Research reports

Ensuring invasive alien plant management delivers biodiversity conservation: insights from an assessment of *Lantana camara* in Australia

Peter J. Turner and **Paul O. Downey**, Pest Management Unit, Parks and Wildlife Group, Department of Environment, Climate Change and Water (NSW), PO Box 1967, Hurstville, New South Wales 1481, Australia.

Summary

Alien plants are widely acknowledged as a major cause of biodiversity decline globally. However, details of which aspects of biodiversity is at risk from alien plant invasions has not been forthcoming. This has hampered alien plant management strategies from delivering biodiversity conservation, as control is not focused on the biodiversity most threatened. Here we describe a two-step approach which ensures that alien plant management delivers biodiversity conservation. This approach is presented through a case study using *Lantana camara* L. (lantana) invasions across Australia, and then discussed more broadly for management of other alien plants for the conservation of biodiversity. The first step identifies the native biodiversity at risk (native plant and animal species and ecological communities) and then the degree of threat to each. The second step assesses locations of the native biodiversity to determine priority sites for control. Using the first step, we identified 1321 native plant and 158 native animal species as being threatened by lantana in Australia. These species were then assessed for the current level of threat from lantana and prioritized based on their likelihood of changing their threatened status in the near future. This process revealed 275 native plant and 24 native animal species requiring immediate protection from lantana invasions within Australia. The results of this approach have now been used to develop a national management strategy that will focus lantana management towards biodiversity conservation.

Key words: Biodiversity conservation, prioritization, Plan to Protect Environmental Assets from Lantana, Weed Impacts to Native Species (WINS) assessment, sites for control, triage.

Introduction

The impact of alien plant species on natural ecosystems has been profound (Groves and Willis 1999, Williams and West 2000, D'Antonio and Meyerson 2002, Richardson and van Wilgen 2004). Yet despite this, the details of which specific species are at risk from such invasions have not been forthcoming (Adair and Groves 1998, Byers *et al.* 2002, Grice *et al.* 2004, Downey 2008a). Knowledge of the native species most significantly impacted by alien plant species is critical to ensure that management focuses on their protection in the first instance (Turner *et al.* 2007, Downey 2008a), yet this information has not been available for even our most invasive alien plant species or accounted for in their management strategies (Downey and Cherry 2005). In addition, to properly restore invaded communities following alien plant control it is essential to understand the impacts of alien plants on native species and their habitats (Walker and Smith 1997, Holmes and Richardson 1999, D'Antonio and Meyerson 2002, Turner *et al.* 2008b).

Lantana camara (lantana) is an invasive shrub originating from tropical central and southern America (Swarbrick *et al.* 1998) which is now naturalized in approximately 60 countries, particularly in Africa, Asia and the Pacific (Day *et al.* 2003). The invasive potential of this plant, introduced for horticultural purposes, is reflected in its listing as one of the world's 100 worst invasive species (Lowe *et al.* 2000), as well as its listing as a nationally significant weed in such countries as South Africa (Robertson *et al.* 2003) and Australia (Thorp and Lynch 2000). In Australia, lantana has invaded over 5% of the continent (Sinden *et al.* 2004), including both agricultural and natural ecosystems, since its introduction in the 1840s (Swarbrick *et al.* 1998). Information on the native species at risk has been limited, however, (see Downey and Cherry 2005), despite the development of a national strategy to reduce its impact (ARMCANZ *et al.* 2001). Even regional assessments have failed to identify the native species at risk. For example, lantana was ranked as the greatest invasive alien plant in south-east Queensland (Qld), posing a significant threat to native species due to its impact on a range of ecological processes (Batianoff and Butler 2003), but no native species at risk were identified during this assessment.

A recent examination of the threat posed from alien plants on biodiversity within a state of Australia (New South Wales: NSW) established that lantana was the most commonly identified alien plant threat, posing a threat to 10% of the biodiversity listed in NSW under the *Threatened Species Conservation Act 1995* (TSC Act) (Coutts-Smith and Downey 2006). Unlike other studies, this examination did reveal the types of biodiversity at risk. However, this study did not assess the level of threat to the biodiversity examined or the overall threat to non-listed biodiversity. In addition, as the assessment by Coutts-Smith and Downey (2006) accounted for only part of the geographical distribution of lantana in Australia, with lantana occupying a larger area in the state of Qld, its impact on biodiversity nationally is likely to be substantially greater than the 96 threatened entities identified in this NSW review. While complete eradication of lantana in Australia is no longer feasible, we argue that reducing the threat and impact to native species is (e.g. see Turner *et al.* 2008a, Downey *et al.* 2009, Downey *et al.* in press, Williams *et al.* 2009). Therefore, information on the native species at risk is required together with a management strategy to focus control on biodiversity outcomes. This focus is necessary as in many instances alien plant control alone does not necessarily lead to biodiversity conservation outcomes (D'Antonio and Meyerson 2002, Turner and Virtue 2006, Downey 2008a, Reid *et al.* 2009).

The threat to biodiversity from widespread alien plant species can be assessed, using a two-step process described by Downey (2008a) and Downey *et al.* (in press). This process enables identification of the native species at risk and the relative threat to each which is then used to direct on-ground management to where the need is the greatest. In this paper, we use lantana as a case study to demonstrate the effectiveness of the first step of this process and the likely outcomes and implications for management. We discuss the information required to achieve the second step and the outcomes that can be achieved through this two-step process for alien plant management.

Materials and methods

There are numerous ways to determine the biodiversity at risk from alien plant species (Adair and Groves 1998, Turner and Virtue 2006, Downey and Grice 2008). However, until recently none allowed for an assessment and prioritization across the entire distribution of the alien plant species on a continental scale and across a broad array of the biodiversity threatened. For example, impacts have historically been restricted to the study of a few native species that either co-occur in a specific location (Turner *et al.* 2008b), are listed as threatened (Coutts-Smith and Downey 2006) or are closely related (e.g. orchids) (Downey and Grice 2008). In order to address some of these shortcomings in assessing the impacts and threats of alien plants on biodiversity, Downey (2006) developed the Weed Impacts to Native Species (WINS) assessment tool, which forms the basis of the first step described in this paper.

The WINS assessment tool was used here to determine the biodiversity (native plants and animals and ecological communities) threatened by lantana in Australia and its relative risk. The WINS system consists of four stages: (1) a review of the literature; (2) collation and assessment of the knowledge from land managers, ecologists and botanists with specific involvement, either in managing lantana, or the native species in lantana infested areas; (3) evaluation and examination of an interim list of species potentially at risk; and (4) ranking the revised list to determine which native species require urgent protection from lantana. More specific details with respect to this assessment of lantana are presented below for stages two, three and four.

Stage two involved 20 workshops held throughout the distribution of lantana in NSW and Qld (Figure 1a). Information on the biodiversity threatened by lantana was collated from 199 participants (Table 1). This accumulation of knowledge from local experts is seen as extremely useful for obtaining species information, particularly in the absence of published information (Weeds CRC and Standards Australia 2006). Information collected from the workshops included the results from numerous localized unpublished studies on control activities or from field surveys, and documented impacts to native plants, animals and ecological communities.

Table 1. Breakdown of the workshop participants.

Workshop participants	Number of people
Local Government (Gov't)	45
Environmental Protection Agency[A] (Qld Gov't)	41
Department of Environment and Climate Change[B] (NSW Gov't)	39
Other state government agencies	16
Natural Resource Management/Catchment Management Authorities	12
Landcare	11
Non-government conservation organizations	11
Non-government bush regenerators	10
Individuals	9
University academics and CSIRO	5
Total	199

[A] The Environmental Protection Agency is now known as the Department of Environment and Resource Management.
[B] The Department of Environment and Climate Change is now known as the Department of Environment, Climate Change and Water.

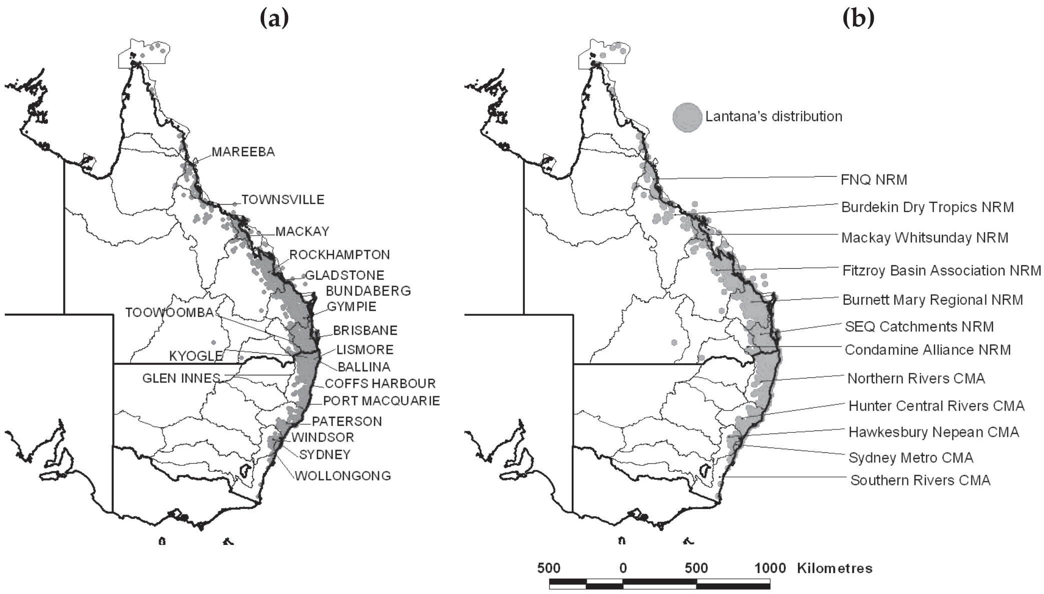

Figure 1. Distribution map of *L. camara* within the states of NSW and Qld in eastern Australia as well as (a) location of workshops (two workshops were held in Brisbane) and (b) Natural Resource Management regions (or Catchment Management Authorities) [FNQ NRM is now known as Terrain NRM and Mackay Whitsunday NRM is known as Reef Catchments NRM].

A modified version of the criteria described by Downey (2006) to assess the impact and threat (Table 2) was used to account for (i) positive benefits of alien plants to native species (e.g. see Loyn and French 1991); (ii) where alien plant species have substituted the role of the native species with no obvious impact (e.g. native animals switching habitat, D'Antonio and Meyerson 2002); and (iii) the inclusion of threats to animals. In addition, as many alien species can co-occur (Simberloff and Von Holle 1999), and potentially pose a similar threat either directly or following control, especially if management is focused on a single alien species (Thomas and Shaw 2007, Turner *et al.* 2008b, Turner *et al.* 2008c), the information on interactions of lantana and other alien species was collected. Therefore, another modification to Stage two of the WINS system was to also collate information on the other alien plant and animals that were associated with lantana invasions that could pose a similar threat to the native species at risk after control.

Table 2. Criteria used to support inclusion of species as being potentially impacted by *L. camara* (modified from Downey 2006). Following discussion in a workshop, one or more codes were assigned for each species identified.

Impact	Code	Description
Negative	NP	The native species is **not present** in infested areas of that species' typical vegetation community or range. This can be determined by comparing infested and uninfested sites, as well as anecdotal or observational data about declines following invasion.
	D	There is clear evidence that *L. camara* **displaces** the native species. For example, the native species occurs at lower than 'normal' densities in invaded sites, but is not totally out-competed or excluded. Displacement may also occur through indirect effects such as changes in fire intensity.
	OCS	**Suppresses** the native species by reducing individual's vigour or reproductive output.
	RP	**Recruitment is prevented** – the adult population is at 'normal' or 'near-normal' density, but few or no juveniles are present.
	CAR	The native species is **considered at risk**, but more information is needed to determine the level of risk.
Positive	AH+	There is clear evidence that the weed provides an **additional habitat** for the native species. For example, the native species occurs at higher than 'normal' densities in invaded sites.
	P+	The weed **promotes** the native species by increasing individuals' vigour or reproductive output through such things as increased resources, providing food for animals or changes to soil characteristics.
Neutral	N	Animals have switched to utilizing the weed as a result of native vegetation being replaced by *L. camara*, but there has been **no change** in their overall density or condition.

Stage three involved the production of an interim list of the native species and ecological communities at risk, and the other alien species present, which was then circulated to a wider audience for consultation. A project specific website was also established (DECC 2007). The list that was circulated and placed on the web contained additional information to help respondents assess the validity of the biodiversity identified as being at risk. The additional information, included: (i) the species distribution relative to that of lantana; (ii) its presence in each of the 12 Natural Resource Management (NRM) regions (which contained the major infestations of lantana – Figure 1b); (iii) the functional group (or form) for each native plant species or the class (or group) of each native animal species at risk; and (iv) the threatened status of the biodiversity at risk (i.e. if they were listed under the State and/or Commonwealth threatened species legislation (e.g. the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)). To help validate the list, field assessments were undertaken on a subset of the native species identified (see Gooden 2007, Gooden *et al.* 2009a, Gooden *et al.* 2009b). A final list was then produced.

