Integrating Adaptive Weed Management and Biodiversity Conservation in the Blue Mountains

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Foreword

The Australian Government has listed lantana as one of the country’s worst weeds. It is expanding its range further south and inland and it is important to understand how it might progress and further compromise Australian landscapes.

The Blue Mountains region was taken as a case study for investigating the potential spread of lantana because Blue Mountains City Council is very interested in maintaining the effectiveness of its weed control operations and better understanding the potential threats new arrivals might pose.

This research aimed to develop a habitat suitability model for lantana in a portion of the Greater Blue Mountains World Heritage Area at present and under forecast warmer climates.

This work identified temperature as the most important environmental variable currently restricting lantana’s presence to the lower altitudes along the eastern reaches of the local government area. In view of the changes probably in store for the climate of the Blue Mountains, the research indicates it is imperative that management make efforts to reduce lantana’s population while it still has the help of cool winters and frequent frosts.

This project was funded in Phase 1 of the National Weeds and Productivity Research Program, which was managed by the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) from 2008 to 2010. The Rural Industries Research and Development Corporation (RIRDC) is now publishing the final reports of these projects.

Phase 2 of the Program, which is funded to 30 June 2012 by the Australian Government, is being managed by RIRDC with the goal of reducing the impact of invasive weeds on farm and forestry productivity as well as on biodiversity. RIRDC is commissioning some 50 projects that both extends on the research undertaken in Phase 1 and moves into new areas. These reports will be published in the second half of 2012.

This report is an addition to RIRDC’s diverse range of over 2000 research publications which can be viewed and freely downloaded from our website www.rirdc.gov.au. Information on the Weeds Program is available online at www.rirdc.gov.au/weeds.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

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Managing Director
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Executive Summary

What the report is about

Invasive weeds present a serious threat to primary productivity and conservation of biodiversity in Australia. The Australian Government has listed lantana, *Lantana camara* L. sensu lato, as one of the country’s worst weeds. This weed is expanding its range further south and inland, and it is important to understand how it might progress and further compromise Australian landscapes.

The Blue Mountains region was taken as a case study for investigating the potential spread of lantana because Blue Mountains City Council is very interested in maintaining the effectiveness of its weed control operations and better understanding the potential threats new arrivals might pose, and in continuously improving its weed management strategies.

In addition, private landholders are keenly aware of the threats weeds pose to native biodiversity.

Finally, Blue Mountains City Council manages the urban–bushland interface between townships and the Greater Blue Mountains World Heritage Area, so its work is often the first line of defence when protecting the World Heritage values of the surrounding national parks.

Because future climatic conditions are likely to become more suitable for lantana, it is important to begin containing the weed now. The weed modelling work done for this study aims to give managers the information they need in order to identify suitable habitat and potential incursion pathways for lantana westward through the Blue Mountains.

Who is the report targeted at?

The research is relevant to anyone trying to manage new weed infestations (particularly lantana) — including land managers at Blue Mountains City Council, private landholders and, since the study area includes portions of Blue Mountains National Park, the New South Wales National Parks and Wildlife Service. Among the relevant townships are mountain towns from Lapstone in the east and along the Great Western Highway to Mount Victoria in the west.

The recommendations arising from the study are aimed at on-ground land managers, policy makers assessing weed management priorities, local government officials making land-use decisions, and private landholders.

Aims/objectives

This research aimed to develop a habitat suitability model for lantana (*Lantana camara* L. sensu lato) in a portion of the Greater Blue Mountains World Heritage Area at present and under forecast warmer climates.

A primary objective of the study was to identify which sections of the local government area were most susceptible to lantana invasion since the weed is currently abundant only in the easternmost townships. Additionally, considering that lantana has historically preferred warmer temperatures, the potential for its spread under climate change throughout the Blue Mountains was investigated by simulating temperature increases. A third objective was to compile a list of at-risk vegetation communities and species, using the results from the identification of susceptible areas.

Methods used

Habitat suitability modelling was used to identify at-risk areas. Specifically, a generalised additive modelling approach was used; taking 2001 survey data compiled by Blue Mountains City Council and using them to identify the factors most responsible for lantana’s persistence in the region, as well as
predicting which areas of the landscape are most suitable for the weed at present and under warmer climate conditions.

The research area consisted of the Blue Mountains City Council local government area, plus a 2-kilometre buffer around its boundary and a north-east extension into the neighbouring Hawkesbury local government area.

