Climate change will exacerbate both the threat to biodiversity and the cost to agriculture of weeds. This is because new and changed levels of weed impacts on the environment will arise, requiring new or significantly altered adaptation responses to reduce negative impacts.

Australia already has many well-developed weed management systems and is well placed to respond to the new issues climate change is bringing to the decision table. For example, weed risk analysis (WRA) is extensively used to assess potential biosecurity risks and helps to identify where quarantine barriers are needed. There have been many eradication programs carried out, some more successful than others. Intensive agriculture in Australia is heavily dependent on the use of herbicides for weed control and has developed rotation systems to manage weeds and to reduce the threat of further herbicide resistance. Australia has a long history of successful biological control of weeds in a wide range of environments. Other control techniques, such as cultivation and fire, are used widely. National coordination has led to the development of national strategies and the Weeds of National Significance (WoNS) program. This background in control provides a strong basis from which to develop adaptation responses to climate change.

__Top Right:__
Image: Blue Periwinkle
Source: NRM South

__Bottom Right:__
Image: Hand slashing of Blackberry at Basket Range.
Source: Adelaide and Mt Lofty Ranges NRM
Photographer: Katrina Warner

WEEDS HAVE LONG BEEN A PROBLEM in Australia, with a large and growing reserve of potential weeds from the 2,700 already naturalised species. Under climate change, the 26,000 alien plant species already grown in Australia, though not yet naturalised, could be an even larger reserve of potential weeds.

While scientists and land managers have a long history of fighting weed invasions, often successfully, climate change will increase the challenge.

CLIMATE CHANGE WILL EXACERBATE the weeds threat mainly through new and changed levels of plant invasions.

Australia's extensive experience in control provides a strong basis to develop adaptation responses to climate change.

See the Australian Weed Strategy which provides overall national policy direction for weed issues: *www.weeds.org.au/*

ADAPTATION REFERS TO

the actions taken to assess risks, or to modify management to specifically account for climate change. For example, using weed distribution models to identify the potential spread of weeds under climate change.

MITIGATION REFERS TO

actions taken to reduce or offset the emission of greenhouse gases such as CO_2. For example, planting rapidly growing trees to remove carbon from the atmosphere.

MALADAPTATION REFERS TO

the unintended negative consequences of adaptation or mitigation actions. For example, if the trees planted above are an alien species and under the changed climatic conditions they become invasive, they could make it difficult for local native species to adapt to climate change. See Section 9.7 for further examples of maladaptation in weeds.

2.1 Definitions

Terms used in the study of invasive species are not always applied consistently across the literature. It is therefore important that terms used in this document are clearly defined.

A weed is simply a plant that is not wanted where it is found. This means that plants are identified as weeds based on a value judgement and within a human context. This also means that a plant may be considered a weed by someone but not by others. This potential conundrum is illustrated in the common names of *Echium plantagineum*, which is known as either Patterson's Curse to those considering it to be a weed, or Salvation Jane to those people that consider it to be a useful pasture species (especially in times of drought). Sometimes reference is made to noxious (or declared) weeds; these are weeds that are the subject of specific weed management legislation (***see www.weeds.org.au/noxious.htm***).

For this management-focused technical guide we choose to use the term weed over other terms because this implies that the plant is not wanted and, therefore, management of its presence is a likely response. If greater detail is required when describing a weed, we recommend the use of a weed status triplet: native/alien, invasive/non-invasive, and a description of known impacts and their value judgement. We provide an expanded list of invasion science terms in Box 2.

In contrast to invasion science, climate change management terminology is less confusing but perhaps just as frequently misapplied. Adaptation refers to the actions taken to assess risks, or to modify (in the case of this guide) the management of weeds, to specifically account for climate change. In most cases climate change adaptation includes actions that can and should be taken now for improved weed management under current climates, both averages and extremes. Mitigation refers to actions taken to reduce or offset the emission of greenhouse gases such as carbon dioxide (CO_2). While, ideally, the two are combined for maximum benefit, sometimes actions taken for one can have negative consequences for the other. In the case of weeds, an example could include planting potentially threatening alien invasive species as a store of carbon. Perverse outcomes such as this, from mitigation or adaptation actions, are called maladaptation.

Left:
Salvation Jane, also known as Patterson's Curse (Echium plantagineum), in the Adelaide Hills, SA
Source: CSIRO
Photographer: John Coppi

BOX 2

Definition of terms used in the Technical Guide

Alien (exotic, non-native):
Occurring outside its natural past or present range and dispersal potential in the timeframe under consideration, its presence being due to human actions (either deliberate or accidental) (Pyšek et al. 2004, Richardson et al. 2011, Webber and Scott 2012).

Naturalised (established):
Self-sustaining over multiple generations without human assistance or intervention (Richardson et al. 2000, Pyšek et al. 2004).

Impact:
A measurable change in the region of introduction that can be attributed, either directly or indirectly, to the addition of an alien species. The assessment of impact can be based on one or more measures and the same measure may be viewed subjectively as positive or negative by different managers. Can be assessed using the Australian Weed Risk Assessment protocol (Parker et al. 1999, Wilson et al. 2014).

Invasive:
A subset of naturalised plants that are undergoing or have the potential for rapid range expansion (i.e. change in extent over time) (Richardson et al. 2000, Wilson et al. 2014). Range expansion rates can be clearly quantified (Wilson et al. 2014), but what is deemed rapid or not remains a subjective decision (perhaps influenced by what is normal for the plant in question in its native range or what might be average range change in the recipient community). No implication of impact or a requirement for change in abundance is associated with this term (Valéry et al. 2008, Wilson et al. 2014). May or may not be a weed or alien.

Native:
Occurring within an appropriate distance from the species region of origin, allowing for natural dispersal potential and a given time frame (Webber and Scott 2012, Trudgen et al. 2012).

Sleeper weeds (alert weeds):
A subset of plants that have naturalised in a region, but have not yet increased their range and/or abundance exponentially. Evidence (or risk assessment) indicates, however, that they may become invasive or have impact in the future (Groves 1999).

Transformers:
A subset of invasive plants that have impact to the extent that they change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem (Richardson et al. 2000).

Weed:
A plant not wanted where it is found. An entirely subjective determination based on value systems within a human context. Weeds usually have detectable economic or environmental effects and are often both alien and invasive, but this is not always the case (Richardson et al. 2000).

Sources

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The changing face of weed management in Australia

SECTION 3

The main drivers for climate change impacts on plants, including weeds, will be changed temperatures and rainfall, altered frequency and intensity of extreme weather events and increasing concentrations of carbon dioxide (CO_2) in the atmosphere.

Below: *Image: Parthenium, Source: BMRG, Photographer: Lalith Gunasekera*

3
The changing face of weed management in Australia

The main drivers for climate change impacts on plants, including weeds, will be changed temperatures and rainfall, altered frequency and intensity of extreme weather events and increasing concentrations of carbon dioxide (CO_2) in the atmosphere. In addition, other components of environmental change will impact on weeds, such as modifications to introduction pathways and land use, altered natural disturbance and changes in the interactions between living things.

All plants are invasive to some degree; this is how populations are maintained, otherwise they become extinct. Yet many of the weeds that represent the greatest threat to Australia are both alien and highly invasive. The response of alien invaders to climate change differs from other plants in two ways. Firstly, the rate of response to climate change is expected to be faster. Secondly, there is a large pool of naturalised species that are likely to become invasive in the future, and climate change is likely to change the severity of impacts and even the species composition of this list of future weeds. Thus, climate change is an additional risk factor for weed management, to add to the risk factors that continue to be present under the current climate, such as changed distributions, ecosystem impacts and management practices.

Likewise, the risk of negative impacts from weeds due to extreme weather events, such as prolonged drought, heat waves, floods and cyclones that occur under today's climate, are similar to the risks associated with average climate change conditions. Thus future climates may further favour weed invasions, which could increase the risk of negative impacts from these species. However, it also means that adaptation responses to reduce the potential impact of weeds may also be just as appropriate to implement today.

Research in Australia and overseas on climate change and weeds has involved the measurement of the effects of temperature, rainfall and atmospheric CO_2 on survival and reproduction, and the description of the effect of extreme climatic phenomena on fitness and survival.

3.1
Increased temperature

Each plant species has a temperature range that is suitable for survival and growth. Increasing temperature is expected to allow species that are presently cold-limited in their southern and altitudinal extents to expand their ranges further southward, and into higher altitudes within their present ranges.

THE MAIN CLIMATE CHANGE DRIVERS OF ALL PLANTS, INCLUDING WEEDS, ARE:

- Increased temperatures
- Changed rainfall
- Increasing CO_2 levels
- More extreme weather
- More frequent frosts
- Changed phenology
- Land use change (from human adaptation)

ALIEN INVASIVE PLANT RESPONSES to climate change differ from other plants in two main ways:

- The rate of response of invasive plants to climate change is expected to be faster
- Climate change is likely to favour the appearance of a new set of weed species

THE RISKS OF WEED INVASIONS from the effects of current extreme weather events are expected to be similar to the risks due to climate change.

Thus, adaptation responses to reduce the future impact of weeds may be just as appropriate to use under today's climate as under future climates.

This may represent a threat to alpine communities and specific management will be needed to contain incipient invasion, especially of species likely to transform alpine ecosystems (e.g. from one dominated by herbs to an ecosystem dominated by shrubs).

Some plants have been planted and maintained in locations that are sufficiently warm for them to grow, but too cold for them to reproduce (e.g. certain street trees). Under a warming climate these satellite populations or specimens may become invasive if their seeds are viable and their seedlings can survive to maturity. Monitoring for new invasions can provide the early detection needed for making timely management decisions. However, this monitoring will be of more value in places where early warning signs are most likely to be detected, such as near to environmental assets or agricultural lands rather than inside major cities.

Some weeds will also be able to tolerate the projected increase in temperature. Buffel grass (*Cenchrus ciliaris*) is one of the few weeds in Australia to be extensively assessed for growth response to climate change (see Box 4). Buffel grass captures energy from the sun in a way (C_4 photosynthesis) that is more efficient than most plants (that have C_3 photosynthesis) in warmer or drier climates, or at lower levels of atmospheric CO_2 (see Box 3 for the types of photosynthesis). Further still, buffel grass plants are able to acclimate and grow at warmer temperatures (growth at 35°C versus 25°C). This means that the area for management of buffel grass is likely to increase, including both the current range (where they will acclimate and persist) and the spread southwards (as the climate becomes warmer).

BOX 3

Types of Photosynthesis

Photosynthesis:
A process used by plants and other organisms to convert light energy into chemical energy that can be later released to fuel the organisms' activities.

C_3:
Plants where the initial steps in photosynthesis builds a three-carbon compound. Most plants have C_3 photosynthesis.

C_4:
Plants that produce a four carbon compound during photosynthesis. This method of photosynthesis is prominent among the grasses but also present in some other groups of plants.

CAM:
A plant that utilises Crassulacean acid metabolism (CAM) and absorbs CO_2 at night for photosynthesis. The plant's stomata are closed during the hottest and driest part of the day to prevent the excessive loss of water. CAM plants (for example cacti) are, therefore, highly adapted to arid conditions.

Sources

Atwell, B. J., Kriedemann, P. E. and Turnbull, C. G. N. (eds.). (1999). Plants in Action. Macmillan Education Australia.

DECISION POINT

Think about the climate change trends and projections for your region, which weeds would you expect to invade, proliferate or recede (and in what direction) if your region becomes:

1. **warmer & drier?**
2. **warmer & wetter?**

The answers to these types of questions may help you prioritise the types and locations of weeds to focus future management efforts on.

Top Left:
Image: Hymenachne plant
Source: Northern Gulf NRM and Qld DNRM
Photographer: Michael Anthony

BOX 4

Buffel Grass (*Cenchrus ciliaris*) and climate change, an example of an invasive plant from the Rangelands NRM Cluster

Buffel grass is one of the most widespread alien grasses in Australia (Figure 2) where it is both a desirable pasture species and an invasive weed driving altered fire regimes in nature conservation. Buffel grass disperses readily by wind often establishing initially along roadsides. It can disperse over long distances, mainly by humans.

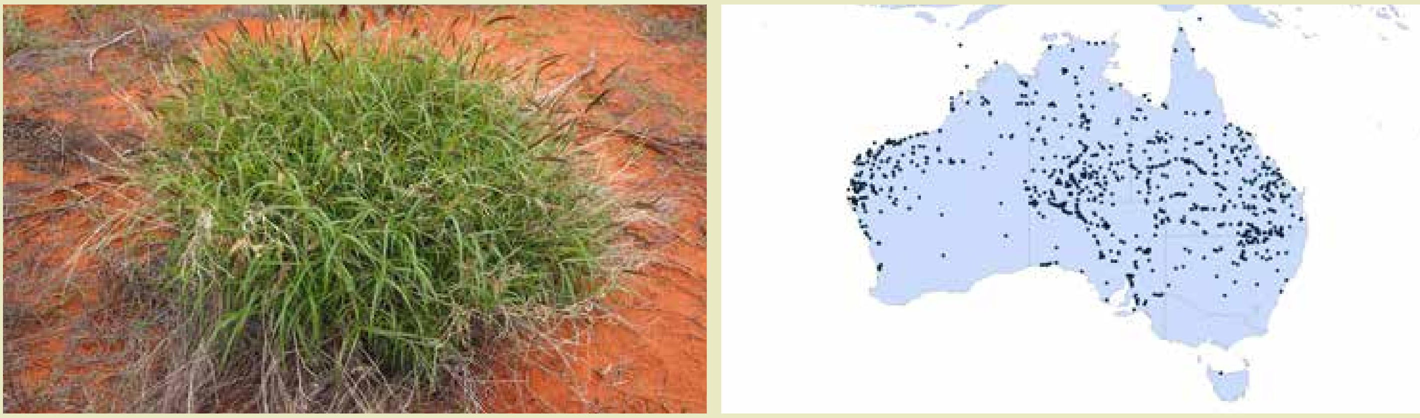

Figure 2.
Buffel grass (*Cenchrus ciliaris*). Photo: Mark Marathon (*www.commons.wikimedia.org/wiki/File:Cenchrus_ciliaris.jpg*).
Distribution of buffel grass (*Cenchrus ciliaris*) (black dots) in Australia based on records from the Atlas of Living Australia (*www.ala.org.au*).