Stage four involved the finalization of the list of biodiversity at risk and an assessment to determine which species had the greatest chance of changing their threatened status in the short term if lantana was not controlled (e.g. change from vulnerable to endangered or become eligible for listing). We used two criteria to assess the level of risk from lantana, being: (i) the degree of overlap between the distribution of the native species or community at risk and that of lantana; and (ii) the current threatened status of the native species or community. Biodiversity with a high degree of distributional overlap with lantana was deemed to have less opportunity to survive the impacts of lantana, than biodiversity with a lower degree of distributional overlap with lantana. Additionally if that biodiversity was listed as threatened (e.g. under EPBC Act, NSW TSC Act or Qld *Nature Conservation Act 1992* (NC Act)) or had the potential to be listed, the likelihood of serious decline was high and the biodiversity was classed accordingly.

As mentioned above, the current threatened status was determined based on the species or community being listed under threatened species legislation, being either the NSW TSC Act, the Qld NC Act, and/or the Commonwealth EPBC Act, or if we deemed the species or community was eligible or had the potential for listing. We considered species and communities that had the potential to be listed from the results of the workshops. Species assigned the codes NP or D (see Table 2) were deemed most likely to be exhibiting a decline in numbers due to lantana invasion and if the species also had a limited distribution then we deemed it to be fit to be placed into the category 'eligible for listing'.

Each species at risk was assessed against each of the two above-mentioned criteria and the risk of lantana ranked as high, medium or low. For example, where the distribution overlap was high (being >90%) and the species was listed or had the potential to be listed it was ranked as a high priority for protection from lantana. These high priority species were considered most likely to move closer to extinction without lantana management within the next five years. Species were ranked as medium priority if they fell within the following criteria: (i) the native species at risk had a medium degree of overlap with lantana (between 40% to 89% overlap) and the native species was listed under the TSC Act, the NC Act, and/or the EPBC Act or if the species had the potential to be listed (using the criteria mentioned above), or (ii) if the native species at risk had a high degree of overlap with lantana (≥90% overlap), but was currently not listed under threatened species legislation and did not have the current potential to be listed. The remaining species not classified as high or medium were placed into the low priority group and thus were a lower priority for management intervention.

High priority communities (or Regional Ecosystems) were also determined as those with a high degree of overlap with the distribution of lantana and listed under the NSW TSC Act, the Qld *Vegetation Management Act 1999* (VM Act), and/or the EPBC Act or if the community had the potential to be listed. In Queensland, ecological communities have been classified across the state using a series of defined Regional Ecosystems (see Sattler and Williams 1999) under the VM Act. Communities with the potential for listing were those being transformed by lantana, with a reduction in community integrity (as determined during the workshops) and which occurred only within a few recognized isolated patches.

Analysis of the list of the native species and ecological communities at risk, and the other alien species was undertaken using a variety of simple statistics. As many animals were identified as being impacted by the displacement of native plants following the invasion of lantana, a simple linear regression was undertaken to confirm if there was a relationship between the number of native plant species at risk (within each NRM region) and the number of native animal species at risk.

Results

Native plant species threatened from L. camara *invasion*

The literature review revealed that 126 native plant species had previously been identified as threatened from lantana invasions in Australia, 83 of which were derived from one study (Coutts-Smith and Downey 2006). The second stage of the WINS process identified a further 1121 native plant species at risk. Examination of these data revealed that just over half of these plant species (n = 634) were identified from more than one source with an average of 2.23 ± 0.05 SE sources per species (e.g. from two workshops or from a workshop and the literature). A workshop/species curve indicated that the number of workshops held was sufficient to capture the majority of species at risk, with very few additional plant species identified during the last three workshops (Figure 2). Assessment of the interim list during Stage three, however, identified an additional 74 plant species, thereby highlighting the need to circulate the interim list as widely as possible. The most threatened plant taxa were either trees or shrubs, accounting for 65% collectively of the plant species at risk, followed by herbs, climbers, grasses and orchids (Table 3). The complete list of plant species at risk from lantana invasion in Australia is available electronically (DECC 2007).

Determining the degree of threat to native plant species

During Stage two of the WINS assessment, information was collected on the likely threat experienced as a result of lantana invasions, using the five negative criteria presented in Table 2. For only 9% of the plant species at risk from lantana invasion was there a poor understanding of threat. The greatest threat was due to lantana's ability to prevent the recruitment of native plant species, or by displacing them totally from a habitat (Table 4). In addition, 3% of the plant species were affected by the compounding influence of lantana and fire. The increase in fire intensity, due to the presence of lantana, had a negative impact on certain plant species not adapted to this phenomenon. Very few native plant species benefited from the addition of lantana to their habitat. Vines comprised the majority of those native species that were reported to benefit from lantana (e.g. as a climbing support). Ironically, many of these vine species were also threatened by lantana invasions as a result of reduced recruitment.

After Stage three, approximately 20% of all plant species at risk were also

Table 3. Plant groups affected by *L. camara*.

Group/form	Total no. of species	% of total number of species	No. of high priority species	% of high priority species
Trees and shrubs	858	65.0	201	73.1
Herbs	112	8.5	11	4.0
Climbers	109	8.3	23	8.4
Grasses	90	6.8	5	1.8
Orchids	66	5.0	19	7.0
Ferns	49	3.7	6	2.2
Rushes and sedges	25	1.9	2	0.7
Cycads	12	0.9	8	3.0
Total	1321		275	

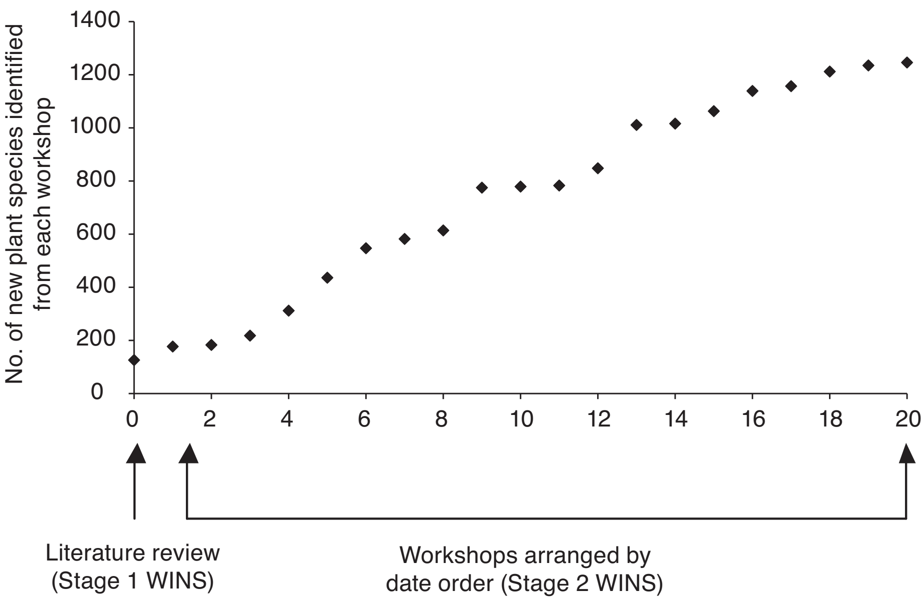

Figure 2. Native plant species curve showing the increase in the number of species at risk following a literature review and the completion of 20 workshops.

Table 4. Percentage of each criterion used to support the listing of a species as being impacted by *L. camara* during the workshops. Code descriptions are as in Table 2 (modified from Downey 2006).

Code	Native plant species (%)	Native animal species (%)
NP (no longer present)	8	<1
D (displaced)	26	30
OCS (suppressed)	18	n/a
RP (recruitment prevented)	38	n/a
CAR (at risk but more information needed)	9	14
AH+ (additional habitat)	<1	18
P+ (promoted)	<1	19
N (neutral or switched to *L. camara*)	n/a	19

formally listed as threatened under one or more of the three applicable threatened species Acts. Of these 285 plant species, 167 are listed under the TSC Act, 152 under the NC Act, and 142 under the EPBC Act (note: some species were listed under more than one Act). A further 40 plant species were listed as rare or threatened in Australia (by Briggs and Leigh 1995), but not formally under the threatened species legislation.

Determining the plant species most likely to change to a higher threatened status if L. camara *is not controlled in the near future*

The prioritization of plant species most at risk from lantana invasions in Australia, rated 275 plant species as high priority, whilst 413 were identified as medium and 623 as low priority in terms of extinction risk and urgency for control. Ten species could not be ranked as there were insufficient details available on their distribution. The South-east Queensland (SEQ) Catchments NRM contained the highest number of plant species at risk and the highest number of high priority plant species (Table 5).

Native animal species threatened from L. camara *invasions*

Five native animal species had previously been identified as threatened from lantana invasions in Australia. A further 136 native animal species at risk were identified after the workshops. After Stage two, on average each native animal species was identified 2.27 (±0.13 SE) times (i.e. from two or more workshops, or the literature plus at least one workshop). The WINS third stage resulted in the addition of an extra 17 animal species being added to the list. The most threatened animal taxa were mammals, followed by birds (Table 6). The majority of the native animal species at risk from lantana invasions were found in the SEQ NRM region and the Northern Rivers Catchment Management Authority (CMA) (Table 5). The complete list of animal species at risk from lantana invasion in Australia is also available electronically (DECC 2007).

Determining the degree of threat

Only three of the five negative criteria presented in Table 2 were used for animals, as these criteria were originally developed for plants. For 14% of the animal species identified as being threatened from lantana invasion there was a poor understanding of the nature of the threat, whilst the displacement of animals by lantana invasions accounted for the greatest cause of decline (Table 4). This displacement of animals reflects the replacement of native vegetation by lantana invasions, which is demonstrated by a significant positive relationship between the number of native plants at risk and the number of native animals at risk across the NRM regions (Figure 3).

Number of native animals benefiting from L. camara

Many animal species benefited from the addition of lantana to their habitat, with

Table 6. Native animal species impacted by *L. camara*.[A]

Class (or group) of animals	Total no. of species negatively affected	No. of high priority species negatively affected	No. of species positively affected
Mammal	55	5	27
Bird	52	5	90
Reptile	24	7	12
Amphibian	14	3	3
Invertebrate	13	4	10
Total	158	24	142

[A] Note some species receive both positive and negative impacts from *L. camara*. Also, species listed as being positively affected include species which have switched to *L. camara* (i.e. listed with the 'neutral' code).

Table 5. Breakdown of the distribution of the total number of native plants and native animals at risk from *L. camara* as well as a subset of high priority species threatened by *L. camara* within Natural Resource Management (NRM) regions.[A]

NRM region	Total no. of native plant species	Total no. of native animal species	Total native species	No. of high priority plant species	No. of high priority animal species	Total number of high priority species
SEQ Catchments NRM	951	123	**1074**	126	17	**143**
Northern Rivers CMA	916	125	**1041**	120	15	**135**
Burnett Mary Regional Group NRM	889	101	**1000**	84	10	**94**
FNQ (Terrain) NRM	682	83	**765**	66	7	**73**
Fitzroy Basin Association NRM	816	90	**906**	59	8	**67**
Condamine Alliance NRM	773	113	**886**	47	10	**57**
Mackay Whitsunday (Reef Catchments) NRM	721	84	**805**	48	7	**55**
Hunter / Central Rivers CMA	698	100	**798**	37	6	**43**
Burdekin Dry Tropics NRM	616	79	**695**	31	6	**37**
Hawkesbury Nepean CMA	574	82	**656**	29	5	**34**
Sydney Metro CMA	559	73	**632**	19	4	**23**
Southern Rivers CMA	473	75	**548**	15	4	**19**

[A] Note many species occur in more than one management group. The species identified may not be at risk across their full distribution. High priority species are those considered as being at the greatest risk to the threats of *L. camara*.

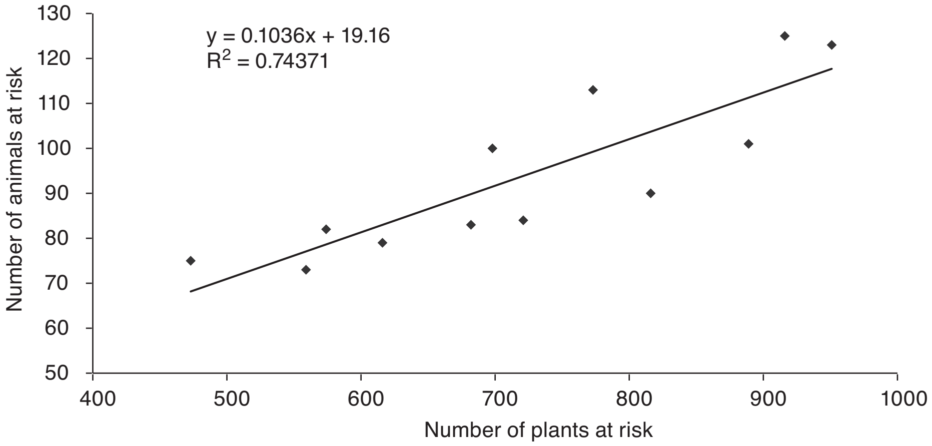

Figure 3. The significant positive relationship between the number of native plant species at risk at each regional management region (NRM or CMA) and the number of native animal species also at risk (d.f. 1,10; F = 29.0; P <0.001).