**Results/key findings**

The habitat suitability modelling work identified temperature as the most important environmental variable currently restricting lantana’s presence to the lower altitudes along the eastern reaches of the local government area.

Although only 15 per cent of the study area was found to be suitable for the weed at present, after a 3°C simulated rise in maximum temperatures 58 per cent of the study area was declared suitable. The region’s riparian areas were identified as relatively high temperature pathways by which lantana might progress into the Greater Blue Mountains World Heritage Area.

Five endangered ecological communities (as mapped by Blue Mountains City Council) were identified as being at risk of lantana invasion in the near future: Shale–Sandstone Transition Forest, Blue Mountains Shale Cap Forest, Sun Valley Cabbage Gum Forest, Blue Gum Riverine Forest, and Sydney Turpentine Ironbark Forest. At least 27 endangered species (as identified by the relevant legislation) are thought to exist in these communities and are thus under additional threat because of lantana invasion.

The research has directly responded to calls for the integration of weed management with biodiversity conservation. Just as the methods for developing the habitat suitability model can be adapted to other weeds where presence and absence data are available, so can the strategy for integrating biodiversity conservation be adapted. If these techniques are extended to other weed species, an assessment of the collective threat Australia’s worst weeds pose for the country’s native biodiversity is possible.

**Implications for relevant stakeholders**

The research led to the identification of important factors determining lantana’s spread into the Blue Mountains and thus Australia’s alpine areas, with potential new considerations for management of warm-weather weeds in these regions—such as emphasising the potential for ingress via riparian areas. In addition, the work explicitly incorporated biodiversity considerations in weed mapping, allowing for targeted control and a greater appreciation of the threat weeds pose to specific vegetation communities and endangered species.

**Recommendations**

In view of the changes probably in store for the climate of the Blue Mountains, it is imperative that management make efforts to reduce lantana’s population while it still has the help of cool winters and frequent frosts: such assistance might not be available for much longer.

Noxious weeds control teams suggested that the model and up-to-date surveys would draw attention to the urgent need to control lantana now rather than in the future. Allocating control measures to existing infestations at present is likely to be cost-effective given the weed’s potential to spread extensively when temperatures become warmer.
Introduction

Invasive weeds cause significant harm to native species, ecosystem processes and natural disturbance regimes. In efforts to manage these weed threats, some of the most useful tools are the outputs of predictive distribution models. Because the models supplement existing distribution data to assess what parts of the landscape are most susceptible to weed invasion, they allow for more efficient weed management: the areas most suited to weed species can be targeted for control.

Blue Mountains City Council is a major player in weed management in the townships cutting through the Greater Blue Mountains World Heritage Area. The council is keenly interested in proactively managing weed threats in order to maintain the ecological integrity of the urban–bushland interface and in supporting efforts to maintain the World Heritage values of the surroundings. The council is aware that an Australian weed of national significance, lantana (*Lantana camara* L. sensu lato), currently has a restricted distribution at lower altitudes in the east but has the potential to spread west. Concern about lantana’s spread is heightened in view of the likelihood of the mountains experiencing warmer temperatures under predicted climate change.

Because future climatic conditions are likely to become more suitable for lantana, it is important to begin containing the weed now. The weed modelling work done for this study aims to give managers the information they need in order to identify suitable habitat and potential incursion pathways for lantana westward through the Blue Mountains. The landscape’s suitability for lantana distribution changes under modelled temperature increases was also investigated in order to elucidate how climate change might affect the weed’s potential spread. As a result, managers will be able to identify habitat suitable for lantana at present and how the landscape’s suitability for the weed might change in the future, allowing for targeted management action along potential invasion pathways so as to prevent the weed’s incursion into council-managed lands and the larger World Heritage Area.

The three main objectives for this project were as follows:

- to analyse the council’s weed management strategies and how they can integrate weed management with biodiversity conservation
- to develop a list of areas that should receive special attention because of the impacts of weeds of national significance on native biodiversity, as well as identify at-risk areas that should be closely monitored
- to develop a strategy for identifying weed impacts on biodiversity during the survey and mapping stage.

Although there were no strict variations to these objectives, the second and third ones stood out as the successes of the project. Lantana was identified as a weed of national significance that was of particular interest to the council and so was made the focus of this study. A list showing the threat lantana currently poses to the region’s vegetation communities as well as at-risk areas was generated (the second objective); it incorporated biodiversity information that allowed for the identification of where the impacts of lantana were greatest (the third objective). The first objective was more difficult to achieve in terms of conclusive publishable material because the council had not coordinated its 2001 survey with the beginning or end of weed control actions. Weed control operations were not synchronised with weed distribution surveys, so it was difficult to attribute any increase or decrease in weed abundance to specific management actions. Observational evidence of successful weed control using a variety of methods was, however, obtained, and suggestions are made for better coordinating weed management with field surveys.
Methods

This research aimed to develop a habitat suitability model for lantana (*Lantana camara* L. sensu lato) in a portion of the Greater Blue Mountains World Heritage Area at present and under forecast warmer climates. A generalised additive model was used; it fits the regression curve used for prediction to the calibration data themselves and allows for an exploration of which environmental conditions favour lantana as well as where in the landscape is most suitable for the weed.

Weed distribution survey data from 2001 were obtained from Blue Mountains City Council, and layers of environmental variables derived from a digital elevation model supplied by the New South Wales Department of Environment, Climate Change and Water were used.

Generalised additive models regressing every possible combination of the potential variables against lantana presence were constructed and the optimal model was chosen. Each combination of predictor variables was iteratively regressed against lantana presence or absence and returned the AIC for each GAM. A binomial distribution was assumed. Because strong linear relationships among the predictors in a regression analysis can diminish the precision of the estimated regression coefficients (Fox 2002), relationships between environmental variables were checked for colinearity. Residual interpolation methods such as those championed by Miller (2005) and Miller et al. (2007) to account for spatial dependence were not invoked because the aim of the modelling exercise was to predict suitable habitat for lantana rather than assess the significance of predictor variables.

Finally, after the models had been built they were used to predict suitable habitat for lantana (that is, lantana presences) on council-managed lands. A polygon of local government area boundaries was obtained from the Department of Environment, Climate Change and Water, and habitat suitability was mapped to the extent of the LGA with a 2-kilometre buffer. In addition, the north-eastern boundary of the prediction extent was manually extended into the neighbouring Hawkesbury LGA, since lantana is known to occur in the area and might progress westward into the northern reaches of the Blue Mountains City Council LGA. A lattice of points spaced 100 metres apart was generated for the prediction extent using Hawth’s Analysis Tools for ArcGIS (Beyer 2004), and the values of all environmental variables used in the models were extracted for each point. A spacing of 100 metres resulted in a total of 235,931 prediction points and was chosen so as to provide adequate coverage while keeping processing time reasonable.

Simulating climate change temperature increases

Selection of a suitable climate simulation model can be an arduous task when predicting changes in species distributions, so researchers have simulated temperature increases uniformly across the landscape of interest in order to minimise the introduction of errors associated with a given climate model (Williams et al. 2003). Such ‘idealised scenarios’ have been primarily used for temperature and might be preferred in places where climate model simulations compare poorly with observations—for example, in spatially heterogeneous mountain regions (Beaumont et al. 2008). To simulate how suitable habitat for lantana might change with predicted climate change (IPCC 2007), 1, 2 and 3°C were therefore added to the extracted TMP-MXT values for the 100-metre spaced lattice of points across the prediction extent. The GAM calibrations were used to predict lantana presence or absence across the prediction extent at all three temperature intervals. A maximum increase of 3°C was chosen in accordance with the Intergovernmental Panel on Climate Change’s predicted increase of 2.9°C for the coastal regions of New South Wales under the A2 high-emissions scenario (IPCC 2007).
Fieldwork

The research contained a fieldwork component designed to supplement Bluespace mapping by determining lantana presence or absence at selected points across the prediction extent. Two hundred randomly spaced points were generated within the prediction extent using Hawth’s Analysis Tools for ArcGIS (Beyer 2004). In the interest of accessibility, points were constrained to lie within 100 metres of a road, as specified by a layer of New South Wales roads obtained from the Department of Environment, Climate Change and Water. The random points layer and roads layer were transferred to a GPS-equipped PDA using ArcPad version 7.1.1 (ESRI 2008). In the field every effort was made to record lantana presence or absence at the exact point, as specified by the points layer. Where points could not be reached, lantana presence or absence was recorded at a new point as close as possible to the original one. Incidental lantana sightings—that is, presences at a location other than one previously specified by a random point—were also recorded as presence points. Fieldwork was used to validate the habitat suitability model.

Impacts on biodiversity

In order to investigate the possible future impact of lantana on native biodiversity, the potential for lantana spread, as identified by the habitat suitability model, was combined with known information about vegetation communities and threatened species in the Blue Mountains.

A layer of mapped vegetation communities was obtained from Blue Mountains City Council. To determine the threat lantana poses to native biodiversity, both now and under warmer climatic conditions, the vegetation community layer was overlaid with the sightings of lantana from Bluespace and the fieldwork for this research. Using the habitat suitability model developed by this project, we designated a vegetation community a ‘priority vegetation community’ if more than 20 per cent of its overall area was classified as suitable habitat at present or if more than 80 per cent of its overall area was classified as suitable habitat after a 3°C increase in temperature. These cut-offs were chosen so as to highlight those vegetation communities most susceptible to lantana invasion at present and under warmer climatic conditions on the basis of an initial assessment of the amount of suitable habitat each vegetation community contained. As noted, 3°C was chosen as the maximum simulated temperature increase because the Intergovernmental Panel on Climate Change predicts an average temperature increase of 2.9°C for the area by 2050 under its A2 high-emissions scenario (IPCC 2007). Inclusion of vegetation communities that have a majority of habitat suitable for lantana after a 3°C temperature increase as priority vegetation communities allows for the identification of biodiversity that could be at risk over longer time frames as the region warms (in addition to communities currently under threat).

Vegetation communities were further categorised as short- or long-term concerns after consideration of the distance of the community to a sighting of lantana and whether the community contained, or itself was listed as, a threatened ecological community under the state’s Threatened Species Conservation Act 1995. If a vegetation community did not contain a lantana sighting, had no portion of its area specified as suitable lantana habitat at present or under any climate scenario, or was not classified as a threatened ecological community it was dropped from further analysis.

The vegetation community layer was overlaid with the results of the lantana habitat suitability model for present-day conditions as well as under simulated increases of 1, 2 and 3°C; it was then assessed for how much of each vegetation community was also classified as suitable habitat by each model. The vegetation community layer was converted to raster with a 25-metre cell size, and the tabulate area function in ArcMap version 9.3 (ESRI 2008) was used to calculate how many grid cells in each vegetation community were also classified as suitable lantana habitat under each model. The number of grid cells returned was multiplied by 625 to obtain the total square metres classified as suitable habitat in each vegetation community. The result was then converted into hectares, and percentages of the total community area considered suitable for lantana were also derived for each vegetation community.
Distance to the closest lantana sighting—as identified by council mapping or the fieldwork for this research—was obtained for each vegetation community polygon using the spatial join function in ArcMap 9.3. This function links the attributes of each lantana sighting with its nearest vegetation community polygon, giving the distance between them as an output. Because there are multiple polygons for each vegetation community, the polygon of a given vegetation community with the shortest distance was chosen to represent the shortest distance of the vegetation community as a whole to lantana. A distance of zero meant that the polygon itself contained a lantana sighting. Distance to lantana was used to further develop priorities for areas for management: priority vegetation communities are more likely to be invaded by lantana if they already contain or are near a lantana sighting.

To further analyse the threat lantana poses to biodiversity in threatened ecological communities in the Blue Mountains, TECs identified as priority vegetation communities (‘priority TECs’) were assessed to determine whether endangered species were known to occur in them. The Department of Environment, Climate Change and Water maintains a threatened species database that includes listings of threatened species in each vegetation community, as mapped by the department (http://www.threatenedspecies.environment.nsw.gov.au/tsprofile/home_species.aspx).

There is, however, a database-matching problem because the vegetation communities as mapped by Blue Mountains City Council (local government level) were named in accordance with a private consultant’s report (Douglas 2001, cited in BMCC 2002), whereas those mapped by the department (state level) were named in accordance with Keith (2004). This results in some naming incongruities between the data sets. Since the threatened species database is based on the department’s vegetation communities, a vegetation community layer was obtained from the department and overlaid with the council’s vegetation community layer to identify the departmental vegetation communities to which each priority threatened ecological community corresponded. The database was then searched for which endangered species occur in each priority threatened ecological community (using the corresponding departmental vegetation community).

Since vegetation communities vary in composition by location, endangered flora within the threatened ecological communities were further assessed to determine whether the species actually occurred in the Blue Mountains. Searches were also run using Australia’s Virtual Herbarium website (http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/avh/avh.cgi). Species names were manually entered into the AVH database, and available AVH maps with locations of herbarium records were visually inspected to determine whether or not the species in question was known to occur within the Blue Mountains region.
Results

As noted, the identification of at-risk areas and at-risk biodiversity while mapping potential lantana infestations stood out as the successes of the project.

A strength of using generalised additive model techniques for habitat suitability modelling is that using original data sets to calibrate the model allows for an investigation of which variables are strongly correlated with current lantana presence or absence. The habitat suitability model explained 48.68 per cent of the overall variance in lantana presence or absence across the landscape. Of that explained variance, temperature explained 90.47 per cent of variance in predicted lantana presence; all other environmental variables each explained less than 3.1 per cent of variance in lantana presence, even though they were included in the most ‘parsimonious’ model in terms of the model selection process.

Table 1 shows the total areas within the prediction extent classified as suitable habitat at present and after temperature increases of 1, 2 and 3°C.

Table 1  Predicted areas suitable for lantana under each temperature model

<table>
<thead>
<tr>
<th>Predicted area extent (ha)</th>
<th>Area considered suitable for lantana (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+0°C</td>
</tr>
<tr>
<td>235,900</td>
<td>37 895</td>
</tr>
<tr>
<td>Percentage</td>
<td>15</td>
</tr>
</tbody>
</table>

Note: +0°C refers to the present-day model.

Figure 1 maps the presence of suitable habitat for lantana across the landscape under present conditions and highlights potential pathways of further ingress into the Blue Mountains. Figures 2, 3 and 4 map suitable habitat after temperature increases of 1, 2 and 3°C respectively.

Appendix A lists the proportions of the total area of mapped vegetation communities classified as suitable lantana habitat. If a vegetation community is not listed there, it did not contain any suitable lantana habitat. Thirteen vegetation communities had over 20 per cent of their total area classified as suitable lantana habitat; an additional five vegetation communities had over 80 per cent of their total area classified as suitable lantana habitat after a simulated 3°C rise in temperature, resulting in a total of 18 priority vegetation communities.

A review of the state’s Threatened Species Conservation Act 1995 identified five priority vegetation communities as threatened (see Appendix A). All five are listed under Part 3 of Schedule 1 to the Act as endangered ecological communities and are referred to in the Act by their Blue Mountains City Council vegetation community name, although the 2L code, *Casuarina cunninghamiana* River Oak Forest, is included in the listing of Sydney Coastal Riverflat Forest (BMCC 2005). The Blue Mountains Swamps vegetation community, while not a priority community in terms of containing suitable lantana habitat, is listed as a vulnerable ecological community under Part 2 of Schedule 2 to the Act.

An assessment of the threatened species occurring in each threatened ecological community’s corresponding departmental vegetation community, using the department’s threatened species database and Australia’s Virtual Herbarium, revealed 27 endangered species at further risk from lantana (see Appendix B). It is important to note that the species listed in Appendix B do not include all those listed as endangered in the departmental vegetation communities. This is because if a species was not identified by Australia’s Virtual Herbarium as existing in the Blue Mountains it was excluded from the list, regardless of whether it is known to occur in the vegetation community. Even though Australia’s Virtual Herbarium consists of opportunistically recorded data and might therefore lack records of flora...
species that actually do occur in the Blue Mountains but have not been recorded, the database nonetheless returned a high number of threatened flora records in the area.

Sydney Hinterland Dry Sclerophyll Forests (shrubby formation)—corresponding to the Blue Mountains City Council vegetation communities of 2B, Blue Mountains Shale Cap Forest; 2D, Shale/Sandstone Transition Forest; and 2I, Sun Valley Cabbage Gum Forest—contained the highest number of threatened species overall (21) as well as the highest number of threatened species unique to the vegetation community (13). Eastern Riverine Forests (corresponding to 2L, *Casuarina cunninghamiana* River Oak Forest) and North Coast Wet Sclerophyll Forests (shrubby formation) (corresponding to 2K, Blue Gum Riverflat Forest) contained one unique species each: *Asterolasia buxifolia* and *Zieria involucrata* respectively. Northern Hinterland Wet Sclerophyll Forests (grassy formation) (corresponding to 2C, Sydney Turpentine–Ironbark Forest) contained only one threatened species identified as existing in the Blue Mountains—*Petrogale penicillata* (brush-tailed rock-wallaby), which is not unique to the vegetation community.
Note: Blue Mountains City Council local government area is outlined in white. Suitability ranges from marginally suitable (blue; near the threshold of 0.1) to very suitable (red; approaching 1.0). Uncoloured areas fell below the 0.1 threshold. The yellow numbered boxes relate to the invasion pathways discussed in the text.

Figure 1 Habitat suitability for lantana under current conditions
Note: Blue Mountains City Council local government area is outlined in white. Suitability ranges from marginally suitable (blue; near the threshold of 0.1) to very suitable (red; approaching 1.0). