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A Proposed Method for Evaluating Management Feasibility When Determining Weed Control Priorities after Major Fires and Floods

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ABSTRACT

Major fires and floods have enormous impacts on natural ecosystems and are predicted to increase in frequency with global warming. Land managers need to make decisions on the prioritisation of weeds for control in post-disturbance landscapes, but little is available in the way of guidance to support timely decision making. Semi-quantitative models (e.g., scoring systems) have been employed routinely in weed risk assessment, which considers the potential impacts posed by weeds, as well as the likelihood of these impacts being realised. Some progress has been made in the development of similar models addressing the topic of weed risk management. Under conditions prevailing after major disturbances, changes (both positive and negative) can be expected in the multiple factors that determine weed management feasibility, relative to pre-disturbance conditions. A semi-quantitative model is proposed that is based on the key factors that contribute to weed management feasibility in post-disturbance environments, along with annotated modules that could be used by land managers in both post-fire and post-flood situations. The fundamental challenge for weed management in these scenarios lies in the identification of differences between weeds and native species in relation to (1) patterns of seedling emergence; and (2) detectability relative to the growth stage. These two factors will determine the timing of control actions that are designed to address the trade-off between weed control and off-target damage during the period when both types of plants are recovering from a major disturbance event. The model is intuitively sound, but field testing is required to determine both its practical value and any necessary improvement.

Keywords: Maintenance control; Natural ecosystems; Semi-quantitative models; Weed risk management

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1. Introduction

Disturbance is a major factor affecting the invasion by and consequent impact of weeds in natural ecosystems [1]. Human-induced disturbances such as fragmentation, nutrient enrichment, and changed grazing and fire regimes are important, as are natural disturbances such as floods and fires. The latter events, which are predicted to increase in frequency with global warming [2-4], are unique forms of disturbance that provide both risks and opportunities for weed management [5].

Prioritising weeds for control and deciding upon the type of control and its associated investment are fundamental to weed management planning [6]. Risk analysis, comprising the activities of risk assessment, risk management and risk communication, is central to this process. Weed risk assessment methodology is highly developed and assists in the identification of the species that could prove to be the most damaging. However, risk management has typically been a secondary matter, often overlooked [7,8]. A key aspect of weed risk management is management feasibility, which relates to the difficulty of achieving a management goal (e.g., eradication, containment or impact reduction) for individual species.

Semi-quantitative models for weed risk assessment, such as scoring systems, have been used with a high degree of success [9]. These have allowed policy makers to prioritise weeds for coordinated management programs (such as eradication) at national or regional geographic scales. At the local scale, i.e., in individual biodiversity assets, there is little practical assistance for land managers. This is in spite of the fact that essential criteria for addressing the feasibility of managing weeds were identified more than two decades ago [10].

There has been a gradual move by invasion scientists and practitioners to develop scoring protocols for the assessment of weed management feasibility [6-8,11]. A partial analysis of the feasibility of containment for the most impactful weeds in Christmas Island National Park (Christmas Island, Indian Ocean) appeared recently [6]. Only two species-intrinsic factors, namely the time to reproduction and the nature of the dispersal vector suite [12] were utilised. This approach provided a means of prioritising the species that posed the greatest ("extreme") weed risk, equivalent to the concept of 'transformer' [13]. Both of these factors are central to the determination of management feasibility, but a more rigorous treatment would need to take additional factors into consideration, such as weed life history characteristics and recruitment dynamics; weed detectability; and control effectiveness and cost [7,10,11].

The aim of the present work was to design decision support tools, specific to post-fire and post-flood conditions, that could be used by land managers to assess management feasibility in order to prioritise weeds—*already recognised* as posing serious risks to biodiversity—for control. In designing these tools, I have been conscious of the need for simplicity, while capturing essential features, so that they will be easy to use.

2. Weed management goals

How individual weed species should be managed in an asset post-disturbance will be informed by considerations at higher spatial levels, e.g., landscape and regional scales. For example, flood waters may introduce the propagules of a weed that has been targeted for eradication or containment elsewhere in a catchment. The requisite level of control would be greater for this weed than if it were already present across the landscape. The two fundamental weed management goals, coordinated control and maintenance control, are described below.