18% gaining an additional habitat and 19% being promoted (e.g. lantana provided a food source). Ironically many animal species that are threatened by lantana also partially benefited from the presence of lantana invasions and for 19% of the animal species invasion led to no change to their level of threat (Table 4). These positive benefits may be attributed to lantana replacing the existing benefit previously provided by native vegetation, such as shelter or food. The number of native animal species identified as benefiting from lantana within Australia was 142 (although some were also negatively impacted by lantana invasion). The major group of animals benefiting or switching to lantana were birds (63%) followed by mammals (19%: Table 6). In total, 241 animal species have been identified as being associated with lantana (threatened, benefiting or switching to lantana), with some species identified as being influenced in more than one way.

The number of threatened native animal species associated with lantana (either benefiting or being threatened) varied across the invaded states of NSW and Qld, with animals listed under the TSC Act (n = 79), NC Act (n = 42), and EPBC Act (n = 27). These results are not independent as some species are listed under more than one Act. A total of 99 native animal species were listed under at least one of these three Acts and were identified as being associated with lantana infestations. The majority of these threatened animal species (n=93) were at risk from lantana, with only six animal species solely benefiting from lantana.

Determining the animal species most likely change to a higher threatened status if L. camara *is not controlled in the near future*

The prioritization of animal species at risk from lantana invasions in Australia, with respect to their extinction risk revealed that 24 were highest priority, 61 were medium and 62 low priority in terms of urgency of control. A further 11 animal species could not be assessed due to insufficient information. The greatest number of high priority animal species at risk from lantana invasions was for reptiles (Table 6).

Ecological communities threatened from L. camara *invasions*

Generally, riparian zones and wet sclerophyll forests in eastern NSW and Qld were identified as being most at risk from lantana invasion. Thirty-eight threatened ecological communities listed under the TSC Act and ten under the EPBC Act were identified as being threatened by lantana invasions. Twenty-eight of these are considered high priority. In Qld, 407 Regional Ecosystems (REs) were identified as at risk from lantana; however for 154 REs, the threat from lantana is limited, with lantana either being in low numbers or it threatens their edges or it invades following disturbance. Under the VM Act, 104 of the 407 Regional Ecosystems at risk are also classed as endangered. From these 407 Regional Ecosystems, 125 are considered as high priority.

Other alien species and L. camara *invasions*

Lantana camara invasion was identified as providing a dense understorey and thus better shelter for red foxes (*Vulpes vulpes* L.), rabbits (*Oryctolagus cuniculus* L.) and cats (*Felis catus* L.) (Table 7). In total, 21 alien animal species were identified as benefiting from lantana invasions in Australia. In addition, 144 alien plant species were identified that were associated with lantana. These weeds would be equally or more difficult to control or could form a barrier to the recovery of native species following the control of lantana (Table 8).

Table 7. The most frequently cited pest animals that utilize *L. camara* or where control of pest animals is hindered by the presence of *L. camara*.

Pest animal	No. of workshops cited
Fox	13
Rabbit	12
Cat	11
Pig (feral)	10
Cattle (wild and domestic)	6

Table 8. The most frequently cited alien plant species that would be equally or more difficult to control or could hinder the recovery of native species following the control of *L. camara*. The complete list of the other alien species at risk from lantana invasions in Australia is available electronically (see DECC 2007).

Scientific name	Common name	No. of workshops cited
Anredera cordifolia (Ten.) Steenis	Madeira vine	10
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	crofton weed	9
Ipomoea indica (Burm.) Merr.	morning glory	9
Macfadyena unguis-cati (L.) A.H.Gentry	cat's claw creeper	8
Ligustrum sinense Lour.	small-leaved privet	7
Panicum maximum var. *maximum* Jacq.	Guinea grass	7
Solanum mauritianum Scop.	wild tobacco	7
Araujia sericifera Brot.	moth vine	6
Ipomoea cairica (L.) Sweet	five-leafed morning glory	6
Ochna serrulata (Hochst.) Walp.	Mickey mouse plant	6

Discussion

Determining the biodiversity at risk from alien plant invasions

While detailed studies of the impacts of alien plant invasions are invaluable, to date such studies have failed to document the extent of the impact or threat across broad groups of native species (such as plants and animals); are constrained by time; pose difficulties in experimental design (e.g. selecting between removal, addition, or assessing 'natural' invasion experiments and the associated problems of each); and the results are rarely incorporated into management strategies (Downey and Grice 2008). Another problem is that information is rarely determined across an alien plant's entire introduced range within a country, because such an assessment could take many years to complete (see Adair and Groves 1998 for a description of techniques) and may still not resolve the causes of biodiversity decline (e.g. see Turner and Virtue 2006, Turner *et al.* 2008b, Gooden *et al.* 2009b). Irrespective, as there are limited resources available to manage alien plants, the need to determine their impacts and threats to biodiversity must be balanced against the need to implement management practices on the ground (Grice *et al.* 2004) and the immediate need to protect biodiversity from future declines (Turner *et al.* 2007, Turner *et al.* 2008a).

Each of the four stages of the WINS approach was developed to account for the limited experimental data available. As additional workshops were held (especially workshops 16 to 20 – see Figure 2), species identified at risk did not differ significantly from the previous workshops, except for those species that only had a limited distribution specific to the area where the workshop was held. Therefore there was considerable agreement between the results of each workshop as well as with the published information on the biodiversity at risk from lantana, highlighting the veracity of the process. While this reflects a greater confidence in the data collected it can't be used to verify the data as some species at risk are known from only a few locations and thus are unlikely to be identified from more than one source. However, the list of species at risk from this process can now be used to generate a range of tailored experiments to better understand the exact nature of the threat (such as the one undertaken by Gooden 2007, Gooden *et al.* 2009b) or determine mechanisms by which the alien plant poses the threat (e.g. Turner and Downey 2008, Virkki 2009) .