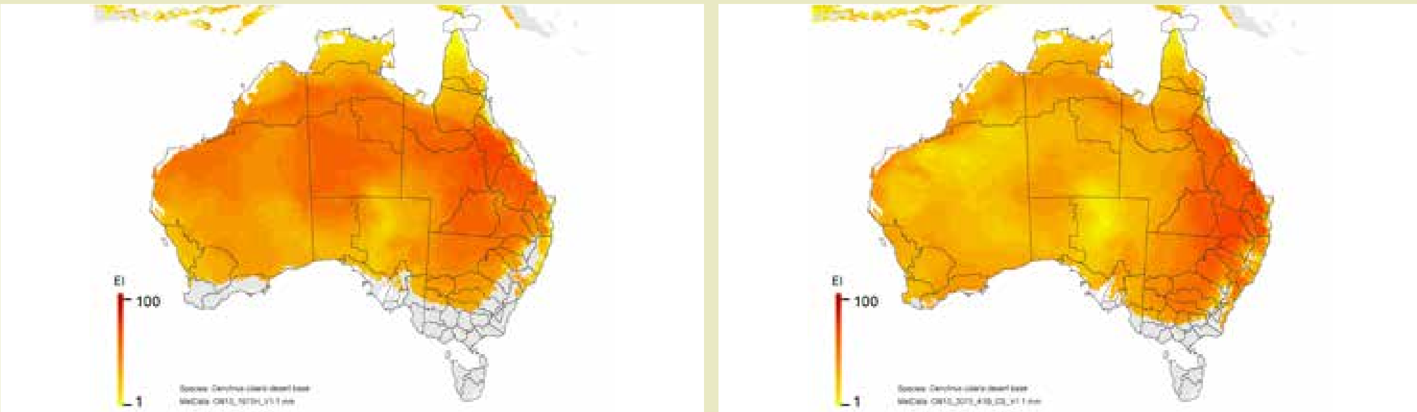

Figure 3.
The image on the left shows NRM regions and a climatic suitability (Ecoclimatic Index, EI) projection for buffel grass in current climates using CLIMEX modelling. The higher the EI value, the more suitable is the climate for buffel grass. Values of EI = 0 (grey areas) indicates regions where populations are projected not to persist. On the right, NRM regions and projected climatic suitability (EI) for buffel grass based on CSIRO Mk3 global climate model (GCM) projections for 2070, based on the A1B SRES emissions scenario.

The regions of projected climatic suitability (Figure 3) indicate a southern range expansion for buffel grass is likely by 2070. This represents a particular threat to the high value nature conservation in areas such as the Great Western Woodlands, the Alinytjara Wilurara Natural Resources Management Region, and the Great Victoria Desert bioregion.

Sources

for figure 3 see CSIRO data access portal **data.csiro.au/dap/**

3.2
Changing rainfall

Like temperature, plant species have a range of soil moistures that are suitable for survival and growth. A decrease in annual rainfall, such as already recorded in south west Australia, will lead to a retraction of plant species' distribution from the dryer inland regions.

Most parts of Australia are characterised by climate that is exceptionally variable in rainfall between years as well as being variable between decades. This variation can affect the recruitment and survival of weeds. The challenge, therefore, is to distinguish the effects of climate change within the context of a naturally variable climate. One approach is to use experiments. For example, experiments have shown that water stress affects the degree of competition between native plants and bitou bush, *Chrysanthemoides monilifera* subsp. *rotundata*, possibly allowing for increased dominance of local ecosystems by this alien invader with further climate change.

3.3
Increasing CO_2

Elevated atmospheric CO_2 (eCO_2) is known to improve the growth of plants due to increased efficiency. The interaction between eCO_2 and growth is strongly influenced by the mode of energy capture (photosynthesis), with some plants (C_4 and CAM), including many grasses and succulents, being more efficient than others (C_3 plants). A field based experiment on Tasmanian grassland ecosystems found eCO_2 and increased temperature had a negative impact on plant growth rates indicating that climate change is not always beneficial for plants. Other studies involving eCO_2, *Parthenium hysterophorus* (C_3-C_4 intermediate) and *Vulpia myuros* (C_3) found these invasive species to be more competitive than native or pasture grasses. A recent larger scale study compared 14 native – alien species pairs (8 C_3 and 6 C_4) and found reduced competitive effects of the native species under eCO_2, suggesting that the relative success of alien species may be increased. These contrasting responses indicate that the degree of competition may be context specific (i.e. it depends on the species and the situation).

Top Right:
Image: Boneseed
Source: NRM South

EXTREME WEATHER EVENTS SUCH AS CYCLONES, DROUGHTS, FLOODS, HEATWAVES, FIRE AND FROSTS ARE EXPECTED TO INCREASE UNDER CLIMATE CHANGE AND WILL HAVE SIGNIFICANT EFFECTS ON WEED DISTRIBUTION.

DECISION POINT

Think about the climate change trends and projections for extreme weather events in your region, which weeds would you expect to invade, proliferate or recede (and in what direction) from more or less:

a. **flooding?**
b. **fire?**
c. **wind?**
d. **frost?**

See Box 5 below for an example of the effects of a cyclone on one weed and the surrounding tropical forest.

Left: Image: Willow trees, Source: South Coast NRM, Photographer: Matthew Kennewell

3.4
Increase in extreme weather events

Extreme weather events include cyclones, droughts and floods, heatwaves and frosts. Fire is a common extreme event in Australia and its frequency and severity is often influenced by extreme weather. All of these factors can cause great changes in plant abundance, competition between weeds and other plants, and weed distributions at a local scale.

Eleven of the thirty two Weeds of National Significance (WoNS), including tamarisk (*Tamarix aphylla*), and willows (*Salix spp.*) are considered to benefit from flooding events. The major weed lippia (*Phyla canescens*) is also sensitive to altered flooding regimes.

Fire is a major disturbance in many Australian landscapes and certain frequencies and intensities are often required for ecosystem health. Fire height, intensity and frequency, however, are likely to be altered by weeds through changes in fuel load and fuel structure. The best known example is the ecosystem transforming impact of gamba grass (*Andropogon gayanus*) in northern Australia, where increased fuel loads increase the severity of fires. Climate change, either through warmer and drier environments, or increased fuel loads from CO_2 efficiencies or increased rainfall, could create greater challenges for fire management in Australia.

Climate change science indicates that tropical regions will experience an increased intensity of cyclones in the future. Cyclones have been shown to accelerate plant invasions and alter the abundance of weeds in tropical forests. Intense cyclones provide a large spatial and temporal window of opportunity for invasion, due to greater disturbance. Empirical research demonstrates that invasive alien species have increased growth rates and recruitment and spread readily following such events. It is the vines, scrambling shrubs and woody invasive alien species that are somewhat shade-tolerant, that are likely to constitute the greatest threat to tropical forests following cyclones (Box 5).

3.5
More frequent and severe frosts

An increase in frequency and severity of frosts seems an unlikely consequence of climate change, but this outcome is likely for some areas. The increase in frosts is related to more clear skies in winter due to rainfall reduction. Its impact is most evident in the cropping region of south west WA where crops are affected by less rainfall, late season starts and increased frost, especially during flowering. This may be a temporary phenomenon, as the increased frequency and severity of frost is not likely to persist as the climate warms further. In the interim, frosts will remain a significant driver of plant range limits, including for weeds.

Some areas may become more or less suitable and where frosts increase, weeds may be killed or prevented from spreading due to frost damage. This effect may also confer an advantage on plant species adapted to more continental climates. A management option could be to be aware of areas susceptible to frosts, determine what weeds are susceptible and reduce weed management accordingly.

3.6 Phenology

The timing of plant growth and reproduction (phenology) will be influenced by changes in seasonal cues, such as temperature and rainfall. Very few observations on changed phenology have been made in Australia, although it is a common study focus for climate change research in the northern hemisphere (e.g. earlier flowering due to rising temperatures). In Australia, the influence of climate change on plant phenology has been investigated for native alpine plants. In contrast, a field based experiment on Tasmanian grassland ecosystems found eCO_2 and temperature did not change the flowering patterns of invasive grasses. Understanding the timing of plant growth and development, however, is critical for guiding the timing of weed control efforts, making this topic an important focus for future research or monitoring and adaptive management.

3.7 Land Use Change

Human responses to climate change, including deliberate adaptation choices, will be a major contributor to weed problems with climate change. Potential responses include:

- Changed farming practices as farmers implement climate change adaptation measures
- Pastoralism replacing agriculture under a drier climate in some parts of south-eastern Australia. Shifting the distribution of crop and pasture species will likely shift the distribution of their associated weeds
- Opportunistic cropping to take advantage of years with good rain
- The introduction of new crop and pasture species better able to tolerate extreme conditions
- Changes in choice of sown crops (e.g. increased area of canola in previously wetter areas)
- Development of new cropping regions (in particular in the north of Australia, aided by irrigation)
- The widespread planting of fast-growing alien species for biofuels; biomass crops (including short-rotation trees and high biomass grasses) and oil seed species that are currently being investigated for large-scale production of biofuels in northern Australia

These changes will likely see a new set of weeds that require ongoing management and investment of resources.

LAND USE CHANGE AS PART OF HUMAN ADAPTATION TO CLIMATE CHANGE WILL BRING WITH IT A NEW SET OF WEEDS.

DECISION POINT

Think about the types of human climate adaptation responses likely to occur in your region. Which weeds would you expect to invade, proliferate or recede (and in what direction) due to these different responses?

BOX 5

The perfect storm: Cyclone Larry and woody weed invasion in tropical forests

The spectacular success of the small, shade-tolerant tree miconia (*Miconia calvescens*) in Tahiti is often attributed to the six cyclones that hit the Society Islands between December 1982 and April 1983. Researchers suggest that the cyclones explained the 'demographic explosion of miconia', and that 'the speed of the invasion then became astonishing'. In Australia, *Miconia calvescens* is the target of a national eradication program and occurs primarily in north Queensland. Both Cyclone Larry (2006) and Cyclone Yasi (2011) caused significant structural damage across the region in which miconia occurs. Growth rates of miconia more than doubled in the year following Cyclone Larry and the species recruited readily in cyclone damaged forest and showed low mortality even 5 years post-cyclone.

The widespread and massive disturbance caused by cyclones provides ideal conditions for rapid recruitment and spread of invasive species. With an increasing intensity of tropical cyclones we should expect to see significant structural and compositional changes to tropical forests as a result of plant invasions such as miconia.

Figure 4.
Left, cyclone damage a month after Larry near El Arish where the largest infestation of *Miconia calvescens* occurs and right, *Miconia calvescens* seedling, included in the monitoring of growth and recruitment after cyclone Larry.

Sources

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Murphy, H.T., Bradford, M.G., Ford, A.J. and Metcalfe, D.J. (2010) Spatial and temporal patterns of exotic species recruitment in a cyclone-damaged tropical forest. In: Zydenbos, S.M. (ed.) Proceedings of the 17th Australasian Weeds Conference. New Zealand Plant Protection Society, pp. 368-371.

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Murphy, H.T., Metcalfe, D., Bradford, M.G., Ford, A.F., Galway, K.E., Sydes, T.A. and Westcott, D.J. (2008) Recruitment dynamics of invasive species in rainforest habitats following Cyclone Larry. Austral Ecology 33, 495-502.

Modelling Distributions: Knowing where to target management

SECTION 4

The aim of modelling a species' potential distribution is to better understand the geographical area in which that species may be found, survive, thrive, or remain absent now or in the future.

Below: *Image: Boneseed, Source: NRM North, Photographer: Emma Williams*

THE TWO BROAD TYPES

of species distribution modelling are correlative and mechanistic. It is important that weed managers relying on distribution models understand the limitations of the types of models they are using.

CORRELATIVE MODELS

can be built easily and quickly, and so are popular in some areas, however they are likely to underestimate the full extent of future weed distribution or misrepresent it if they are allowed to extrapolate.

4.1 Modelling geographical distribution

The aim of modelling a species potential distribution is to better understand the geographical area in which that species may be found, survive, thrive, or remain absent now or in the future. Combined with the species present known distribution, this information can be particularly useful for informing strategic management efforts aimed at reducing current and future weed impacts in a rational manner.

Many different factors control where plant species are presently found. These factors can be broadly grouped into four areas: climate, soil, co-occurring species, and their ability to get there from where they were previously (e.g. their native range). Of these factors it is climate that represents the most useful 'outer limit' of where we might need to apply weed management strategies. It is, therefore, climatic suitability that weed models should be first trying to capture in their projections. Once this outer limit has been defined, it can subsequently be partitioned up by then considering non-climatic limitations to weed distributions.

Most modelling techniques for describing (or projecting – see Box 6) species' distributions fall into two groups. Firstly, correlative models relate known distribution records for the species of concern to variables presumed to explain the known range. This produces a projection that represents geographical areas with similar climates to the distribution records, at least according to the variables used in the model. However, we know that species ranges are limited by factors other than climate, so appropriately constructed models based solely on distribution records are likely to underestimate the full potential distribution of the climatically suitable area for a weed.

BOX 6

Projection versus Prediction

Projection:
The term "projection" is used in two senses in the climate change literature. In general usage, a projection can be regarded as any description of the future and the pathway leading to it. However, a more specific interpretation has been attached to the term "climate projection" by the IPCC when referring to model-derived estimates of future climate.

Forecast/Prediction:
When a projection is branded "most likely" it becomes a forecast or prediction. A forecast is often obtained using deterministic models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.

Sources

www.ipcc-data.org/guidelines/pages/definitions.html

The second group, mechanistic models, can also be informed by distribution data, but can also make use of information from other sources, such as physiology experiments and expert knowledge, to understand the true climatic limits of the species in question. The nature of the variables and the form of the functional responses used in these models are usually informed by biological theory.

Mechanistic models can get much closer to understanding the full climatic limits for weed distributions, but they take longer to build than correlative models. Importantly, modelling weeds and then projecting to future climates are both likely to require an understanding of modelled suitability beyond the range of variables experienced by existing populations (i.e. model extrapolation). Correlative models are poorly equipped to deliver ecologically plausible projections consistently when extrapolating.

Even so, both types of modelling studies have flourished in recent years (see the Information Sources section (13) for data sources). All modelling techniques have limitations and the method applied needs to be appropriate the both the spatial scale and question posed. Unfortunately, models are not always applied in this manner, and hence weed managers should understand how to identify how reliable these model projections are for informing weed management decisions. Carefully considered modelling done appropriately can be highly informative, but poor modelling done carelessly can be extremely misleading.

Depending on factors such as the type of model used, the care taken in cleaning input data and the skill of the modeller, potential distribution models can include substantial errors of omission (areas modelled as unsuitable when they are in fact suitable) and commission (areas modelled as suitable when they are in fact not suitable). Both types of errors can be costly, leading to wasted management effort on surveillance (commission error), or worse, an undetected but preventable invasion (omission error). These errors can be substantial, spanning entire Australian States, let alone an NRM region (e.g. Kriticos and Randall 2001; Webber et al. 2011; also see Figure 5 in Box 7). There is good reason, therefore, to try to gauge the reliability of potential distribution models before they are considered for guiding management (Box 7). These uncertainties also highlight the need for adopting an adaptive management perspective to managing weed risks under current and future climates.