2.1 Coordinated control

Coordinated weed control strategies include eradication and containment. *Eradication* has been defined as the elimination of every single individual (including propagules) of a species from a defined area in which recolonisation is highly unlikely. Where recolonisation is possible, *extirpation* (the elimination of all individuals from an area in which the possibility of recolonisation cannot be ignored in practice [11]) could be the appropriate strategy for high value assets. This would be the case when such assets are isolated spatially and potential pathways of recolonisation are either inactive or can be managed effectively.

Containment can be either absolute (stopping spread) or relative (slowing spread), but the concept of absolute containment has limited application [12], often restricted to a scenario combining species that naturally spread slowly with the existence of strong barriers. Slowing spread can provide substantial benefits, including 'buying time' while more effective control methods, such as biological control, are developed. In contrast to (successful) eradication or extirpation efforts, this strategy requires an indefinite commitment of funding and other resources.

2.2 Maintenance control

In most cases 'maintenance management' (i.e., controlling a major weed to densities at which it can be tolerated) will be the most appropriate response. Where damage functions are non-linear, this would involve ensuring that invader densities lie below the impact threshold zone (**Figure 1**).

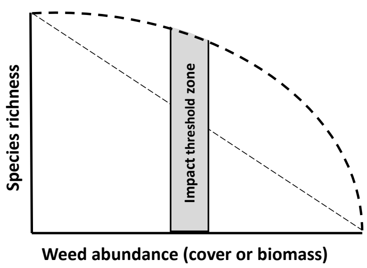

Figure 1. Weed damage relationships may be either linear or non-linear. Weed impact threshold relationships can be defined as non-linear declines in one or more ecosystem properties with increasing weed abundance. For natural ecosystems, such properties as the number of native plant species or the occurrence of rare and threatened species will be of concern. The objective of maintenance control is to keep the cover abundance of major weeds at levels sufficiently low to minimise their impacts on ecosystem values. Modified from [14].

3. Post-disturbance risks and opportunities

3.1 Risks

Management activities that may contribute to weed introduction, establishment and spread include soil disturbance associated with firebreak/fire containment lines, access track construction, and the use of potentially weed-contaminated heavy vehicles, such as bulldozers and other management vehicles. The introduction of fodder, for native or domestic animals can provide opportunities for weed seed introduction. Weeds may also be dispersed by animals farther than is usual in unburnt vegetation, as animals may travel farther than usual to find food, including onto open pastures [5]. Similar pathways of weed introduction are likely to be active after major flood events.

Some weeds have highly persistent seed banks and germinate prolifically after fire. In the absence of targeted control efforts in the first few seasons post fire, they may increase in cover abundance locally, as well as spread further through the landscape. Timely post-fire management action is necessary to prevent both potential outcomes.

3.2 Opportunities

Fire may cause high mortality in weeds that are not fire-adapted and may therefore create an opportunity for increased management impact. Control of weeds that are adversely affected by fire (i.e., where established plants are killed or reduced in size before they can reach the reproductive stage) presents an opportunity for changing the relative cover abundances of weeds vs native species in favour of the latter.

Improved access immediately after fires may provide new opportunities for control. This may apply especially in dense riparian vegetation or in wet forests, where the vegetation generally impedes access to weeds, or wherever the foliage of established weeds is beyond reach of standard foliar chemical methods. Finally, the relatively open conditions following a major fire event will provide an opportunity for enhanced weed surveillance that could permit the detection of new and emerging weeds [5]. Similar opportunities may exist after floods, although in some cases the deposition of large amounts of debris may cause problems relating to accessibility and consequently weed detection and control.

4. Changes in weed management feasibility post disturbance

Management feasibility will likely differ between species in the post-disturbance environment. Some changes in management feasibility, whether positive or negative, will act "across the board" in relation to the weed flora and hence will be of little use in their prioritisation for management. For example, the availability of resources (including participation by volunteers) will influence whether or not weed management is undertaken in an asset, rather than which weeds are targeted for control. Similarly, site accessibility after a catastrophic fire or major flood may impede the ability to conduct weed control activities. The focus here will be on the factors that will permit discrimination between weeds with regard to management feasibility in circumstances where control can actually be undertaken. By all appearances, a major fire event would, overall, increase management feasibility more than would a major flood, whose net effect would be negative (**Tables 1 and 2**).

Table 1. Generic change in weed management feasibility post fire in natural ecosystems. (Negative = reduced feasibility; Mixed = neutral effect).