Some authors suggest that there are inherent problems with using lists of species for conservation purposes. For example, Majer and Beeston (1996) suggested that an important feature was missed when the conservation of biological diversity was reduced to species lists only, as the consideration of the integrity or departure from the pristine state is not examined and therefore fails to portray the changes in the quality of the environment. In addition, Possingham *et al*. (2002) suggested that targeting species with the highest extinction probabilities was not the most efficient way of promoting recovery as some species require a large amount of recovery efforts with a limited chance of success. The issues identified by Majer and Beeston (1996) and Possingham *et al*. (2002) are addressed by a second step to the process which assesses the value of specific sites (in terms of species overall survival) and the ability to deliver control and recovery of the species at risk from alien plant invasions (Downey 2008a, Turner *et al.* 2008a, Downey *et al.* in press). This second step examines a range of specific locations for each of the high priority biodiversity at risk to determine priority sites for control. Priority sites are ranked based on (i) the ability to achieve effective control at the site level; (ii) the degree of impact from lantana present at the site; (iii) the value of the site/population to the native biodiversity's overall survival; (iv) the condition of the biodiversity present at the site; and (v) the other threats present and the management of these other threats (Downey *et al.* in press).

There are also a series of benefits in using lists of species for conservation purposes. For example, Downey (2008a) stated that through the identification of the species at risk, control and monitoring programs can be tailored to help ensure conservation outcomes occur as a result of alien plant control. Such lists are also critical for selecting such sites in the first instance. Also once a native species is selected for protection, the knowledge of the biology and ecology of such species can help to predict the likelihood of restoration success (D'Antonio and Meyerson 2002) and determines the appropriate lantana control technique as well as what other restoration measures are needed (e.g. see Turner and Virtue 2009). In addition, as our list of biodiversity at risk also includes information on the likely cause of their decline, management/control programs can be tailored to ensure species recovery. For example, given that the greatest number of high priority animal species at risk from lantana invasions were reptiles (Table 6), research was then directed to the impacts of both lantana and lantana control on reptile assemblages (see Virkki 2009).

Implications for managing L. camara

The results from the WINS assessment across the entire introduced range of lantana in Australia revealed greater than an order of magnitude more species at risk than what was reported previously. This increase is not a reflection of a sudden increase in the problem, but rather a better understanding of the current situation. While many researchers have described the impacts of lantana on native species, either from post-control studies (e.g. Macleay 2004, Thomas and Shaw 2007, Gooden *et al.* 2009a) or from invasion studies (e.g. Alcova 1987, Fensham *et al.* 1994, Kooyman 1996, Gentle and Duggin 1998), this information had not been collated prior to our assessment.

The results of our assessment build on previous studies investigating the impacts of lantana. For example, Macleay (2004) observed an increase in native plants following the removal of lantana at a site in northern NSW. Thomas and Shaw (2007) reported the recovery of many native plants following the removal of lantana in a national park in southeast Qld. This included the recovery of five rare and threatened species. Fensham *et al.* (1994) reported reductions in plant species richness with increasing levels of lantana, in a study undertaken within Forty Mile Scrub National Park in northern Qld. On the central coast of NSW, Gentle and Duggin (1998) showed that lantana was able to suppress at least one native species and in a woodland near Brisbane, Alcova (1987) suggested that the abundances of native shrubs, saplings and trees were lower in lantana infested areas of the woodland compared to lantana-free areas. Gooden *et al*. (2009b) established that native plant species richness and abundance declined with increasing lantana abundance. Species richness of fern, herb, shrub, tree and vine growth forms declined following lantana invasion into wet sclerophyll forest communities (Gooden *et al.* 2009b).

One of the mechanisms identified from the literature by which lantana threatened native plants was its ability to out compete native plants and alter the successional process following a disturbance event (e.g. Duggin and Gentle 1998). This issue was also prevalent in the results of the workshops in that many species were described as being impacted through the prevention of recruitment, particularly following a disturbance. Such knowledge is critical in determining effective management strategies that aim to save native species.

Information derived from this assessment can be used to fill a major knowledge gap and significantly contribute towards the national management of lantana in natural ecosystems in Australia. For example, this list of priority species has been used to develop a national plan aimed at reducing lantana's impacts (Plan to Protect Environmental Assets from Lantana – DECC 2007, NLMG 2009), similar to the NSW *Chrysanthemoides monilifera* Threat Abatement Plan (DEC 2006), which the WINS system was developed for. In addition, information from our study also highlights the role of alien plants in native animal declines as well as interactions between alien plants and native animals (e.g. in providing positive benefits when the native plant species have been displaced – see Loyn and French 1991). Such information is critical for management, given that control could inadvertently impact on these species. Knowledge of the other alien plant species that may invade following control of lantana is also critical for developing effective management strategies. Information on the alien animals that utilize lantana invasions is also useful from a management context as some of the animals may be posing a compounded threat to native plants and animals as well as acting as a dispersal agent. This may result in the need for multiple threat management to occur simultaneously (e.g. Grice *et al.* 2008).

Conserving biodiversity: a two-step process

The WINS assessment is only the first step in a two-step triage process aimed at delivering biodiversity conservation through alien plant management. The second-step is to assess the sites or locations at which the species at risk occur in order to select/prioritize sites for control (Downey *et al.* in press). Information of 442 sites has been collected (see DECC 2007, NLMG 2009) and assessed through the PIC-sites prioritization process (Downey 2008b, Downey *et al.* in press). This process allows for an efficient use of resources, by prioritizing sites where control is achievable and where there is a high likelihood of success towards protecting the biodiversity at risk (Turner *et al.* 2008a). By undertaking these two steps, control of alien plants can be delivered in a strategic manner for the conservation of biodiversity, by targeting areas where control is likely to result in the greatest protection to biodiversity.

The WINS assessment process has now been undertaken for two of the 20 Weeds of National Significance (Thorp and Lynch 2000) within Australia, being *C. monilifera* (DEC 2006) and now lantana. In addition, this process has also been trialled on two other widespread alien plant species in Australia (Downey 2006). If the WINS approach is used in conjunction with the determination of sites for control, it can merge alien plant management with biodiversity conservation, something that has been previously lacking from a policy and management context (Downey *et al.* 2009).

Acknowledgments

We thank the 199 workshop participants for their time and willingness to share their knowledge. Point data for *L. camara* supplied from Wildnet Data, Qld Environmental Protection Agency and Wildlife Atlas, NSW Department of Environment and Climate Change. Funds for this project have been provided by the Australian Government's, Defeating the Weeds Menace initiative. We thank Marion Winkler and Mark Hamilton for collecting information on the biodiversity, such as their distribution and threatened status. We also thank Marion Winkler, Andrew Leys, Scott King and Mark Hamilton for their critical reviews of this manuscript.