MECHANISTIC MODELS TYPICALLY TAKE LONGER TO BUILD, HOWEVER THEY ARE BETTER AT PROJECTING WEED DISTRIBUTIONS UNDER FUTURE CLIMATES.

SOME MODELS ATTEMPT

to combine climate and other environmental conditions with the weed's biology. Model developers may also have to undertake new, strategically placed, surveys of species distribution to improve the range and accuracy of model outputs.

Background: Image: Mist flower, Source: BMRG, Photographer: Lalith Gunasekera

BOX 7

Issues to consider when using weed distribution models

There are many bioclimatic modelling platforms available for estimating the potential distribution of weeds. The results of these models are often used to plan and make resource allocation decisions on eradication, containment and control of weeds. In Australasia, these maps often feed into the Post-Border Weed Risk Management System, identifying areas at risk of invasion (Standards Australia 2006). Thus, they have an important role in strategic weed management. Given their importance, how do we tell if they are useful for our intended purpose of gauging the potential distribution of invasive weeds under climate change?

Here is a brief guide to some of the issues to consider, without necessarily dealing with more fundamental methodological problems that may exist. See the references below for a discussion of more technical issues.

- Does the modelled suitable area cover all the known distribution points of the weed under historical climatic conditions? If not, can the presence of outliers be explained by microclimates?
- Does the potential distribution map make ecological and biological sense? A model of a tropical species that shows high suitability for both the north east of Australia and the Nullarbor, but not other desert regions, is likely to be a result of a modelling artefact. For Mediterranean climate species does the model show suitability for southern Australia, but not the Perth region despite the weeds' presence there? Any model that is highly fragmented across inland Australia would have to be questioned, given our shallow environmental gradients.
- Does the modelling method have a history of being able to project reliably into novel climatic conditions?
- Is it clear whether or not the model projection involves extrapolation beyond the known environmental range of the species?
- Is there a detailed description of how the particular species potential distribution model was developed, including reference to species ecology, physiology and life history stages, and how issues of input data quality and model performance were handled? Modelling species niches accurately and reliably is a skilled operation, and doing so into novel environments doubly so. Highly automated modelling typically fails to detect even gross errors in input data and modelling variables, and makes projections that are sometimes highly erroneous, spanning multiple NRM regions (Figure 5).
- Are there taxonomic issues that may compromise the results?

If any of these quality indicators are compromised for a model, you should treat the results with extra caution. Given the cost implications of incorrect risk assessments, it is often better to proceed with the caution you would apply if you had no knowledge, rather than rely on dubious information.

For example, where there is doubt, you may wish to adopt an adaptive management approach to dealing with a potential invader, sharing surveillance information across NRM regions in the zone of modelling uncertainty.

Sources

Kriticos, D.J. and Randall, R.P. (2001) A comparison of systems to analyse potential weed distributions. In: Groves, R.H., Panetta, F.D. and Virtue, J.G. (eds) Weed Risk Assessment. CSIRO Publishing, Melbourne, Australia, pp. 61-79

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BOX 7 (CONTINUED)

Issues to consider when using weed distribution models

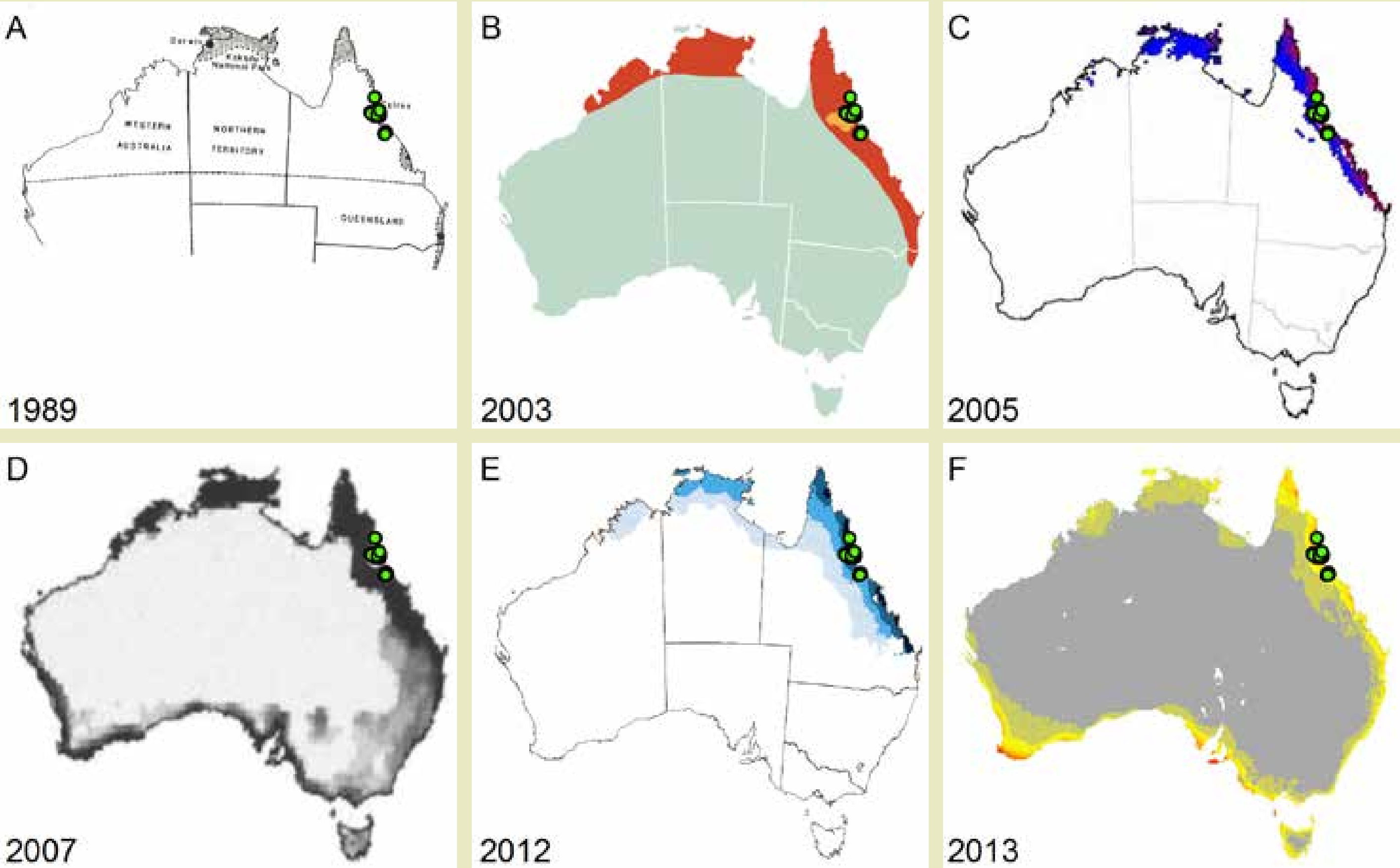

Figure 5.
Modelling of the distribution for *Chromolaena odorata* (Siam weed) showing the very large potential variation between projections from different models. Some projections (a, b) simply show binary presence and absence, while multichromatic projections (c to f) have increasing colour intensity indicating increasing modelled suitability. Green dots indicate currently known distribution records in Australia as recorded in Atlas of Living Australia in June 2014. Chosen projections were sourced from publically available online sources and were selected to highlight geographic variation in modelled suitability.

We are aware of other model projections that exist in the public domain that differ again to these presented here. Projections arranged in chronological order were generated by models using a precipitation threshold (a), an unknown method (b), CLIMEX (c, e), the genetic algorithm for rule-set production (GARP; d), and MaxEnt (f). Projections also likely differ in their input data and methodology decisions. Sources: a – McFadyen (1989); b – CRC for Australian Weed Management (2003); c – Kriticos et al. 2005; d – Raimundo et al. (2007); e – Day and McFadyen (2012) f – Duursma et al. (2013) and Weed Futures (*www.weedfutures.net*).

Sources

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Duursma, D.E., Gallagher, R.V., Roger, E., Hughes, L., Downey, P.O. and Leishman, M.R. (2013) Next-generation invaders? Hotspots for naturalised sleeper weeds in Australia under future climates. PLoS ONE 8, e84222. doi:10.1371/journal.pone.0084222.

Kriticos, D.J., Yonow, T. and McFadyen, R.E. (2005) The potential distribution of Chromolaena odorata (Siam weed) in relation to climate. Weed Research 45, 246-254.

McFadyen, R.E.C. (1989) Siam weed: a new threat to Australia's north. Plant Protection Quarterly 4, 37.

Raimundo, R.L.G., Fonseca, R.L., Schachetti-Pereira, R., Peterson, A.T. and Lewinsohn, T.M. (2007) Native and exotic distributions of Siamweed (Chromolaena odorata) modeled using the Genetic Algorithm for Rule-Set Production. Weed Science 55, 41–48.

CLIMATE CHANGE GENERALLY

produces a pole-wards, or southern, shift in species' distribution.

THE OVERALL RESULT

may be a retreat of invasive species towards the southern coastline.

THE FUTURE

for northern Australia is far less certain, mainly due to uncertainty around changing rainfall patterns.

DECISION POINT

Potential model limitations to consider when selecting or using species distribution models in NRM planning are:

a. quality

The quality of distribution data used in the model

b. reliability

Whether or not the model is able to project reliably into new climatic conditions

c. availability

Not all species may be included so some weeds may not have models available

d. other factors

Models tend to rely on climate averages, thus model outputs may not reflect extreme climatic events, microclimates and other factors such as soil type, fire and flood regimes, and changing land use patterns.

4.2 Climate change and species distributions

The general trend that can be drawn out of the many modelled weed distributions is a poleward shift in modelled suitability (i.e. towards the south in Australia; Sutherst et al. 2007). Assuming species are able to move from their existing range we may, therefore, see a shift, expansion, or retraction of species distributions with climate change (Box 8).

An important implication for this southerly range shift is that Australia does not extend far enough south to include the majority of regions of potential future suitability for current southern weeds. The implication may be that the southern displacement of species will result in more species ranges contracting to the southern coastline.

The modelling of weed distributions for the north and centre of Australia is particularly uncertain. While temperature is projected to increase with climate change, in common with other regions, the global climate change models are not clear on the level and direction of rainfall change. Decreasing uncertainty for climate projections is likely to improve our ability to interpret model projections in northern Australia, and this remains an area that requires further research and that requires a cautious approach to weed management.

4.3 Issues to consider when using distribution modelling for weed management

There are many species distribution models available in the scientific literature and on the web. However, preparing a reliable species' distribution model requires considerable skill and effort. Box 7 lists some of the issues that should be considered before using the output of species modelling to guide management. There is extensive discussion in the scientific literature on these and other relevant issues .

Gaps in species modelled

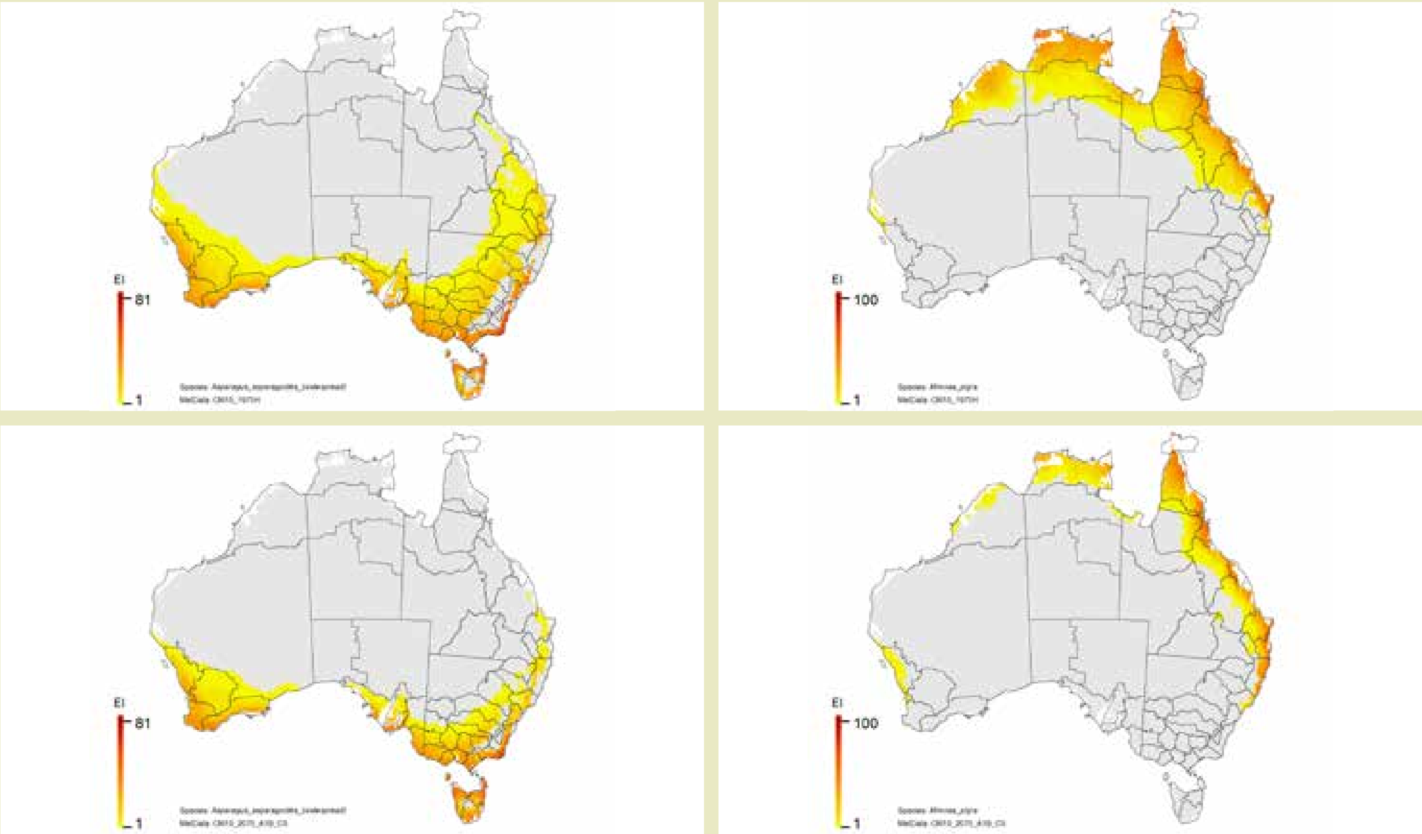
Most of the invasive plant species that have been the subject of species distribution models are those on national priority lists, such as Weeds of National Significance and sleeper species. The major gaps in the types of species modelled include those of tropical Australia, agricultural weeds, and native invasive species.

BOX 8

Examples of modelled suitability change for weeds in future climates

Figure 6.

Top row: NRM regions and a climatic suitability (Ecoclimatic Index, EI) projection for bridal creeper and mimosa in current climates using CLIMEX modelling. The higher the EI value, the more suitable is the climate for weed survival. Values of EI = 0 (grey areas) indicates regions where populations are projected not to persist. On the bottom row: NRM regions and projected climatic suitability (EI) for bridal creeper and mimosa based on CSIRO Mk3 global climate model (GCM) projections for 2070, based on the A1B SRES emissions scenario.



Asparagus asparagoides (bridal creeper)

Adaptation response

1. There is an increased risk in Tasmania which supports the strategy of maintaining Tasmania free of this weed.
2. Inland in NSW and Queensland is currently free of the weed and is likely to remain so with climate change.

Sources

Kriticos, D.J., Crossman, N.D., Ota, N. and Scott, J.K. (2010) Climate change and invasive plants in South Australia. Report for the South Australian Department of Water, Land and Biodiversity Conservation. CSIRO Climate Adaptation Flagship, Canberra, Australia 92 pp.

Scott, J.K. and Batchelor, K.L. (2006) Climate-based prediction of potential distributions of introduced Asparagus species in Australia. Plant Protection Quarterly 21, 91-98.

Mimosa pigra (mimosa)

Adaptation response

1. The Kimberley region shows a declining risk. This would make it more feasible to eradicate any populations that appear.
2. Limit the spread of Mimosa southward through Queensland. This is a no regrets climate adaptation policy.
3. There is potential for the plant to spread into NSW, so it should be treated as a quarantine issue for this state.

Sources

Walden, D., van Dam, R., Finlayson, M., Storrs, M., Lowry, J. and Kriticos, D. (2004) A risk assessment of the tropical wetland weed Mimosa pigra in northern Australia. Australian Department of the Environment and Heritage, Darwin, Australia, 66 pp.

General limitations to modelling

Looking beyond the many potential pitfalls in modelling methodology, as well as the appropriateness of the methodology for the question being addressed, there are other more general limitations to modelling insight.

For example, species distribution models are mostly based on climate averages and rarely consider climatic extremes or other environmental factors such as soil type, fire and flood regimes, changing land use patterns and altered competitive and trophic (e.g. foodchain) interactions. Modelling may also be inappropriate for species with strong associations to microhabitats, where the environment may be very different from that shown by climate averages. An example of the latter would be a plant species only found on rocky outcrops where rainfall collection gives a raised moisture level not captured by the resolution of the variables driving the model.

4.4 Recent developments

Recent modelling in Australia has sought to address the issue of combining models using climate and biology with other environmental factors that influence establishment and persistence of invasive plant populations. For example, fundamental changes in land use and altered flood regimes with future climate change in the Murray Darling Basin are likely to impact on the potential distribution of invasive plants such as lippia (*Phyla canescens*).

DECISION POINT

Are you aware of the types of models you are using, or potentially could use, and the specific limitations associated with them? Are you aware if any new or improved models are currently under development or planned, that may be relevant to your region?

Weed dispersal in a connected future

SECTION 5

The dispersal pathways for weeds have already been highly modified from what happens naturally in their native range. On one hand, long distance dispersal abilities have been improved, through the deliberate and accidental movement of plants via vehicles, trade, horticulture and agronomy.

Below: *Image: Hymenachne flower, Source: Northern Gulf NRM*

Bottom: Image: Singapore Daisy infestation at Babinda Ck, Source: Terrain NRM

5.1 Dispersal Pathways

The dispersal pathways for weeds have already been highly modified from what happens naturally in their native range. On one hand, long distance dispersal abilities have been improved, through the deliberate and accidental movement of plants via vehicles, trade, horticulture and agronomy. This has helped plants and their propagules (seeds, suckers, cuttings etc) to increase distances travelled, increase the number, size and severity of barriers crossed and the volume of plants or propagules moved.

On the other hand, shorter distance dispersal opportunities have been reduced due to an increase in the size and frequency of barriers, such as habitat fragmentation, changes in land use and the construction of artificial barriers. Climate change is unlikely to directly influence or change dispersal pathways. Instead, changed land use patterns as adaptations to climate change may improve dispersal opportunities and provide new dispersal pathways.

HUMAN ACTIVITY HAS CHANGED WEED DISPERSAL PATHWAYS GREATLY. WEEDS CAN TRAVEL GREAT DISTANCES MORE EASILY BUT THEIR ABILITY TO SPREAD LOCALLY MAY BE REDUCED.

CLIMATE ADAPTATION RESPONSES

such as restoration of landscape connectivity, refugia protection and managed relocation, may change weed dispersal pathways in new ways.

NATIVE PLANTS

may move into new areas as they adapt to climate change. This could represent a solution but also a threat to pre-existing native plants in those areas.

5.2
Landscape connectivity, refugia and managed relocation

In particular, adaptation approaches for management of biodiversity may change the spatial relationship between weed introductions and their preferred climate. For example, improving the connectivity of landscapes is often a preferred way to support natural ecosystems, ideally enabling native species to track shifts in suitable climates as well as increase the functional size of populations. Landscape-scale connectivity initiatives may especially attempt to link areas that represent regions of refugia for the survival of species either now or into the future. In turn, refugia may be prioritised as areas suitable for receiving species that are the focus of managed relocation (assisted colonisation) efforts. Such conservation-focused introductions of populations to new areas can take place in areas where the species would be considered alien.

Although these examples of climate change adaptation measures may be implemented based on the best intentions, they can have unintended consequences for weeds. Three examples illustrate that weed management may need to be an integral part of each of these adaptation approaches:

First, an unintended consequence of improving landscape connectivity (e.g. by providing vegetation corridors) for natural ecosystems is improving the opportunity for weeds associated with these ecosystems to spread. Australia has a number of landscape-scale initiatives with an emphasis on improving connectivity between patches of remnant vegetation as an adaptation response for the conservation of native species. Many of these initiatives have climate change as a major design consideration (Gondwana Link, the Great Eastern Ranges Initiative, Habitat 141º, NatureLinks, Trans-Australia Eco-Link, Tasmanian Midlandscapes) and already recognise that they could inadvertently become pathways for the dispersal of invasive alien plants.

One possible adaptation response to managing species movements through landscape corridors is to provide “pinch points” (i.e. natural or artificial restriction points) and actively manage the migration of species through the area. A natural “pinch-point” could be a landscape constricted between ocean and mountains, or a constricted part of a river corridor. An artificial restriction point could be provided by an urban landscape (e.g. Perth) that constricts movement of species along the Swan Coastal Plain. These could remain permanent focal points for ongoing monitoring, borrowing management insight from border biosecurity and quarantine barriers. It may also be necessary to translocate native species to parts of the corridors where they do not occur. This should be planned after appropriate risk assessment.

AN UNINTENDED CONSEQUENCE

of improving landscape connectivity (e.g. by providing vegetation corridors) is improving the opportunity for invasive plants to spread.

ACTION POINT

Adaptation responses to combat invasion from corridors include monitoring, pinch points and translocation.

Similarly, as native species shift their distributions in response to climate change or managed relocation, they have the potential to negatively impact other native species in their newly expanded range, thus becoming weeds themselves.

ACTION POINT

The best adaptation response is to monitor the consequences of distribution shifts of native species to recognise negative impacts when they arise.

Refugia have an increased risk of invasion under climate change with potentially greater consequences for biodiversity.

ACTION POINT

The key climate adaptation response to protect refugia is to maintain and enhance current invasive plant quarantine, surveillance and control measures.

Second, both landscape connectivity initiatives and managed relocation are intended to permit native plants to shift or expand their range with climate change. That is, we may see a whole suite of range-shifting native plants moving, due to rapid climate change, into communities where they have not been previously found. This presents an often ignored management paradox in that these invasive natives may have negative impacts on other native species in their newly expanded range. Thus, should this still be viewed as a landscape connectivity success story or an invasion science failure that requires control? Already there are about 600 native species that have changed their distribution in Australia. Some of this change has been due to dispersal via garden plantings, while other aspects of global change, such as changed fire regimes, have led to other distribution shifts. The key adaptation approach here may involve monitoring the consequences of shifting distributions of native plants to evaluate whether they have a negative impact on environmental or economic values and thus should be considered weeds.

Finally, various types of refugia may be particularly important for native species under climate change, including refugia from extreme events like flood and fire, areas that may be more climatically stable where species may persist and/or retreat to, and evolutionary refugia which are naturally isolated and important sources of genetic and species diversity. Climate change will provide additional stress on many of these types of refugia and this may present opportunities for invasion of species not originating in the refugia. Weeds present a particular risk for refugia because the surrounding environment (on land) usually has a high abundance and diversity of weeds. This means that refugia are likely to have a high and sustained risk of weed introductions. Therefore, quarantine, surveillance and control of invasive plants must be an ongoing and increasingly important priority for Australia's environmental refugia.

Right:
Image: Gorse infestation (mid ground)
Source: NRM North
Photographer: Monique Case

The changing biosecurity threat

SECTION 6

New weeds will continue to arrive as introductions and naturalise in Australia. At regional, state and national levels, biosecurity measures are required to address this threat.

Below: *Image: Rubber vine, Source: BMRG*

6.1
New introductions and naturalised plants

New weeds will continue to arrive as introductions and naturalise in Australia. At regional, state and national levels, biosecurity measures are required to address this threat. The arrival of new weeds takes place at different scales, both spatially and temporally. Spatially, new weeds can come from overseas, from other States within Australia, or from neighbouring regions, nature reserves or farms. Weeds of agriculture may cross into natural ecosystems, for example, from farms to nature reserves. This exchange may also happen in the other direction.

With regards to timing, new weed arrival can be rapid, as with a few agricultural weeds, whilst others (especially trees) can take many generations to become established and display invasive characteristics. Conversely, the invasion process of new weeds can occur at slow rates of increase, for example, the group identified as 'sleeper weeds'. These weeds-in-waiting are seemingly innocuous and apparently non-invasive, but known to be significant problems elsewhere in the world.

In addition, another form of invasion will come from native plant species rapidly shifting their range in response to factors such as fire dynamics, climate change and native vegetation clearing. With climate change, our ability to assign native or alien status to weeds in an ecologically meaningful way will be more challenging.

Potential new introductions of weeds are usually considered to have the highest likelihood of establishment and become weedy if they come from a region of similar climate. Matching climates from Australia to those overseas or elsewhere in Australia (Box 9) demonstrates two notable points. First, on a world scale, areas that share similar climates now are projected to share similar climates in the future. Part of the reason is that Australian climates do not have exact matches elsewhere in the world. Also, Australia spans many climate zones from the wet tropics to alpine; hence the geographical footprint of climatic similarity is very large to start with.

Second, and most importantly, the areas that most closely match the Australian climatic regions are adjacent regions in Australia. This pattern can also be explained by the high frequency of flat regions where topography does not influence climate variation. This implies that the most likely source of new invasive species, both today and under climate change are neighbouring regions.

NEW WEED ARRIVALS

pose a continual threat and can represent a risk over two dimensions:

- Space (geographic location and range)
- Time (rapid or slow invasion)

The most likely source of new invasive species, both today and under climate change, is neighbouring regions with a similar climate.

Right:
Image: Century plant: Agave americana at Cape Portland, Tasmania
Source: NRM North
Photographer: Emma Williams

BOX 9

Matching climates between Australia's wet tropics and the world

Northern Australia is predisposed to a unique set of biosecurity risks due to its close proximity to New Guinea and the Indonesian archipelago (areas with similar climates now and into the future), in combination with the annual northwest monsoon (Figure 7). Greater intensity tropical cyclones and projected increases in wind speeds over northern Australia may increase the likelihood of wind-borne incursions by weeds, pests and pathogens that occur in countries to the north.

The Northern Australian Quarantine Strategy (NAQS) maintains a list of high-risk alien insect pests, plant diseases, weeds and animal diseases (*www.daff.gov.au/biosecurity/quarantine/naqs*). Targeted organisms are considered serious threats to Australia's agricultural productivity, export markets or the environment. A number of species on the NAQS list are wind-dispersed and occur in countries in close proximity to Australia, and therefore are potentially at higher risk of introduction and subsequent invasion. This level of risk remains similar under current and future climates (Figure 7). For example, the densely tussocked, perennial grass *Digitaria insularis* (Poaceae) produces large volumes of wind-dispersed seed. It is an alien invader throughout the Pacific as well as in Papua New Guinea (Figure 8). It is a serious problem because it competes strongly with crops and has developed herbicide resistance. Several species of wind-dispersed Asteraceae are also included on the NAQS list, including *Chromolaena odorata* (siam weed) (Figure 8). Siam weed is currently limited to the Wet Tropics region south of Cairns. However, it is a widespread alien in Papua New Guinea and is moving closer to the Torres Strait. In the future it poses a very significant risk of introduction to Australia via wind to the islands of the Torres Strait, Cape York Peninsula and the Northern Territory.

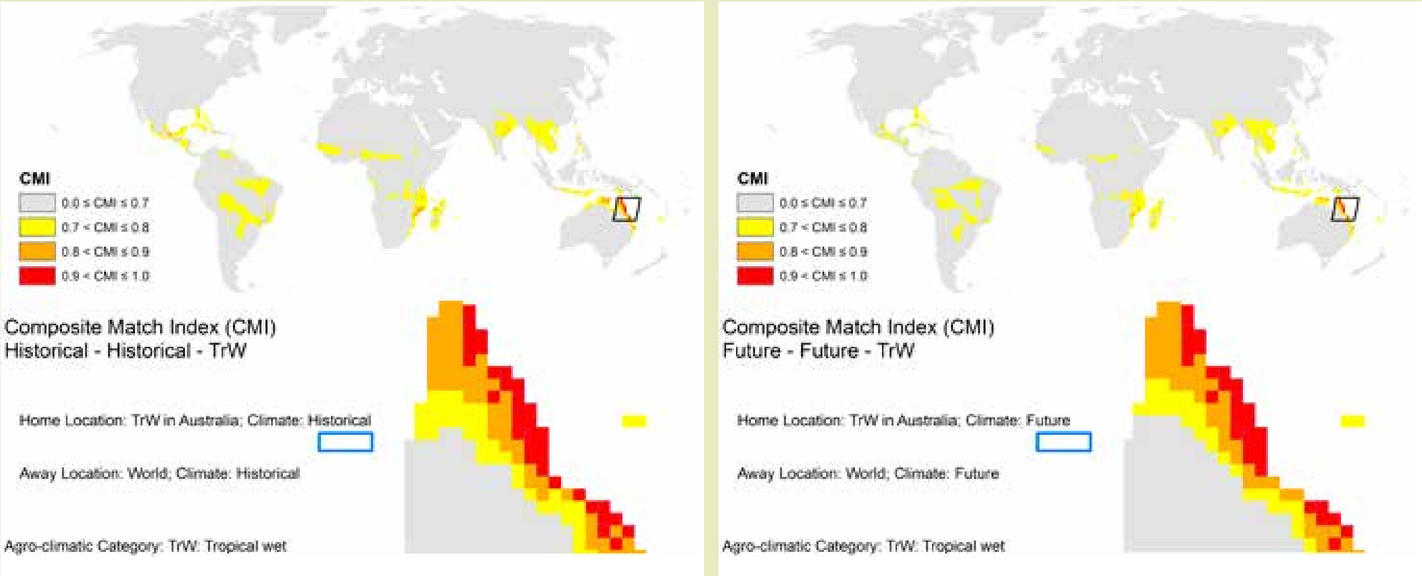


Figure 7.
Left, CLIMEX match climates for the Wet Tropics using climate averages from 1961-1990, and right, CLIMEX match climates for the Wet Tropics using CSIRO Mk3 projections to 2070 based on the A1B SRES scenario.

BOX 9 (CONTINUED)

Figure 8.
Left, *Digitaria insularis* (Sour grass) Photo from ***www.wiki.pestinfo.org/wiki/Digitaria_insularis_(weed)*** and right, *Chromolaena odorata* (Siam weed). Photo from ***www.fnqpaf.com.au/resources/chromolaena.html***

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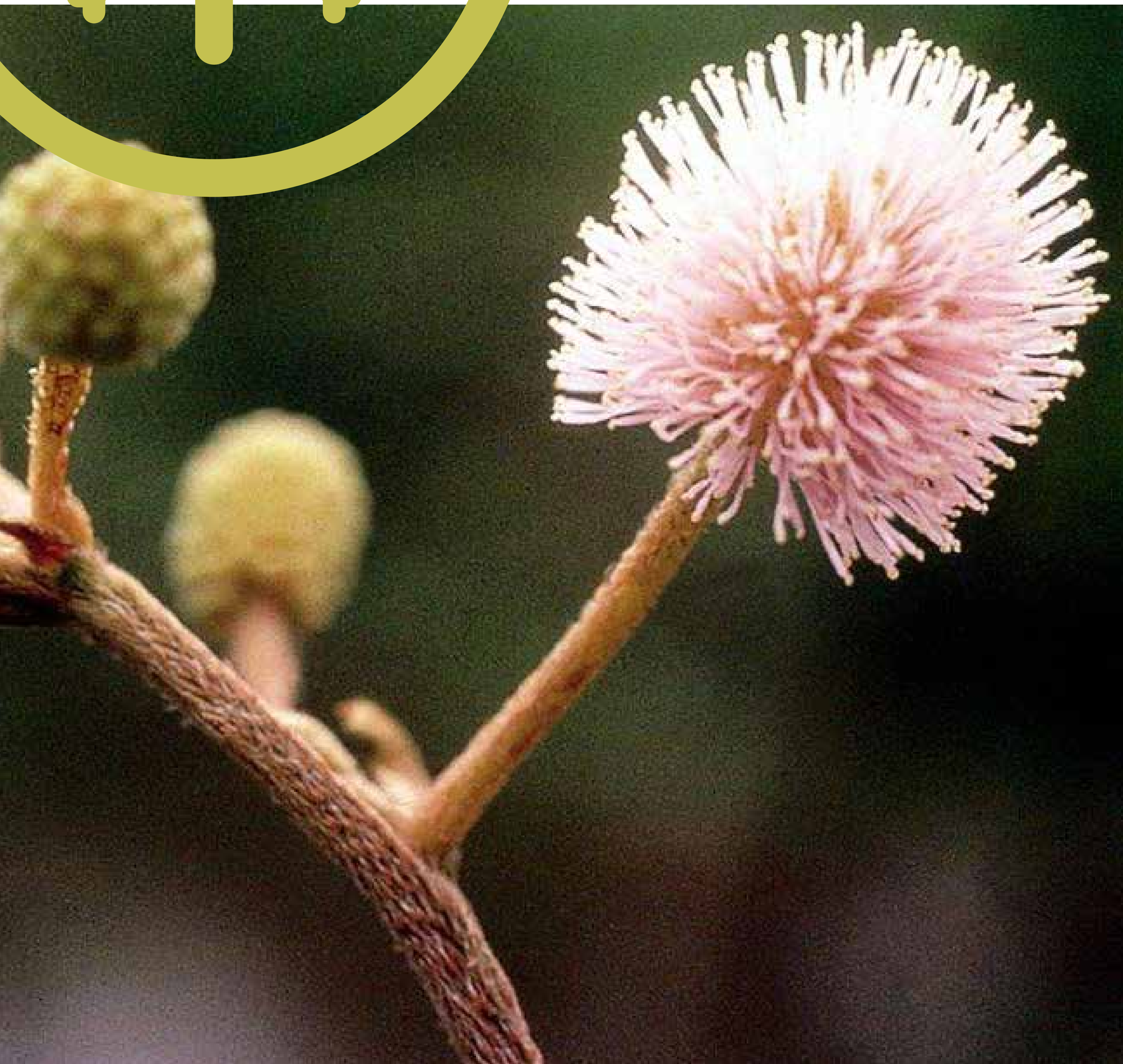
Weeds and novel ecosystems

SECTION 7

The massive change already occurring and projected to occur with climate change has led to the idea that there is a role for novel ecosystems.

***Below**: Image: Giant sensitive tree flower, Source: Northern Gulf NRM.*



NOVEL ECOSYSTEMS

are ecosystems that arise composed of new combinations of species.

NOVEL ECOSYSTEMS

can still provide important ecosystem services such as clean water, soil stabilization, habitat and aesthetic value.

NOVEL ECOSYSTEMS

can therefore challenge our traditional understanding of what is a weed.

HUMAN INTERVENTIONS

often create novel ecosystems, either deliberately, for our benefit, or unintentionally.

A PLANT IS CLASSIFIED

as a weed in a novel ecosystem based on the values ascribed to its impact on ecosystem function and resilience.

Bottom Left: *Image: Cat's ear infestation, Source: BRMG*

7 Weeds and novel ecosystems

The massive change already occurring and projected to occur with climate change has led to the idea that there is a role for novel ecosystems. These are ecosystems that are composed of new combinations of species, but that provide ecosystem functions (clean water, soil stabilization, aesthetic values etc) similar to the ecosystem services provided by intact ecosystems. Novel ecosystems are generally associated with the consequences of human activity. The question then arises as to what is a weed in this context?

There are many examples of novel ecosystems in Australia. Examples may not be obvious, such as remnant bushland in cities where maybe half the plant species are alien in origin. A revegetation project may only include part of the original species assemblage and reflect choices for the ecosystem structure, for example, planting trees and shrubs. A more obvious example is developed pastures, comprised of a majority of alien species (mostly annuals), that are found over a very wide area of the south west and south eastern corners of Australia.

These systems have gone through one or more phase shifts. Phase shifts are where the magnitude of changes has overwhelmed the resilience thresholds of the pre-existing phase to produce a new phase. For example, wetlands along the Murray-Darling River Basin became dry as water from the river was managed, ploughing converted the area to farmland and the latest phase shift has been to a resilient invasion by the weed lippia, to the detriment of biodiversity and agriculture. Returning to a more resilient biodiverse agricultural phase could be achieved through a program of management of lippia, with an emphasis on biological control. After a succession of phase changes, this ecosystem is very different from its original state. Its future depends on the strategy chosen by the land managers.

The main aspect to focus on is impact when assessing if a plant species is a weed in novel ecosystems (see Box 2). Is the plant so abundant that it transforms the ecosystem leaving it with undesirable outcomes? The answer to this question may differ according to different values or interests (e.g. those of farmers, suburban gardeners, conservationists) pointing to the human, subjective and situational context around defining a plant as a weed. Does the weed prevent ecosystem resilience (as in "the capacity of a system to absorb change so as to still retain essentially the same function, structure, identity and feedbacks"; Walker et al. 2004)?

Management decisions need to be made based on the vision and strategy that the land managers have for that ecosystem, followed by a weed management plan that takes into account the values of assets. These ideas are explored in the second part of this document, which focuses on weed management and climate change adaptation.

Development of a vision and strategy for managing weeds under climate change

SECTION 8

Like all good planning, a relevant and useful weed management plan, adapted to climate change, requires first, an agreed vision, second, a strategy to achieve this vision and third, a plan to implement the strategy.

Bottom: *Athel Pine, Source: Mallee NRM, Photo credit: Mallee CMA*

The vision encapsulates or expresses the highest level goals or aims of the plan such as "to significantly reduce the social, economic and environmental impact of weeds in the region".

The strategy sets out the higher level steps toward reaching the vision, such as "to prevent incursions of specific weeds identified as key threats to the region while reducing the impact of current priority weed species x & y and eradicating weed z".

The plan then sets out the detailed steps that need to be taken to achieve the strategy and vision.

A vision and strategy are important not just because they are higher level guides to action, but because they reduce the risk that time and resources will be wasted on unproductive activities. Knowing what you are aiming to achieve is also a way of knowing what your lower priorities are. For this reason, weed management strategies and plans also need to take into account the values of assets to stakeholder communities, as this will influence how much should be invested to protect them. It will help target efforts more effectively and thus ensure limited resources are used for a better outcome.

To some extent the regional vision for weed management is already set, as expressed in national and state laws and policies. Developing strategy and management approaches that flow from an understanding of national and state responsibilities can help regions better define their role and be more targeted and cost-effective with their own approaches.

The sections below will provide a brief overview of how the different levels of weeds governance in Australia guide regional level decision-making about a weed management vision.

8.1 National Level

Weed management does not occur in a vacuum; there are Federal and State laws and policies that provide a framework for strategy. National climate change mitigation policies encourage the planting of vegetation for carbon capture (carbon farming). The planting of invasive species is explicitly excluded based on national lists of weed species. While the national climate change adaptation strategy does not mention invasive organisms, it is recognised that native biological diversity is threatened by climate change and that this is exacerbated by the threat of invasive plants.

The Australian Weed Strategy and the agreement on 32 Weeds of National Significance (WoNS) has provided overall national policy direction for weed issues. For example, in the Australian Weed Strategy there is an objective (1.4) to "Implement weed risk management practices to respond to climate change". These strategies can be seen at ***www.weeds.org.au/*** and they include a listing of climate change actions (Box 10). A summary of national and state strategy and activity in weed management is provided by Cattanach et al. (2013) and can be downloaded at ***rirdc.infoservices.com.au/items/13-019***.

8.2 State and Regional Level

Each State has developed its own weed strategy matching that of the National level (see the Australian Weed Strategy and Cattanach et al. 2013). The degree of mitigation and adaptation responses to weeds and climate change vary between States, from little emphasis, to detailed assessments.

The Australian Weed Strategy and various State Weed Strategies can be used as a starting point for the development of strategic weed management and adaptation to climate change (Box 11) for regional bodies such as Catchment Councils, Natural Resource Management Regions and local governments.

8.3 NRM Planning Level

The strategies mentioned above are specifically focused on weeds. This is strongly emphasised in the determination of 32 Weeds of National Significance, and aligns with a threats-based approach to planning. Alternatively, where the focus of planning is on the assets and values of a region, the "things" of value are identified and a strategy developed for their management. In most cases this strategy would include a weed component. In a resilience approach to planning, weeds might be prioritised for management where they are key drivers impacting on the resilience of systems and causing changes to less desirable states (Folke et al. 2010).

Thus, regardless of the type of planning used by an individual NRM group, weed management will be a component and should thus be part of the vision, strategic plan and implementation plans in

Bottom Right: *Weed identification in the field, Source: Terrain NRM*

a climate-appropriate way. In all cases a clear vision and strategy is needed so that a weed management plan can be developed. The information above will assist and guide regional planners in thinking and engagement with experts and stakeholder groups, to develop a shared regional vision and appropriate strategies for weed management. While the vision will outline the overall weed management goals for the region, the strategy will typically help prioritise the most important weeds, and thereby, the key geographic areas on which to focus management efforts.

The following section examines specific methods of weed management, in terms of climate change and their potential role as adaptation options, that could be included in an implementation plan once a vision and strategy have been agreed. This information will be required for planning based on threats, assets or system resilience.

BOX 10

WoNS Climate Change Actions

Australia's most detailed repository of information on weeds is held in the documents found on the ***www.weeds.org.au*** website. Each Weed of National Significance has a guide to its control. The National Weeds of Significance coordinators led the development of these plans and have developed the following set of climate change actions to complement the plan for each weed (***www.weeds.org.au/climatechange.htm***).

- Identify priority areas for research and monitoring of the response of weeds to climate change.
- Periodically monitor, record and analyse changes in distribution, abundance and impact of weeds to ensure management practices are adapted to minimize future impacts on biodiversity and primary production.
- Develop adaptation methodology and initiatives that reduce the impacts of weeds on biodiversity in future climates and incorporate these into management actions in conjunction with NRM regional bodies and other stakeholders.
- Research and understand the interactions between climate change, weeds, biodiversity and primary production, including negative and positive impacts: Improve knowledge of those impacts to develop specific impact reduction actions. This includes planning for situations where weeds may provide ecosystem functions (e.g. connectivity, harbour) that may no longer be provided by native species under altered climates.
- Raise community awareness and share knowledge of the increased impacts of weeds on biodiversity and primary production under climate change. Provide opportunities for public participation in impact reduction actions

GOOD WEED MANAGEMENT PLANNING BEGINS WITH AN AGREED VISION WHICH GUIDES STRATEGY DEVELOPMENT THAT IN TURN GUIDES PLAN DEVELOPMENT

VISION AND STRATEGY

development are important because they can save resources and time that could otherwise be spent on unproductive activities.

FEDERAL AND STATE LAWS

and policies regarding climate change and weed control provide a framework for managing weeds for climate change.

ACTION POINT

What is the region's weed management vision and strategy?

Download and review the AWS and State strategies mentioned here for guidance.

Have you engaged with regional stakeholders around these guides to develop a shared regional vision and strategies?

Have you engaged with weeds experts to discuss an appropriate weeds vision and strategy for your region?

BOX 11

Framework for a regional weed strategy (based on the Australian Weed Strategy)

Vision statement:
The region's economic, environmental and social assets are secure from the impacts of weeds under current and future climate change.