Factor	Net effect	Comments
Detectability pre-reproduction	Positive	The habitat should become more open as a result of removal of above-ground biomass, markedly improving detectability.
Minimum time to reproduction	Negative	May be reduced owing to lessened competition.
Control effectiveness	Positive	For some resprouting species rapid growth post-fire may make a weed particularly susceptible to chemical control.
Accessibility	Mixed	Has two components: getting to a site (reduced owing to tree falls) and moving within the site (improved owing to reduction in above-ground biomass).
Control cost	Positive	Cost of labour reduced owing to increased ease of movement within a site
Land manager participation	Negative	Other actions (e.g., replacement of infrastructure) likely to be prioritised.
Volunteer participation	Positive	Individuals from unaffected areas may volunteer.
Potential for off-target damage	Positive	Improved targeting of control owing to reduction in above-ground biomass

Table 2. Generic change in weed management feasibility post flood in natural ecosystems. (Negative = reduced feasibility; Mixed = neutral effect).

Factor	Net effect	Comments
Detectability pre-reproduction	Mixed	A site may become more open post flood, but reduced accessibility and presence of debris may hinder timely detection.
Minimum time to reproduction	Negative	May be reduced owing to lessened competition
Control effectiveness	Neutral	No change (once accessibility issues have been overcome)
Accessibility	Negative	The soil is likely to be boggy for a protracted period after a major flood event, preventing timely access for purposes of weed control. There may also be impedance issues owing to the deposition of debris.
Control cost	Neutral	No change (once accessibility issues have been overcome)
Land manager participation	Negative	Other actions (e.g., replacement of infrastructure) likely to be prioritised.
Volunteer participation	Positive	Individuals from unaffected areas may volunteer.
Potential for off-target damage	Neutral	No change because desirable spp. will have chance to regrow/re-establish while site dries out.

5. A scoring system for post-border weed risk management feasibility

A simple and transparent scoring system for the prioritisation of weed species for strategic management (coordinated control) at a range of spatial scales was presented some time ago [15]. In this system, there were two key considerations in prioritising weeds for coordinated control programs—*weed risk* and *feasibility of control*. A version of this system was designed for use in South Australia [16] and a complementary system for New South Wales was developed [17].

In both systems, a score for 'Feasibility of Containment' was generated by multiplying separate scores (each ranging between 0 and 10) for the three criteria of 'Control Costs', 'Current Distribution' and 'Persistence'. Scores for each of these criteria were generated from a series of multiple-choice questions (whose possible answers were "high", "medium", or "low"), with accompanying definitions to aid in the consistency of assessments.

For the present exercise, a series of questions relating to the factors influencing management feasibility was established. Only some of the questions [16,17] are considered because they are not relevant to *maintenance control*, which would be the appropriate management goal in most post-disturbance situations. These questions are set out in **Box 1** and annotated versions specific to post-fire and post-flood conditions are presented in post-fire and post-weed risk management feasibility modules in **Boxes 1 and 2** respectively. In each module, the summed scores for all of the feasibility components provide an estimate for weed management feasibility. Note that all components have been weighted equally to present the simplest formulation. However, a case could be made for applying more weight to the time to reproduction (i.e., weed juvenile period), since this will influence the frequency of control [18] required to achieve the expressed management goal for an asset.

Box 1. Questions for post-disturbance weed management feasibility assessment. See **Boxes 2 and 3** for question rationales.

Recruitment dynamics (RD)

RD1 What is the reproductive strategy of the weed following a disturbance?
RD2 If recruitment of the weed occurs from seed, what is the pattern of emergence?

Life history characteristics (LH)

LH1 For weeds recruiting from seed, what is the minimum time to the production of sexual or vegetative propagules?
LH2 For resprouting weeds or those regenerating from fragments, what is the minimum time to the production of sexual or vegetative propagules?

Detectability (D)

D1 Can weed identity be ascertained early (by the expansion of the seedling's first true leaves)?
D2 Can weed seedlings be readily distinguished from those of native species?
D3 Can the juvenile (sub-reproductive) growth of the weed be identified easily?

Cost of control (CC)

CC1 Might repeated control efforts be required to kill individual plants that have regenerated by resprouting?
CC2 Is the plant community likely to be subject to grazing pressure during its recovery from disturbance? If so, might the weed be palatable at any stage of its life cycle?
CC3 Does the weed growth form differ from the dominant ecosystem growth form(s) such that the selectivity of control increases?
CC4 For species that are targeted for coordinated control, will the search-and-control area increase as a result of dispersal by floodwaters?