References

Adair, R.J. and Groves, R.H. (1998). Impact of environmental weeds on biodiversity: a review and development of a methodology. Biodiversity Group, Environment Australia, Canberra.

Alcova, P.A. (1987). The effects of the presence of *Lantana camara* on local bird populations in Brisbane Forest Park. Project Report No T(AS)99. Queensland University of Technology, Brisbane.

ARMCANZ, (Agriculture and Resource Management Council of Australia and New Zealand), ANZECC, (Australian and New Zealand Environmental and Conservation Council) and Forestry Ministers (2001). Weeds of National Significance lantana (*Lantana camara*) strategic plan. (National Weeds Strategy Executive Committee, Launceston).

Batianoff, G.N. and Butler, D.W. (2003). Impact assessment and analysis of sixty-six priority invasive weeds in south-east Queensland. *Plant Protection Quarterly* 18, 11-17.

Briggs, J.D. and Leigh, J.H. (1995). Rare or threatened Australian plants. (CSIRO Publishing, Collingwood).

Byers, J.E., Reichard, S., Randall, J.M., Parker, I.M., Smith, C.S., Lonsdale, W.M., Atkinson, I.A.E., Seastedt, T.R., Williamson, M., Chornesky, E. and Hayes, D. (2002). Directing research to reduce the impacts of nonindigenous species. *Conservation Biology* 16, 630-40.

Coutts-Smith, A.J. and Downey, P.O. (2006). Impact of weeds on threatened biodiversity in NSW. Technical Series 11. (CRC for Australian Weed Management, Adelaide).

D'Antonio, C. and Meyerson, L.A. (2002). Exotic plant species as problems and solutions in ecological restoration: a synthesis. *Restoration Ecology* 10, 703-13.

Day, M.D., Wiley, C.J., Playford, J. and Zalucki, M.P. (2003). Lantana: current management status and future prospects. Australian Centre for International Agricultural Research, Canberra).

DEC (2006). NSW Threat Abatement Plan – invasion of native plant communities by *Chrysanthemoides monilifera* (bitou bush and boneseed). Department of Environment and Conservation (NSW), Hurstville: see www.environment.nsw.gov.au/bitoutap/.

DECC (2007). Managing the impact of lantana on biodiversity: a national challenge. NSW Department of Environment and Climate Change, Hurstville: Accessed online 9/4/08: www.environment.nsw.gov.au/lantanaplan.

Downey, P.O. (2006). The weed impact to native species (WINS) assessment tool – results from a trial for bridal creeper (*Asparagus asparagoides* (L.) Druce) and ground asparagus (*Asparagus aethiopicus* L.) in southern New South Wales. *Plant Protection Quarterly* 21, 109-16.

Downey, P.O. (2008a). Determination and management of alien plant impacts on biodiversity: examples from New South Wales, Australia. *In* Plant invasions: human perception, ecological impacts and management, eds B. Tokarska-Guzik, J. Brock, G. Brundu, L. Child, C. Daehler and P. Pyšek, pp. 369-85. (Backhuys Publishers, Leiden).

Downey, P.O. (2008b). Determining sites for weed control and biodiversity conservation. Proceedings of the 16th Australian Weeds Conference, eds R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan, pp. 387-8. (Weeds Society of Queensland, Brisbane).

Downey, P.O. and Cherry, H. (2005). Delivering strategic conservation outcomes, through the integrated management of a Weed of National Significance. Proceedings of the 2nd Victorian Weeds Conference, pp. 41-5. (Weed Society of Victoria, Frankston, Melbourne).

Downey, P.O. and Grice, A.C. (2008). Determination and management of the impacts of weeds on biodiversity. Proceedings of the 16th Australian Weeds Conference, eds R. D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan, pp. 23-5. (Weeds Society of Queensland, Brisbane).

Downey, P.O., Williams, M.C., Whiffen, L.K., Turner, P.J., Burley, A.L. and Hamilton, M.A. (2009). Weeds and biodiversity conservation – a review of managing weeds under the NSW *Threatened Species Conservation Act 1995*. *Ecological Management and Restoration* 10 S1, S53-S58.

Downey, P.O., Williams, M.C., Whiffen, L.K., Auld, B.A., Hamilton, M.A., Burley, A.L., Turner, P.J. (in press). Managing alien plants for biodiversity outcomes – the need for triage. *Invasive Plant Science and Management.*

Duggin, J.A. and Gentle, C.B. (1998). Experimental evidence on the importance of *Lantana camara* L. in dry rainforest-open forest ecotones on north-eastern NSW, Australia. *Forest Ecology and Management* 109, 279-92.

Fensham, R.J., Fairfax, R.J. and Cannell, R.J. (1994). The invasion of *Lantana camara* L. in Forty Mile Scrub National Park, north Queensland. *Australian Journal of Ecology* 19, 297-305.

Gentle, C.B. and Duggin, J.A. (1998). Interference of *Choricarpia leptopetala* by *Lantana camara* with nutrient enrichment in mesic forests on the Central Coast of NSW. *Plant Ecology* 136, 205-11.

Gooden, B. (2007). The effect of the woody plant invader *Lantana camara* on vascular plant diversity in wet sclerophyll forest. Honours thesis, School of Biological Sciences, University of Wollongong, Wollongong.

Gooden, B., French, K. and Turner, P.J. (2009a). Invasion and management of a woody plant (*Lantana camara* L.) alters vegetation diversity within wet sclerophyll forest. *Forest Ecology and Management* 257, 960-7.

Gooden, B., French, K., Turner, P.J. and Downey, P.O. (2009b). Impact threshold for an alien plant invader, *Lantana camara* L., on native plant communities. *Biological Conservation* 142, 2631-41.

Grice, A.C., Field, A.R. and McFadyen, R.E.C. (2004). Quantifying the effects of weeds on biodiversity: beyond Blind Freddy's test. Proceedings of the 14th Australian Weeds Conference, eds B.M. Sindel and S.B. Johnson, pp. 464-8. (Weed Society of New South Wales, Sydney).

Grice, A.C., Perry, J.J., Nicholas, D.M. and Williams, P.R. (2008). Managing complexity: the example of invasive wetland forage grasses. Proceedings of the 16th Australian Weeds Conference, eds R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan, pp. 27-9. (Weeds Society of Queensland, Brisbane).

Groves, R.H. and Willis, A.J. (1999). Environmental weeds and loss of native plant biodiversity: some Australian examples. *Australian Journal of Environmental Management* 6, 164-71.

Holmes, P.M. and Richardson, D.M. (1999). Protocols for restoration based on recruitment dynamics, community structure, and ecosystem function: perspectives from South African Fynbos. *Restoration Ecology* 7, 215-30.

Kooyman, R.M. (1996). Growing rainforest: rainforest restoration and regeneration. State Forests of New South Wales, Casino District.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M. (2000). 100 of the World's worst invasive alien species: a selection from the global invasive species database. (The Invasive Species Specialist Group a specialist group of the Species Survival Commission of the World Conservation Union, Auckland).

Loyn, R.H. and French, K. (1991). Birds and environmental weeds in southeastern Australia. *Plant Protection Quarterly* 6, 137-49.

Macleay, R. (2004). Regeneration response after removal of *Lantana camara* L. from mixed forest in the lower Bellinger valley, northern New South Wales. *Ecological Management and Restoration* 5, 70-1.

Majer, J.D. and Beeston, G. (1996). The biodiversity integrity index: an illustration using ants in Western Australia. *Conservation Biology* 10, 65-73.

NLMG (2009). Draft plan to protect environmental assets from lantana. (National Lantana Management Group, Moorooka: see www.weeds.org.au/WoNS/lantana/).

Possingham, H.P., Andelman, S.J., Burgman, M.A., Medellin, R.A., Master, L.L. and Keith, D.A. (2002). Limits to the use of threatened species lists. *Trends in Ecology and Evolution* 17, 503-7.

Reid, A.M., Morin, L., Downey, P.O., French, K. and Virtue, J.G. (2009). Does invasive plant management aid the restoration of natural ecosystems? *Biological Conservation* 142, 2342-9.

Richardson, D.M. and van Wilgen, B.W. (2004). Invasive alien plants in South Africa: how well do we understand the ecological impacts? *South African Journal of Science* 100, 45-52.

Robertson, M.P., Villet, M.H., Fairbanks, D.H.K., Henderson, L., Higgins, S.I., Hoffmann, J.H., Le Maitre, D.C., Palmer, A.R., Riggs, I., Shackleton, C.M. and Zimmermann, H.G. (2003). A proposed prioritization system for the management of invasive alien plants in South Africa. *South African Journal of Science* 99, 37-43.

Sattler, P.S. and Williams, R.D. (1999). The conservation status of Queensland's bioregional ecosystems. Environmental Protection Agency and the Queensland National Parks Association, Brisbane.

Simberloff, D. and Von Holle, B. (1999). Positive interactions of nonindigenous species: invasional meltdown? *Biological Invasions* 1, 21-32.

Sinden, J., Hester, S., Odom, D., Kalisch, C., James, R. and Cacho, R. (2004). The economic impact of weeds in Australia. Technical Series 8. (CRC for Australian Weed Management, Adelaide).

Swarbrick, J.T., Wilson, B.W. and Hannan-Jones, M.A. (1998). *Lantana camara* L. The Biology of Australian Weeds, Vol. 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 119-40. (RG and FJ Richardson, Melbourne).

Thomas, R. and Shaw, S. (2007). Weed management in significant natural areas – a case study. Proceedings of the 9th Queensland Weeds Symposium, eds C. Love and P. Maher, pp. 91-5. (Weed Society of Queensland, Brisbane).

Thorp, J.R. and Lynch, R. (2000). The determination of Weeds of National Significance. (National Weeds Strategy Executive Committee, Launceston).

Turner, P.J. and Downey, P.O. (2008). The role of native birds in weed invasion, species decline, revegetation and reinvasion: consequences for lantana management. Proceedings of the 16th Australian Weeds Conference, eds R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan, pp. 30-2. (Weeds Society of Queensland, Brisbane).

Turner, P.J., Hamilton, M.A. and Downey, P.O. (2008a). The triage approach to conserving biodiversity from lantana invasion. Proceedings of the 16th Australian Weeds Conference, eds R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan, pp. 393. (Weeds Society of Queensland, Brisbane).

Turner, P.J., Scott, J.K. and Spafford, H. (2008b). The ecological barriers to the recovery of bridal creeper (*Asparagus asparagoides* (L.) Druce) infested sites: impacts on vegetation and the potential increase in other exotic species. *Austral Ecology* 33, 713-22.

Turner, P.J., Scott, J.K. and Spafford, H. (2008c). Implications of successful biological control of bridal creeper (*Asparagus asparagoides* (L.) Druce) in south west Australia. Proceedings of the 16th Australian Weeds Conference, eds R.D. van Klinken, V.A. Osten, F.D. Panetta and J.C. Scanlan, pp. 390-2. (Weeds Society of Queensland, Brisbane).

Turner, P.J. and Virtue, J.G. (2006). An eight year removal experiment measuring the impact of bridal creeper (*Asparagus asparagoides* (L.) Druce) and the potential benefit from its control. *Plant Protection Quarterly* 21, 79-84.

Turner, P.J. and Virtue, J.G. (2009). Ten year post-fire response of a native ecosystem in the presence of high or low densities of the invasive weed, *Asparagus asparagoides*. *Plant Protection Quarterly* 24, 20-6.

Turner, P.J., Winkler, M.A. and Downey, P.O. (2007). Establishing conservation priorities for lantana. The 14th Biennial NSW Weeds Conference Proceedings, 24-27 September 2007, (University of Wollongong, Wollongong).

Virkki, D.A. (2009). Lantana management and its impacts on reptile assemblages and habitat quality within a wet-sclerophyll forest in south-east Queensland. Honours thesis, Griffith University, Gold Coast Campus.

Walker, L.R. and Smith, S.D. (1997). Impacts of invasive plants on community and ecosystem properties. *In* Assessment and management of plant invasions, eds J.O. Luken and J.W. Thieret, pp. 69-86. (Springer-Verlag, New York).

Weeds CRC and Standards Australia (2006). HB 294:2006 National post-border weed risk management protocol. (CRC Australian Weed Management, Adelaide, Standards Australia, Sydney and Standards New Zealand, Wellington).

Williams, J.A. and West, C.J. (2000). Environmental weeds in Australia and New Zealand: issues and approaches to management. *Austral Ecology* 25, 425-44.

Williams, M.C., Auld, B.A., Whiffen, L.K. and Downey, P.O. (2009). Elephants in the room: widespread weeds and biodiversity. *Plant Protection Quarterly* 24, 120-2.