Strategy Objective 1:
Prevent new weed problems.

Strategy Objective 2:
Reduce the impact of existing priority weeds.

Strategy Objective 3:
Enhance the region's capacity and commitment to solve current and future weed problems.

The Australian Weed Strategy can be found at
www.weeds.org.au/

***Background:** Image: Gleditsia control, Capertee Valley, Source: Greater Sydney LLS, Photographer: Esther Beaton*

Adapting weed management

SECTION 9

This section examines the climate change adaptation options for methods of weed management once a vision and strategy has helped identify the priority weeds to focus on. It starts by outlining three basic approaches that could be taken for the implementation of control options in response to climate change and then considers the key control methods in detail.

Below: *Image: Caltrop, Source: Mallee CMA.*

9.1 Implementation of the strategy

Overall, the management of weeds under climate change could range from:

1. **Continuing current control options.**
These may be the most appropriate methods for controlling weeds under the current climate. Progress in weed control tends to be incremental; there has been no radical change in methods in recent times. However, continued investment in improving weed control could take into account climate change as it progresses. The rate of incremental evolution needs to be appropriate for the observed changes. An example is the management of annual weeds for herbicide resistance (see Section 9.5).

2. **Adopting control options suitable for weed management under current extreme weather conditions.**
This is the "no regrets" approach that aims at developing management techniques that are useful under today's climate (and weather extremes) and by consequence these are methods likely to be suitable for use under future climates. An example would be to preferentially control cacti that might be found near ephemeral water courses in dry areas. Extreme events (e.g. flooding) have the potential to spread the cacti to a much larger area making future control difficult. Removing the plants from near watercourses will reduce that risk.

3. **Developing new weed management techniques adapted for climate change.**
This will require new approaches that take into account projected future climates. An example is the biological control of opuntioid cacti where new biological control agents or a different approach to control might be needed in the face of increasing CO_2 concentrations (see Box 13).

Within these various management approaches we also need to consider what are the most appropriate responses to climate change for quarantine, eradication and containment (see Box 12 for definitions). Likewise, how are existing methods, herbicides, biological control and other techniques best adapted for climate change.

Right:
Image: Woody weed control: Pussy Willow/Grey Sallow (Salix cinerea)
Source: Greater Sydney LLS
Photographer: Esther Beaton

DECISION POINT

Consider three potential types of strategies to guide management of invasive plants under climate change:

- Continue current control options
- Use control options suitable for current extreme events, and/or
- Develop new control methods adapted for climate change

KEY WEED CONTROL METHODS

that require (re)consideration include:

- Quarantine barriers
- Eradication and/or containment
- Biological control
- Herbicides
- Cultivation

Background:
Image: Burning buffel grass.
Source: Natural Resources South Australian Murray Darling Basin
Photographer: Ms Lauren Burdett

BOX 12

Some terms used in weed management

Eradication:
The removal of all individuals from an area into which migration is unlikely to occur (Myer et al. 1998).

Containment:
Deliberate action taken to prevent range expansion within a predefined area (Clarkson and Grice 2013, Grice et al. 2012, 2013).

Control:
The use of chemicals and other means to cause a reduction in density of a plant population.

Classical Biological Control:
Introduction of host specific organisms (usually arthropods or fungi) for the control of invasive plants. It is called "classical" because it has been practiced for over 100 years. Other forms of biological control include augmentation (e.g. bioherbicides) and conservation approaches (McFadyen 1998).

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THE CURRENT OVERALL NATIONAL APPROACH TO QUARANTINE OF INVASIVE PLANTS IS EXPECTED TO BE ADEQUATE AS A RESPONSE TO CLIMATE CHANGE.

ACTION POINT

Review the location of regional quarantine barriers and determine the species to be excluded.

Develop information packages for local land managers on developing quarantine approaches adapted for climate change.

***Bottom Left:** Image: Establishing a quarantine area, Source: Rangelands NRM, Photographer: Jane Bradley*

9.2 Quarantine Barriers

National

The current overall national approach to quarantine of invasive plants is expected to be adequate as a response to climate change. There will continue to be a threat of invasion from overseas, but the source areas will not change greatly as climate changes. However, the weed risk assessment (WRA) protocol does not have an assessment component specifically for climate change (***www.daff.gov.au/ba/reviews/weeds/system***).

States

The general southwards invasion projected from the various studies modelling species distributions points to the need to establish new quarantine barriers as an adaptation response. These could be at state boundaries, such as the Queensland – New South Wales border.

Regions

Likewise, there may be situations where it is feasible to strategically place quarantine barriers within corridors used as an adaptation response for nature conservation for a NRM region, although in many cases the small size and location and lack of natural barriers would make quarantine barriers difficult.

The CSIRO climate change and invasive plants report for NRM regions of South Australia (Kriticos et al. 2010) identified potential quarantine barriers within South Australia. In the case of Kangaroo Island a natural level of quarantine exists, which can be used to back a biosecurity plan (***www.naturalresources.sa.gov.au/kangarooisland/about-us/our-region/protecting-ki***). Other potential barriers could be used to reduce weed spread between Eyre, Yorke and Fleurieu Peninsulas. The south east of South Australia has an increased weed threat under climate change and could be protected from invasion, but this would need to consider the level of threat of invasive plant spread from Victoria.

Farms and nature reserves

At this level there will not be legislative backing, so individual action is the most effective means of preventing invasion at the farm or small nature reserve scale. Farm level biosecurity (including farms at all scales, from peri-urban hobby farms to outback stations) will be important to minimise negative impacts of or prevent plant invasions. Having a biosecurity approach to new plant invasions under the current climate, will ensure that the practices and awareness is in place to deal with future, climate change related, biosecurity issues. In addition, monitoring for new weed problems and seeking advice may result in preventing a future weed problem.

__Top Right:__ Image: Biological control release for Salvation Jane, Source: Natural Resources SAMDB, Photographer: Mr Sandy Cummings

9.3 Eradication and containment

Plants are relatively slow to invade (compared with insects, for example), which gives greater opportunity to instigate eradication or containment. Both control objectives should not be undertaken lightly as considerable time and funds are usually required for eradication (for example, 12 or more years).

A policy of containment implies that control actions against an invasive species will have to go on forever (but this still may be very worthwhile).

An adaptation response is to preferentially target search and control efforts in the area that falls within the region of possible future migration under climate change. Species distribution models should help in delimiting the area where control is needed, as well as the likely direction of species migration.

DECISION POINT

Eradication requires very high resource commitments in the short term; a containment policy implies that control actions will have to go on forever. Both may offer considerable benefits for the cost. Which weeds in the region are appropriate for these different goals?

DECISION POINT

Think about weeds in your region that are currently managed with a biological control agent: are there risks of mismatch under a changing climate such that any of these weeds could escape their control agents? Can you monitor that situation?

WHILE BIOLOGICAL CONTROL

methods generally have a history of success in Australia, interactions between biological control agents and their host weeds are complex and could be compromised by climate change.

Left:
Image: Sea Spurge control
Source: NRM North
Photographer: Emma Williams

Bottom Left: *Image: Lantana, Source: BMRG, Photographer: Lalith Gunasekera*

9.4 Classical biological control

Over 90 weed species have been targeted in Australia using some 242 biological control agents, mainly arthropods and pathogens. These have provided permanent and effective control for some major weed species. Part of the process of biological control is to search for and select biological control agents in regions that match the part of Australia that has been invaded. Usually climate change is not considered in the assessment of the agent-target association.

The changing dynamics between target weeds and their biological control agents is likely to be complex because the environmental response of the weed may not be the same as the agent's or their interaction. In addition, the changed climate may become unsuitable for the existing biological controls. Interaction between increased CO_2, fast growth and plant nitrogen levels needed to support biological control agents such as herbivores may change.

Some of the main factors that may affect biological control include:

- Increases in temperature leading to increased growth rate by the plant could enable it to "escape" the herbivore
- Changes to rainfall that could make the plant and its environment unsuitable for the agent
- Higher CO_2 concentrations (see Box 13)
    - o Increased carbon to nitrogen ratio in the plant which could slow herbivore development
    - o Changes to plant secondary chemistry which make the plant less palatable

Two biological control examples show some of the complexity of assessing the interaction between biological control agents, invasive plants and climate change. The growth of the leaf miner *Dialectica scalariella* on Patterson's Curse, *Echium plantagineum*, was mostly related to higher temperatures and not CO_2 concentration, but at the cost of poorer survival of the leaf miner.

A second example concerns the chrysomelids, *Octotoma championi* and *O. scabripennis*, which are leaf miners as larvae and leaf feeders as adults on the widespread invasive shrub, *Lantana camara*. The insects were affected by increased leaf loss at higher temperatures, but insects preferred leaves grown at normal levels of CO_2. In both cases the plants showed the typical response of increased biomass and reduced leaf nitrogen and increased carbon - nitrogen ratio when grown under elevated CO_2.

Adapting biological control

Adaptation responses suitable for the biological control component of weed management include:

- Monitoring the weed – biological control interaction to determine if additional controls are required

ACTION POINT

Adaptation responses to assist biological control include:

- Monitoring biological control agent effectiveness
- Redistributing biological control agents to suitable locations
- Assessing new biological control agents

***Background:** Image: Opuntia elatior infestation, Murchison Range, WA, Source: Rangelands NRM, Photographer: Andrew Reeves*

- Prioritising biological control agent redistribution to areas with a more favourable climate
- Searching for and assessing new biological control agents from overseas areas with climates that anticipate the future climate of target regions in Australia

BOX 13

Increased atmospheric CO_2 and the biological control of cacti in Australia

The role of carbon dioxide in insect behaviour may be particularly relevant to biological control in Australia, in relation to one of the best known examples of successful biological control worldwide: *Cactoblastis cactorum* moth and its control of opuntioid cacti (e.g. Prickly Pear) (Figure 9). To detect oviposition sites on healthy leaf pads of *Opuntia stricta*, the female moth uses the CO_2 gradient generated by the plant's CAM photosynthesis mechanism (a type of photosynthesis typical of cacti, other types of photosynthesis are C_3 and C_4 – see Box 3). The eggs hatch on the leaf pads and the larvae then consume the leaf pad from the inside, leading to death of the cactus and control of the invasion.

While the moth's sensors are adapted to pre-industrial levels of atmospheric CO_2 concentration, a CO_2 enrichment experiment showed that likely future CO_2 levels are outside the range that tested moths could detect. The implication is that the moth may fail to recognise its host cactus under increased CO_2 levels. The invasion of Opuntia cacti in Queensland and New South Wales in the 1930s covered more than 25 million hectares and at its peak was expanding at about 50 ha per hour. Today, the cactus is still scattered at low levels across the old invasion area. Any widespread failure of the *Cactoblastis* biological control agent due to rising atmospheric CO_2 concentrations could lead to a proliferation by opuntioid cacti that would be at the scale of a national disaster for Australia.

The adaptation response of invasive plant managers is to monitor the levels of control of cactus by *Cactoblastis* over the invasive plant's range. The monitoring would indicate if other existing biological control agents could become more effective or additional biological control agents could be sought. Additional control methods could be applied or investigated if it looks like the biological control is failing. There is also an urgent need for research to establish whether or not the moth could acclimate to the increased CO_2 levels or if there is genetic variability and the potential for evolution to maintain the ability to detect the host cactus.

Figure 9.
Photo on left, invasion of *Opuntia* sp. in Queensland before biological control (photo from Dodd 1940) and photo on right, invasion of *Opuntia* sp. in Queensland after biological control (photo from Dodd 1940).

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Stange, G., Monro, J., Stowe, S. and Osmond, C.B. (1995) The CO_2 sense of the moth Cactoblastis cactorum and its probable role in the biological control of the CAM plant Opuntia stricta. Oecologia 102, 341-352.

Bottom: *Image: Weed spraying, Rubicon River*
Source: Goulburn-Broken CMA, Photographer: Sue Kosch

9.5
Herbicides

Herbicides are an integral part of weed control in Australian crops and are increasingly used to control environmental weeds. Research both overseas and in Australia show that weedy species have an increased tolerance to herbicides when grown under elevated CO_2 conditions. Moisture stress is also likely to decrease the effectiveness of herbicides. However, where Australian cropping regions differ is that they already have some of the world's highest incidences of herbicide resistance.

Herbicide resistance is widespread in cropping areas of Australia. It can potentially develop within a relatively short period after eight consecutive years of application of the same herbicide. Many invasive plants in agricultural situations have short generation times, mostly with annual generations. It is this combination of high selection pressure (herbicide application), short generation time, and inherent genetic variability that allows for the rapid evolution of herbicide resistance. It is reasonable to assume that these invasive plants could also evolve rapidly in response to climate change. This implies that today's major agricultural weeds (e.g. wild radish, annual ryegrass) are likely to remain as major problems under climate change. This assumes that current agricultural practices continue.

This indicates that the main adaptation response is to manage for herbicide resistance through an integrated approach to controlling agricultural weeds. With a drying environment, this integration is likely to include a move away from continuous cropping to include a greater reliance on pasture phases. Innovative management of weeds, including careful use of genetically modified crops, will be required to avoid a return to weed species favoured by crop-pasture rotations in the past (e.g. doublegee, *Emex australis*), or changed cropping practices (e.g. hoary cress, *Lepidium draba*).

WEED TOLERANCE TO HERBICIDES

is likely to increase due to elevated CO_2 levels and greater moisture stress. The capacity of weeds to rapidly evolve and adapt means today's major agricultural weeds are likely to remain major problems under climate change.

DECISION POINT

Adaptation responses to consider:

- Pasture phases in rotation rather than continuous cropping
- Improved methods of herbicide application
- Cultivation and fire as strategic weed control options
- New innovations in weed control such as weed seed destruction

Top:
Image: Spraying Blackberry
Source: Greater Sydney LLS
Photographer: Esther Beaton

DECISION POINT

Carefully assess proposed control options to ensure they are not maladaptive, using examples from the past, other regions or those listed below, to help identify future risks.

Herbicides are widely used and transported unintentionally away from the application area, for example, in runoff from cane farms that eventually arrives in the ocean and on the Great Barrier Reef. The negative effect of herbicides on corals is additive to the negative effect of increased sea surface temperatures.
The adaptation of new methods of herbicide application makes possible the reduction of herbicide in runoff, for example into the Burdekin River, effectively removing a stressor making corals more sensitive to sea surface temperature increases.

9.6 Other control methods

Cultivation has been the weed control method used over most of agricultural history. Climate change, especially under a drying environment, may make the general use of cultivation problematic given the increased risk of wind erosion and soil moisture loss.
The adaptation response might be to use cultivation strategically as part of an integrated weed management approach.