Control effectiveness (CE)

CE1 Is the weed a resprouting species?

Box 2. Annotated post-fire weed management feasibility module.

This module is designed to assess weed management feasibility relative to that which would have existed before the fire. Some generic changes in management feasibility factors can be anticipated after a major fire (see **Table 1**). There should be increased within-site accessibility and a reduced cost of control, plus a reduced potential for off-target herbicidal damage, resulting from a marked reduction in above-ground biomass—these factors will likely be of little value in the prioritisation process. Similarly, the availability of resources (such as labour, equipment, fuel and chemicals) is something that will determine the capacity to manage an asset as a whole, rather than providing a basis for discriminating amongst the weeds that are present. Such discrimination needs to be based on the biological and ecological features of the weeds and how these might influence the timing and effectiveness of control efforts.

Some weeds have highly persistent seed banks and germinate prolifically after fire. In the absence of targeted control efforts, they may increase in cover abundance locally and spread further through the landscape. Control of weeds that are adversely affected by fire (e.g., where mature plants are killed or reduced in size before they can reach the reproductive stage) presents an opportunity for changing the relative cover abundances of weeds vs native species in favour of the latter.

- ***Factors are scored on a scale of increasing management feasibility***
- ***Y =Yes; N =No; DK = Don't Know (defaults to less feasible state)***

Recruitment dynamics (RD)

Mass emergence of seedlings may necessitate control over a larger area than if only resprouters are present. Seedlings will generally be easier to kill than resprouters but may be difficult to control without reducing recruitment of native species.

RD1. What is the reproductive strategy of the weed following a fire?

From seed bank (soil or above-ground) only	*1*	
Resprouting plus from seed bank	*1*	☐
Resprouting only	*2*	

RD2. If recruitment of the weed occurs from seed, what is the pattern of emergence? *(Fewer control actions will be needed if emergence is synchronised.)*

Highly synchronised (a flush of seedling emergence occurs within weeks of germination-stimulating rainfall)	*2*	
Protracted	*1*	☐
Don't know	*1*	

Life History (LH)

The time that must elapse before a plant can reproduce will determine how frequently control measures must be applied (and hence the total control effort) to prevent this. Weeds that have the capacity to survive a major fire will likely reproduce more quickly than those that only regenerate from seed.

LH1. For weeds recruiting from seed, what is the minimum time to the production of sexual or vegetative propagules?

Less than 1 year to 3 years	*1*	
More than 3 years	*2*	☐
Don't know	*1*	

LH2. For resprouting weeds or those regenerating from fragments, what is the minimum time to the production of sexual or vegetative propagules?

Less than 3 months	*1*	
More than 3 months	*2*	☐
Don't know	*1*	

Box 2. (*cont.*)

Detectability (D)
Seedlings of both weeds and native species may be present post flooding, so weed control may need to be delayed until weed seedlings are readily distinguishable. It will be more difficult to achieve selective control when the weed resembles a native species.

D1. Can weed identity be ascertained early (by the expansion of the seedling's first true leaves)?
Y = 2
N= 1

D2. Can weed seedlings be readily distinguished from those of native species?
Y = 2
N= 1

D3. Can the juvenile (sub-reproductive) growth of the weed be identified easily?
Y = 2
N= 1

Cost of control (CC)
CC1. Might repeated control efforts be required to kill individual plants that have regenerated by resprouting? (*The need for repeated control will increase costs associated with travel, labour and materials.)*
Y = 2
N= 1
DK=1

CC2. Is the plant community likely to be subject to grazing pressure during its recovery from a flood? If so, might the weed be palatable at any stage of its life cycle? *(Grazing is a form of biological control that will reduce the need to implement other control methods.)*
Y = 2
N= 1
DK=1

CC3. Does the weed growth form differ from the dominant ecosystem growth form(s) such that selectivity of control increases, e.g., where a woody weed may be invading a herbaceous wetland community? (*The potential for utilising selective control measures will reduce the control effort required.)*
Y = 2
N= 1
DK=1

CC4. For eradication or containment targets, will the search-and-control area increase as a result of dispersal by floodwaters? *(This will increase the overall cost of management.)*
Y = 2
N= 1
DK=1

Control effectiveness (CE)
For some resprouting species rapid increase in leaf area post-flood may make a weed particularly susceptible to foliar-applied herbicides.

CE1. Is the weed a resprouting species?
Y = 1
N= 2

Total management feasibility score = ΣRD + ΣR + ΣD + ΣCC + ΣCE
Unweighted totals for each of the feasibility factors are summed to produce a total score.

Box 3. Annotated post-flood weed management feasibility module.

This module is designed to assess weed management feasibility relative to that which would have existed before a major flood. Some generic changes in management feasibility factors can be anticipated after a major flood (see **Table 2)**. These are expected to be largely negative, relative to post-fire conditions. The effects of major floods will depend upon floodwater velocity, which can be expected to vary over both space and time. Where the velocity is very high, a significant part of the standing vegetation and its associated soil seed banks may be removed, meaning that the post-flood environment will present a relatively "clean slate". At the opposite extreme (such as in broad floodplains), where water velocity has been mostly low or close to negligible, soil and biomass deposition will occur, and deep standing water may persist for some time.

Some weeds have highly persistent seed banks and may germinate prolifically after a flood. In the absence of targeted control efforts, they may increase in cover abundance locally and spread further through the landscape. If more weeds than native plants are killed by flooding, this will present an opportunity for changing the relative cover abundances of weeds vs native species in favour of the latter.

- ***Factors are scored on a scale of increasing management feasibility***
- ***Y =Yes; N =No; DK = Don't Know (defaults to less feasible state)***

Recruitment dynamics (RD)

Mass emergence of seedlings may necessitate control over a larger area than if only resprouters are present. Seedlings will generally be easier to kill than resprouters but may be difficult to control without reducing the recruitment of native species.

RD1. What is the reproductive strategy of the weed following flooding?

From pre-existing seed bank or seed deposited from floodwaters	*1*	
Resprouting only	*2*	☐
Resprouting plus from seed	*1*	
From fragments deposited from floodwaters	*2*	

RD2. If recruitment of the weed occurs from seed, what is the pattern of emergence?*(Fewer control actions will be needed if emergence is synchronised.)*

Highly synchronised (a flush of seedling emergence occurs within weeks of germination-stimulating rainfall)	*2*	
Protracted	*1*	☐
Don't know	*1*	

Life History (LH)

The time that must elapse before a plant can reproduce will determine how frequently control measures must be applied (and hence the total control effort) to prevent this. Weeds that have the capacity to survive a major flood will likely reproduce more quickly than those that must regenerate from seed.

LH1. For weeds recruiting from seed, what is the minimum time to the production of sexual or vegetative propagules?

Less than 1 year 1 to 3 years	*1*	
More than 3 years	*2*	☐
Don't know	*1*	

LH2. For resprouting weeds, what is the minimum time to the production of sexual or vegetative propagules?

Less than 3 months	*1*	
More than 3 months	*2*	☐
Don't know	*1*	

Box 3. *(cont.)*

Detectability (D)
Seedlings of both weeds and native species may be present post flooding, so weed control may need to be delayed until weed seedlings are readily distinguishable. It will be more difficult to achieve selective control when the weed resembles a native species.

D1. Can weed identity be ascertained early (by the expansion of the seedling's first true leaves)?
Y = 2
N = 1 ☐

D2. Can weed seedlings be readily distinguished from those of native species?
Y = 2
N = 1 ☐

D3. Can the juvenile (sub-reproductive) growth of the weed be identified easily?
Y = 2
N= 1 ☐

Cost of control (CC)
CC1. Might repeated control efforts be required to kill individual plants that have regenerated by resprouting? (*The need for repeated control will increase costs associated with travel, labour and materials.*)
Y = 2
N = 1 ☐
DK = 1

CC2. Is the plant community likely to be subject to grazing pressure during its recovery from a flood? If so, might the weed be palatable at any stage of its life cycle? (*Grazing is a form of biological control that will reduce the need to implement other control methods.*)
Y = 2
N = 1 ☐
DK = 1

CC3. Does the weed growth form differ from the dominant ecosystem growth form(s) such that selectivity of control increases, e.g., where a woody weed may be invading a herbaceous wetland community? (*The potential for utilising selective control measures will reduce the control effort required.*)
Y = 2
N = 1 ☐
DK = 1

CC4. For eradication or containment targets, will the search-and-control area increase as a result of dispersal by floodwaters? (*This will increase the overall cost of management.*)
Y = 2
N = 1 ☐
DK = 1

Control effectiveness (CE)
For some resprouting species rapid increase in leaf area post-flood may make a weed particularly susceptible to foliar-applied herbicides.