Likewise, increased temperatures will make fire an increasingly risky weed management tool. Frequent fires at certain times of the year might not be the appropriate adaptation response depending on the response of invasive species, which might increase in abundance under frequent fire. Also, consideration needs to be given to the impacts of fire on the vegetation being protected.

It is difficult to see how mechanical weed control (chain pulling, stick raking, blade ploughing and specialised weeding machines) can be adapted for the increased risk of climate change. Recent developments such as mechanical destruction of seeds as part of the harvesting process will continue to be useful. Managing grazers (goats, camels, kangaroos, cattle etc) as part of a pest management adaptation response may also be beneficial to weed control. The management plan for pest animals (see section 13 for the web link) also provides a model for how to involve the community in a weed management plan.

Considerable attention has been given to robotic means of weed control. These technological innovations for weed control will improve current techniques, such as herbicide use, and may provide specific adaptation responses to climate change, such as enabling highly targeted herbicide spraying during the night, when is it cooler.

Bottom: Image: Opuntia elatior, Source Rangelands NRM, Photographer Andrew Reeves, DAFWA

9.7 Maladaptation

Are there clear examples of maladaptation for climate change in weed management? Maladaptation means adopting a response to climate change that in the end is detrimental to agriculture or the environment. Maladaptations are difficult to predict. The following examples are intended only to illustrate the concept.

Example 1.
Spiny nursery shrub
Control and containment lines are established for a spiny shrub in rangelands in areas that are potentially under threat by the species range expansion under climate change. Climate change also leads to an increase in grazing pressure (by native animals and livestock) in the same area leading to the extinction of small plant species previously protected from grazing by growing under the spiny shrub.

Example 2.
Controlling the wrong weed
Invasive plant control expenditure is spent on managing alien species that are moving through vegetation corridors established for connections between landscapes. However, some native species have also used these corridors to move to new regions, and in these regions they have become weedy with negative impact on their recipient ecosystems. Even so, they cannot be managed because of legislative barriers that classify them as protected native species.

Example 3.
Water-wise weeds
Invasive cacti have recently been included as Weeds of National Significance, thus requiring national coordination for their control. A possible maladaptation to climate change could be the promotion of "water wise" gardens based on cacti without considering the risk of subsequent invasion by garden escapees that are pre-adapted to a drying environment.

Example 4.
Inviting trouble, introduction of new pasture species
Introduction of new, but potentially invasive, pasture species as a climate change response for grazing industries. Very often the characters that are being targeted for new pasture species are the same characters that define an invasive weed with negative impacts (e.g. drought tolerance, fast growth rates, high reproduction). The past record of pasture species introductions has led to many new weeds (Lonsdale 1994).

Example 5.
New crops or invasive species?
An example of new crops is the planting of species suitable to be used for biofuel crops or plantings of vegetation designed for carbon capture. New crops should be experimentally assessed and monitored to assess the risk that they might become weeds and to show the controls that may reduce this risk (Box 14).

BOX 14

Biofuels: new crops or invasive species?

Climate change and concerns about the sustainability of traditional sources of energy (and links between these drivers) are leading to the formulation of ambitious targets for renewable energy. Biofuel crops, which may be either native or alien, offer potential benefits to a world adjusting to the challenges of climate change and declining fossil fuel stocks. However, the plant attributes that make plants ideal biofuel crops are frequently the same as those that make them invasive: fast growth, high yields, and tolerant of a wide range of environmental conditions (Barney and DiTomaso 2011, Ragu et al. 2006).

In particular, tropical lignocellulosic crops (woody trees and grasses) and oil seed crops (e.g. *Millettia pinnata, Pongamia* (Figure 10)) have huge potential for use as feedstocks (Richardson 2013) and their feasibility for large-scale production of energy is currently being investigated in Australia. However, there is considerable uncertainty regarding the commercial viability of many potential biofuel species in Australia. For example, despite there currently being no established industry or demand for Pongamia oil in Australia, and significant uncertainty around many aspects of the production system (Murphy et al. 2012), an increasing number of growers are investing in large-scale plantations. It is inevitable that there will be some abandonment of plantations due to their being commercially unviable. Prudent risk management requires balancing the potential climate change mitigation benefits of biofuel crops with measures to reduce maladaptive impacts on biodiversity, other production systems and livelihoods, should these species become an invasion risk (Kriticos et al. 2013).

Figure 10.
Pongamia plantation in north Queensland (source: Helen Murphy, CSIRO).

Sources

Barney, J.N. and DiTomaso, J.M. (2011) Global Climate Niche Estimates for Bioenergy Crops and Invasive Species of Agronomic Origin: Potential Problems and Opportunities. PLoS ONE 6, e17222.

Kriticos, D.J., Murphy, H.T., Jovanovic, T., Taylor, J., Herr, A., Raison, J. and O'Connell, D. (2013) Balancing bioenergy and biosecurity policies: estimating current and future climate suitability patterns for a bioenergy crop. GCB Bioenergy, doi: 10.1111/gcbb.12068.

Murphy, H., O'Connell, D., Seaton, G., Raison, R., Rodriguez, L., Braid, A., Kriticos, D.J., Jovanovic ,T., Abadi, A., Betar, M., Brodie, H., Lamont, M., McKay, M., Muirhead, G., Plummer, J., Arpiwi, N., Ruddle, B., Saxena, S., Scott, P., Stucley, C., Thistlethwaite, B., Wheaton, B., Wylie, P. and Gresshoff, P. (2012) A common view of the opportunities, challenges, and research actions for Pongamia in Australia. BioEnergy Res 5, 778-800.

Raghu, S., Anderson, R.C., Daehler, C.C., Davis, A.S., Wiedenmann, R.N., Simberloff, D. and Mack, R.N. (2006) Adding biofuels to the invasive species fire? Science 313, 1742-1742.

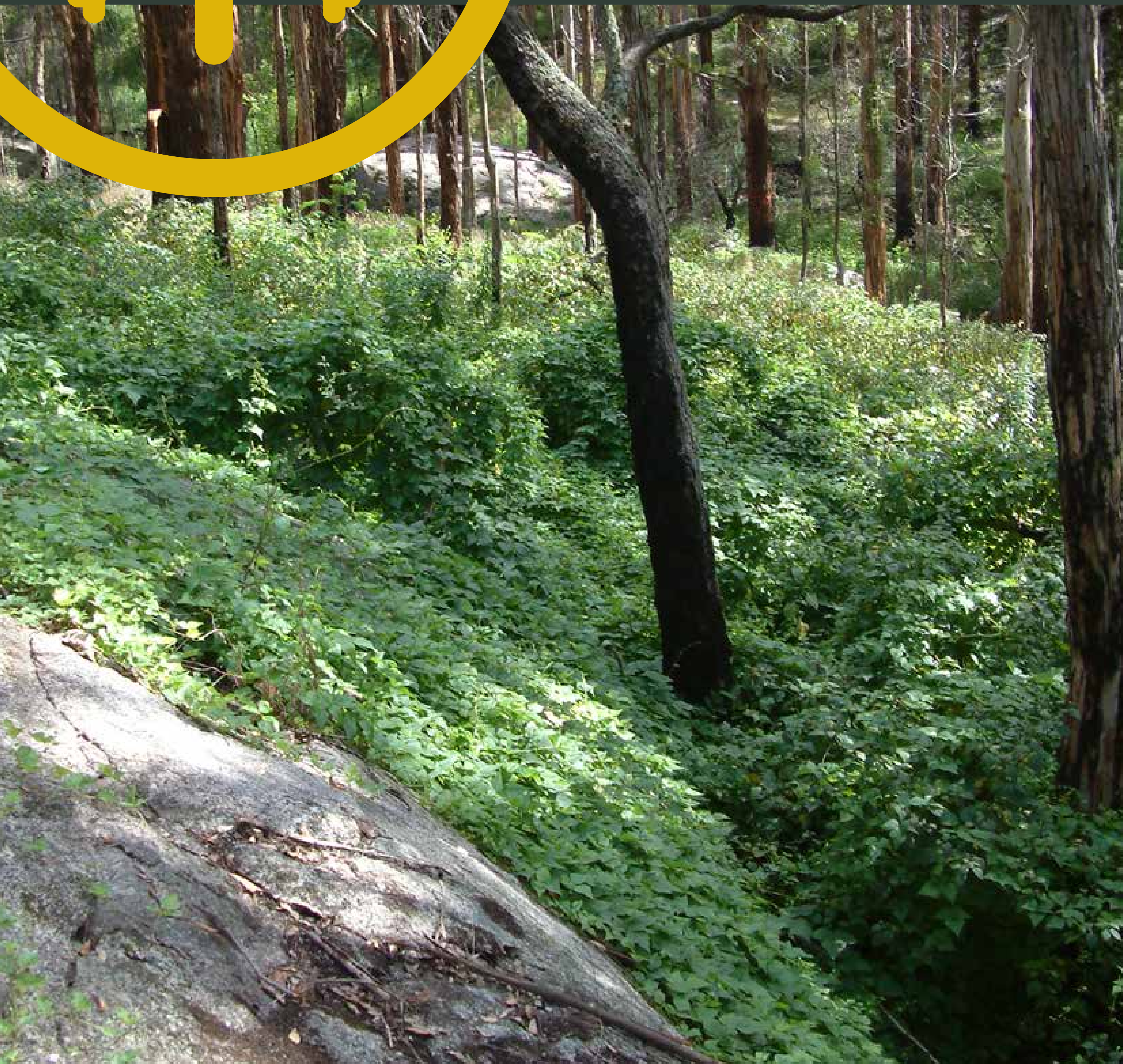
Richardson, D.M. (2013) Lessons learned: how can we manage the invasion risk from biofuels? Biofuels 4, 455-7.

Framework for a weed management plan that addresses climate change adaptation

SECTION 10

This section set outs the key elements of a weed management plan within a climate change adaptation context.

Below: *Image: Dolichos in the Porongorup Range, WA*
Source: South Coast NRM, Photographer: Matthew Kennewell



Bottom: Image: Willow control, Source: NRM North, Photographer: Alistair McKinnon

10
Framework for a weed management plan that addresses climate change adaptation

Once a vision and strategy have been agreed (Section 8) a weed climate adaptation management plan can be developed. The following framework outlines a standard weed management plan that follows an adaptive management approach and includes consideration of risks and adaptation options under climate change.

ACTION POINT

This plan framework can be used in a number of ways:

- For NRM groups that already have a weed management plan (WMP) that considers climate change, it could be used to check it has covered the key issues
- For NRM groups that have a WMP that doesn't yet incorporate climate change, use this framework to identify where your plan may need to be modified
- If your group doesn't yet have an explicit WMP, you could use this guide to help you build one that incorporates climate change adaptation

It may help to consult a range of examples of climate change adapted invasive plant or weed management guides (see Section 13).

Figure 11.
General components of weed management planning through an adaptation lens.

The Framework

comprises five main planning components: (i) assessment, (ii) strategy and prioritisation, (iii) implementation, (iv) monitoring, and (v) reflection. This framework structure aligns with a general adaptive management approach but information is provided (below) on how each component under climate change may differ somewhat from a generic approach. Further, each component is considered an iterative process, because the most effective responses to weed problems under climate change may not be known and outcomes may only be achieved after trying a range of options, assessing the responses, and making appropriate changes.

Step 1
Assessment

Under climate change, assessment may need to include:

- new weed threats from outside the region
- existing weed threats that may get worse
- new weed threats from changing land uses and other adaptation responses

Step 2
Strategy & Priorities

Under climate change, strategic planning and prioritisation may be different because:

- an increasing number of potential weed problems may require stricter prioritisation to focus on weeds that impact what communities value
- priorities may need to shift substantially over time as new threats emerge
- increased coordination with national and state level strategies will be helpful for minimising regional effort

Step 3
Implementation Planning & Action

Under climate change, implementing weed management may need to be different because:

- the effectiveness of some forms of weed control is expected to decrease
- new weeds may need new forms of control
- control measures suitable for extreme events rather than average conditions may be a robust approach

Step 4
Monitoring

Under climate change, monitoring may need to be different because:

- a cost-effective approach may involve lots of monitoring for new threats rather than immediate management of any new species detected
- widespread monitoring for new threats could involve high levels of community engagement

Step 5
Reflection

Under climate change, reflection may need to be different because:

- it may need to happen more frequently to ensure new threats detected by monitoring can be acted on quickly
- it may need to consider adaptation responses in other sectors or regions that affect weed distribution

10.1
Assessment

Background information

- Decide on the scale (consider uniformity and size of the region)
- A stock-take of all weeds naturalised in the region including their current distributions. This needs to include both alien plant species and invasive native plant species
- Climate change projections for the region
- Legislative framework applicable to the region
- Sharing of data and experience of weed management with neighbouring regions
- Consider bringing in weed specialists to workshop key weeds species and help develop your weed management plan

Risk assessment of potential threats from outside the region

- Plant species in neighbouring areas that represent a potential threat to the region (quarantine species) based on likely trajectories with climate change
- Consult species distribution models as well as consider potential for weed dispersal from human adaptation responses to climate change
- Declared or noxious weed species
- Specific WoNS related management (*see www.weeds.org.au*)

Risk assessment of potential threats from inside the region

- Species naturalised in a few locations and that represent a future threat to the region (sleeper species)
- Species grown in horticulture or gardens that represent a future threat to the region (sleeper species)
- Species, while not of local concern, that represent a future threat to neighbouring regions

Weeds of National or State Significance

- Declared or noxious weed species
- Specific WoNS related management (*see www.weeds.org.au*)

DECISION POINT

Think about the climate change trends and projections for your region, which weeds would you expect to invade, proliferate or recede (and in what direction) if your region becomes:

1. **warmer & drier?**
2. **warmer & wetter?**
3. **suffered from more or less:**
    a. **flooding?**
    b. **fire?**
    c. **wind?**
    d. **frost?**

Think about the types of human climate adaptation responses likely to occur in your region. Which weeds would you expect to invade, proliferate or recede (and in what direction) due to these different responses?

The answers to these types of questions may help you prioritise the types and locations of weeds to focus future management efforts on.

DECISION POINT

Are you aware of the types of species distribution models you are using, or potentially could use, and the specific limitations associated with them (see Section 4)?

Right: Image: Gorse, Cape Portland, Source: NRM North, Photographer: Emma Williams

10.2
Strategy and prioritisation

Select the priority weed species (transformer species or species causing negative impacts)

- Assess for invasiveness, impact and feasibility of control (formal weed risk assessment can help with this assessment)
    - o Impact to include social, economic and environmental aspects:
        - In agriculture
        - In the environment

From this, identify the key regional assets and geographic locations requiring most management focus.

ACTION POINT

Climate adaptation responses, such as restoration of landscape connectivity, refugia protection and managed relocation, may change weed dispersal pathways in new ways. Incorporate these considerations into your assessment of potential threats.

DECISION POINT

Given resource constraints, it is unrealistic to manage every weed species in every location.

Rather, the emphasis needs to be on:

- Identifying priority future weed species and problem areas
- Identifying the most appropriate control options in the context of available resources
- Enhancing regional capacity
- Monitoring the spread and impact of priority weeds
- Evaluating the effectiveness of management actions, and
- Adjusting the plan accordingly.

Bottom: Image: Sea spurge control, Source: NRM North, Photographer: Allison Hugo

10.3 Implementation Management

Consider an appropriate implementation approach for the key weed problems identified:

- Continue current control options
- Use control options suitable for current extreme events
- Develop new control methods adapted for climate change

Management options (see section 9 for more details)

- Quarantine barriers
- Eradication and containment
- Herbicide issues (runoff, resistance)
- Biological control options (redistribution)
- Cultural control options (fire, cultivation, weeding by community groups)
- Legislative framework
- Can the weed be put to positive use (biochar, bioenergy)?

Capacity issues

- Engagement with weeds experts to guide implementation
- Support for and engagement with local/regional experts knowledgeable on invasive plants
- Community engagement to build weed awareness
- Training on identification of invasive plants, recognition of weed impact and weed control
- Support for and involvement in weed research

ACTION POINT

Adaptation responses to combat invasion from corridors include monitoring, pinch points and translocation.

ACTION POINT

Review the location of regional quarantine barriers and determine the species to be excluded.

Develop information packages for local land managers on developing quarantine approaches adapted for climate change.

ACTION POINT

Adaptation responses to assist biological control include:

- Monitoring biological control agent effectiveness
- Redistributing biological control agents to suitable locations
- Assessing new biological control agents

Bottom: Image: Surveying lower lakes during drought, Source: Natural Resources SAMDB, Photographer: Mr Joel Horn

10.4 Monitoring

- Probably the most important action to manage potential weed invasions is to monitor the consequences of shifts in distributions of species, in order to recognise negative impacts when they arise
- Monitoring for new invasions can provide the early detection needed for making timely management decisions
- Consider method and timing of monitoring to detect weeds responding to climate change
- Monitoring weed impacts will help evaluate which are the priority weeds to focus on in future
- Monitoring the effectiveness of management actions is also important to help evaluate adaptation responses

ACTION POINT

Monitoring will be of most value in places where early warning signs are most likely to be detected. Decide where these are likely to be in your region based on:

- directions of potential distribution shifts
- where connectivity may provide movement pathways
- where shifting land uses might provide new opportunities for weeds

Consider whether a widespread but simple community monitoring effort could be employed in these areas.

EVALUATING THE EFFECTIVENESS of the management plan and actions taken to respond to climate change, naturally leads to reassessment of weed distributions and impacts. This then leads back to the Assessment phase in a continual adaptive management cycle.

Under climate change, reflection may need to be different because:

- It may need to happen more frequently to ensure new threats detected by monitoring can be acted on quickly
- It may need to consider adaptation responses in other sectors or regions that affect weed distribution

***Bottom:** Image: Boxthorn control, Source: NRM North, Photographer: Friends of Bass Straight Islands Wildcare Inc.*

10.5 Evaluation and reflection

Noting achievement against the plan

- Was it under- or over-ambitious?
- Effectiveness of strategy and implementation
- Influencing factors and mitigating circumstances
  - o Will these continue?
  - o New ones?

Ensure appropriate method and timing of review

Alignment with current and revised strategies

Revision of the plan

Right: *Image: Weed identification workshop, Source: Terrain NRM*

10.6 Other planning considerations

Some of this planning will require accessing specialist knowledge to identify possible sleeper and transformer species. The many sleeper species are identified in State weed strategies, but the best long term plan is to have monitoring in place for potential problems. Serious transformer species are usually well known and are a small percentage of all invasive plants (perhaps about 1%).

Holding workshops among local weed specialists can address selection of important weed species as well as the weed risks due to climate change. More detailed systematic analyses have been made for various regions, and this represents a more robust method for developing a priority list of weed species.

Once a set of priority species or actions are decided then this information can be fed into planning based on threats, assets or resilience thinking. An example of these types of plans includes those prepared by the Adelaide and Mt Lofty Ranges NRM region.

A weed focused approach is adopted in the plan running from 2008 to 2014 (***www.naturalresources.sa.gov.au/adelaidemtloftyranges/about-us/our-regions-plan***). In Table 24 of this plan, a list of weeds is presented with the management priority for each species. This is backed by a thorough analysis of weeds and climate change published in a scientific paper (Crossman et al. 2011). The latest AMLR strategic plan (2014 – 2024) builds from the earlier plan and takes a systems (or resilience) approach. Each component of the landscape is assessed separately, but now there is little mention of specific weeds although the need for weed control is clearly identified. It is likely that both a weed plan and a plan for resilience is needed.

SOME OF THIS PLANNING

will require accessing specialist knowledge to identify possible sleeper and transformer species. Holding workshops among local weed specialists can help identify important weed species under climate change.

DECISION POINT

Weed management plans can be based on an assets, threats and impacts approach or a systems resilience approach.

Both can be helpful but it is probably more important to identify specific weed threats to key assets first. Potential impacts on system resilience can then be assessed at a later stage.

What are the major gaps in our knowledge?

SECTION 11

Australia has a well developed weed management system, based on considerable research.

This provides a good basis for addressing new issues such as climate change. The following gives some ideas of directions for research, without being comprehensive and prescriptive.

Below: *Image: Harrisia cactus infestation, Source: Northern Tablelands Local Land Services, Photographer: Jonathon Lawson*

11.1
Strategic needs

- Very few strategy documents or plans concerning weeds have any detail on adaptation responses to climate change. This Guide will hopefully assist planning that will help remedy this situation
- Policies and regulations, including declared or noxious species, need to include the risks due to climate change

11.2
Research needs

- Long term monitoring of weed species composition and populations is needed to detect and document climate change versus ecosystem change that comes from new invasions
- There is an urgent need to assess the risk of biological control agents decoupling from their hosts (especially of opuntioid cacti (Box 13), and to put in place suitable adaptation procedures to maintain the effective management, biological control or otherwise, of weeds
- The balance in geographic coverage of species distribution modelling needs addressing with a focus on species that are threats to central and northern Australia
- A better understanding is needed of the ecological, economic and social impact of invasive plant species, both positive and negative, in the context of climate change
- Climate change has the potential to change people's perceptions of what is an invasive plant or even what is alien, because so many other changes may be occurring, including an increase in the prevalence of novel ecosystems. This will present a major challenge to the vision, strategy and planning of weed management
- New forms of weed management, underpinned by revised conceptual and policy frameworks, may be required under climate change, especially for novel plant communities

WHILE THE PRIMARY RESPONSIBILITY for many of the actions listed here tend to reside with other organisations, NRM groups can do a lot to help, especially around:

- developing climate adapted weed plans
- hosting, informing, monitoring or otherwise assisting research activities
- fostering innovative forms of weed management
- communication with stakeholder groups and the community
- informing policy discussions
- sharing your progress and challenges with neighbouring NRM regions

Top:
Image: Mesquite (Prosopis sp.) Longreach area.
Source: Desert Channels Queensland NRM

Bottom: *Image: Gorse seedling removal, Blue Mountains, Source: Greater Sydney LLS, Photographer: Esther Beaton*

11.3 Communication needs

Communication on weed issues is needed to help in the development of adaptation responses for management of weeds under climate change:

- Regional guides to weeds and training in weed recognition at the level of communities. How to identify weeds and how to recognise important species should be included in the training
- It needs to be established what the community wants as far as controlling weeds. This could form part of developing a weed strategy with adaptation to climate change
- At some point the issue has to be addressed of how to manage the displacement of all plant species, including native species
- Sharing of data and experience of weed management between NRM regions
- Information about adaptation responses could be used to not only harness community support, but get on-ground individual action
- Scientists researching and managers controlling weeds need to communicate the options for the future in a manner that helps inform choices for management of weeds

12
Conclusions

Weeds are a major threat to agriculture and the environment. That threat will continue because of the large number of potentially invasive species that are already in Australia, or that might arrive by new introductions. Climate change, be it through future global change or through the occurrence of extreme events, adds another layer of risk to the existing risk from weeds. This Technical Guide summarises the science and outlines an adaptive management approach.

The science of invasion ecology indicates that the suite of weed species will change and that impact may increase under climate change. Increased temperature, changed rainfall, increasing CO_2, changes in extreme weather events and frosts coupled with land use change will be the drivers for the changed weed profile. Species distributions will move, mostly in a southwards direction in Australia. This will modify the biosecurity threat, including from native invasive species. Corridors may both aid management or be new conduits for invasion, especially to refugia.

This Guide has emphasised the importance of NRM regional groups developing an agreed vision and strategy for addressing weeds issues under climate change, from which a more detailed weed management plan can be developed. It provides a general adaptive management framework to guide weed management planning and emphasises the importance of identifying the main potential weed threats to aid strategic prioritisation of resources to key species, locations and control methods.

The management of invasive plants under climate change could range from:

1. Continuing current control options (incremental evolution).
2. Adopting control options suitable for invasive plant management under current extreme conditions (the no regrets approach).
3. Developing new invasive plant management techniques adapted for climate change (future proofing approach).

Each of these approaches will need to be modified as community expectations change once confronted with new invasions accompanying global change. Weed management will move into uncharted territory over the next century. Adaptive planning to learn from our efforts and continued research to provide more options will be necessary to assist the adaptation of weed management to meet social, economic and environmental needs.

While the perennial problem of limited resources may make the task ahead appear daunting, applying the principles of adaptive weed management planning outlined in this guide should help NRM groups be prepared for most eventualities. One of the most cost effective responses to climate change will be monitoring the consequences of shifts in distributions of species, in order to recognise negative impacts when they arise, so that timely action can be taken. Not every weed species needs to be the focus of intensive management, rather it will be the early identification and targeting of priority weed threats and learning from past efforts that will ensure NRM groups are best situated to respond to future weed challenges.

This Page: *Image: Boxthorn control team, Source: NRM North, Photographer: Friends of Bass Straight Islands Wildcare Inc.*

13
Information Sources

13.1 Supporting materials and data

Webber, B.L., van Klinken, R.D. and Scott, J.K. (2014) Invasive plants in a rapidly changing climate: an Australian perspective. In: Invasive Species and Global Climate Change (eds L.H. Ziska and J.S. Dukes) CABI Publishing, Wallingford UK, pp 169-197. This review lists some 70 references to Australian studies and was used as the basis for this Technical Guide.

Other supporting materials and information on weeds and climate change has been placed in the data access portal ***data.csiro.au***. The entire dataset can be found by searching using the keyword "adaptNRM". Other keywords such as weed or invasive plant will work also. The data is organised so that each invasive plant species has a separate access point and searches can be made using species names. The data access site has the following information:

- Australian and world maps of Species Distribution Models for current and 2070 climates for about 100 invasive plant species for which there are published CLIMEX models of relevance to Australia. The time period to 2070 was chosen so that potential changes in species distribution will be obvious.
    - The parameters for each model are listed in an Excel table.
    - A cxp file is provided for use in CLIMEX.
    - The CLIMEX references are listed in a Word document.
    - GIS data are provided for each species' climate suitability.

13
Information Sources (cont.)

13.2 Websites

While we recognise that there is a large amount of information on the internet to help guide weed management, we caution users that the internet remains an unfiltered way of distributing data. Here we list some examples of management plans and guides, as well as repositories of species distribution modelling output. By listing an internet resource here we are not endorsing the content or the quality of the information available. We urge readers to refer back to the content of this report to critically assess any products listed below before they are considered for guiding weed management plans and decisions.

Examples of invasive plant (or weed) management plans that include climate change.

www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/236900/nsw-invasive-species-plan.pdf

www.darwin.nt.gov.au/sites/default/files/Weed%20Management%20Guideline%20Final.pdf

www.senrm.sa.gov.au/Portals/10/Pest%20Plants%20and%20Pest%20Animals/Part%202%20010610.pdf

www.northcoastweeds.org.au/wp-content/uploads/NCWAC-Weed-Book1.pdf

www.amlrnrm.sa.gov.au/Plans/RegionalNRMPlan/ThePlan.aspx

Other NRM weed plans

Wimmera Invasive Plant and Animal Management Strategy 2010-2015 www.wcma.vic.gov.au/

The following websites contain information of use when planning the management of invasive plant species including weed risk assessment. The location of websites change and new ones are added so additional searches are recommended.

www.weeds.org.au/

pandora.nla.gov.au/pan/64168/20080620-0000/www.weeds.crc.org.au/index_flash.html

www.environment.gov.au/biodiversity/invasive/weeds/

www.daff.qld.gov.au/plants/weeds-pest-animals-ants/educational-resources-and-careers/publications/pest-risk-assessments

www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity/weeds/sa_weed_risk_mgt_system

www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity/weeds/weed_distribution_maps

live.greeningaustralia.org.au/nativevegetation/pages/pdf/Authors%20C/15_CRC_Weeds.pdf

The following guides to planning for pests is applicable to weeds also.

www.feral.org.au/pestplan-toolkit-a-guide-to-setting-priorities-and-developing-a-management-plan-for-pest-animals/

data.daff.gov.au/brs/brsShop/html/brs_prod_90000002773.html

Sites with invasive plant species distribution models including potential climate change.

Refer to Section 4 for guidance on the appropriate interpretation, selection and use of weed distribution modelling and mapping tools. See also https://data.csiro.au and use a keyword search.

www.climatechange.vic.gov.au/__data/assets/pdf_file/0007/73249/Whithertheweedsunderclimatechange2008v1.pdf

www.nccarf.edu.au/publications/naturalised-plant-species-threat-assessment-decision-tool

http://appliedecology.edu.au/wp-content/uploads/2014/04/2011_Wilson-et-al-Modelling-climate-suitability.pdf

www.gmdc.org.au/biodiversity-pests/weed-mapping.html

www.weedfutures.net/

13
Information Sources (cont.)

13.3 Literature consulted

The list below was used, in part, as source material for this Technical Guide. Other references are listed in the example Boxes in the text and in Webber et al. 2014.

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ABOUT ADAPTNRM

The National AdaptNRM Impacts and Adaptation Project is a multidisciplinary endeavour that brings together a diverse group of scientists working with NRM practitioners.

While the project itself consists of researchers from CSIRO and NCCARF, our output and initiatives have been shaped and informed through the generous input of NRM practitioners across Australia as well as a multitude of researchers, state and federal government stakeholders.

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