CE1. Is the weed a resprouting species?
Y = 1
N = 2 ☐

Total management feasibility score = ΣRD + ΣR + ΣD + ΣCC + ΣCE ☐
Unweighted totals for each of the feasibility factors are summed to produce a total score.

6. Discussion

Urgency, defined as the increase in total control effort that would be required to achieve maintenance control should there be a delay in action [19], is an additional factor that could be considered when determining weed control priorities. This has not been included in either of the modules because post-disturbance environmental conditions will influence the degree of urgency for control but are essentially unpredictable. The generic increases in weed management feasibility that occur following a major fire will be time-limited, with the duration of this 'enhanced management feasibility window' being determined by the incidence of rainfall and by temperature. A long spell without rainfall would allow land managers and volunteers to attend to alternative immediate and critical needs, such as the restoration of infrastructure. The situation is somewhat more problematic after a major flood—an asset is likely to be boggy for a protracted period, delaying access for purposes of weed control. In contrast to the situation with fire, subsequent flood events may occur that prolong (or renew) the period of low accessibility and potentially affect the regeneration of both weeds and native species.

Appropriate responses to weed invasions are commonly set out in a weed risk versus feasibility-of-control matrix [7,15]. The present treatment has generally neglected weed risk, except to acknowledge that some species are potential transformers [13]. At the other end of the weed risk continuum are those plants, commonly annuals and biennials [5,20] whose occurrence post-disturbance will be transient in nature and therefore not require control. In an examination of the weed flora of Christmas Island, species were ranked as posing "high", "very high" and "extreme" risk [6]. For determining the feasibility of containment of weeds that had restricted distributions on the island, only a few species that posed "extreme" risk (i.e., transformers) were nominated as targets for containment because of the relatively high demand for resources associated with this management goal.

Where maintenance control would be the nominated management goal (as would be the case in most post-disturbance scenarios) a larger set of potentially impactful species would need to be assessed for management feasibility. But it is important to be aware that management feasibility is inversely related to management cost—more resources will need to be allocated to achieve the same management goal where a weed demonstrates lower management feasibility [11]. Limitations in resource availability will therefore restrict the weeds that can be targeted to the most impactful species.

For any given site, practitioners will likely know the weeds of concern and perhaps their life history traits, such as time to reproduction and seed persistence. The basic difficulty in weed management lies in the identification of differences between native species and weeds relative to (1) patterns of seedling emergence; and (2) detectability in relation to growth stage. These two factors will determine the timing of control actions that attempt to address the trade-off between weed control and off-target damage during the period when both categories of plants are recovering from a major disturbance event. The proposed model will encourage the practitioner to focus on factors that capture the fundamental problem of controlling serious weeds within a native species matrix—how to maximise control of weeds while minimising damage to the indigenes.

7. Conclusions

This work should be considered as a first pass attempt at tackling the problem of how those tasked with protecting biodiversity values might best respond to the challenge of managing weeds after major disturbances. The hypothesised changes in weed management feasibility under post-fire and post-flood conditions are likely to be sound, but the modules for each of these disturbance types need to be tested in post-fire and post-flood situations over a range of environments. The model as presented is in the simplest form—additive, with equal weighting given to each of its factors. Experience gained from its application may well indicate that in certain situations some factors are more important than others and could reveal a need to include additional ones.

Conflict of Interest

The author declares that he has no conflict of interest.

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References

[1] Hobbs, R.J., Humphries, S.E., 1995. An integrated approach to the ecology and management of plant invasions. Conservation Biology. 9(4), 761-770.
DOI: https://doi.org/10.1046/j.1523-1739.1995.09040761.x

[2] Abram, N.J., Henley, B.J., Sen Gupta, A., et al., 2021. Connections of climate change and variability to large and extreme forest fires in southeast Australia. Communications Earth & Environment. 2(1), 8.
DOI: https://www.nature.com/articles/s43247-020-00065-8

[3] Kumar, A., Nagar, S., Anand, S., 2021. Climate change and existential threats. Global climate change. Elsevier: Amsterdam. pp. 1-31.

[4] Angra, D., Sapountzaki, K., 2022. Climate change affecting forest fire and flood risk—Facts, predictions, and perceptions in central and south Greece. Sustainability. 14(20), 13395.
DOI: https://doi.org/10.3390/su142013395

[5] Zimmer, H., Cheal, D., Cross, E., 2012. Post-fire Weeds Triage Manual: Black Saturday Victoria 2009—Natural Values Fire Recovery Program [Internet] [cited 2023 Jun 17]. Available from: https://www.ari.vic.gov.au/__data/assets/pdf_file/0023/34970/VBRRA-report-23-web.pdf

[6] Panetta, F.D., Grigg, A., 2021. A weed risk analytical screen to assist in the prioritisation of an invasive flora for containment. NeoBiota. 66, 95-116.
DOI: https://doi.org/10.3897/neobiota.66.67769

[7] Booy, O., Mill, A.C., Roy, H.E., et al., 2017. Risk management to prioritise the eradication of new and emerging invasive non-native species. Biological Invasions. 19, 2401-2417.
DOI: https://doi.org/10.1007/s10530-017-1451-z

[8] Vanderhoeven, S., Branquart, E., Casaer, J., et al., 2017. Beyond protocols: Improving the reliability of expert-based risk analysis underpinning invasive species policies. Biological Invasions. 19, 2507-2517.
DOI: https://doi.org/10.1007/s10530-017-1434-0

[9] Gordon, D.R., Flory, S.L., Lieurance, D., et al., 2016. Weed risk assessments are an effective component of invasion risk management. Invasive Plant Science and Management. 9(1), 81-83.
DOI: https://doi.org/10.1614/IPSM-D-15-00053.1

[10] Virtue, J.G., Groves, R.H., Panetta, F.D., 2001. Towards a system to determine the national significance of weeds in Australia. Weed risk assessment. CSIRO Publishing: Melbourne. pp. 124-150.

[11] Wilson, J.R., Panetta, F.D., Lindgren, C.J., 2016. Detecting and responding to alien plant incursions. Cambridge University Press: Cambridge. pp. 1-265.

[12] Panetta, F.D., Cacho, O.J., 2012. Beyond fecundity control: Which weeds are most containable? Journal of Applied Ecology. 49(2), 311-321.
DOI: https://doi.org/10.1111/j.1365-2664.2011.02105.x

[13] Richardson, D.M., Pyšek, P., Rejmanek, M., et al., 2000. Naturalization and invasion of alien plants: Concepts and definitions. Diversity and Distributions. 6(2), 93-107.
DOI: https://doi.org/10.1046/j.1472-4642.2000.00083.x

[14] Panetta, F.D., Gooden, B., 2017. Managing for biodiversity: Impact and action thresholds for invasive plants in natural ecosystems. NeoBiota. 34, 53-66.
DOI: https://doi.org/10.3897/neobiota.34.11821

[15] Virtue, J., Cunningham, D., Hanson, C., et al., 2006. National Post-border Weed Risk Management Protocol [Internet] [cited 2023 Jun 17]. Available from: https://www.saiglobal.com/pdftemp/previews/osh/as/misc/handbook/hb294-2006.pdf

[16] Virtue, J.G., 2010. South Australia's weed risk management system. Plant Protection Quarterly. 25(2), 90-94.

[17] Johnson, S., 2009. New South Wales Weed Risk Management System [Internet] [cited 2023 Jun 17]. Available from: https://www.researchgate.net/publication/275347123_New_South_Wales_Weed_Risk_Management_System_Instruction_Book

[18] Panetta, F.D., 2007. Evaluation of weed eradication programs: Containment and extirpation. Diversity and Distributions. 13(1), 33-41.
DOI: https://doi.org/10.1111/j.1472-4642.2012.00932.x

[19] Hiebert, R.D., 1997. Prioritizing invasive plants and planning for management. Assessment and management of plant invasions. Springer: New York. pp. 195-212.

[20] Gooden, B., French, K., Turner, P.J., et al., 2009. Impact threshold for an alien plant invader, *Lantana camara* L., on native plant communities. Biological Conservation. 142(11), 2631-2641.
DOI: https://doi.org/10.1016/j.biocon.2009.06.012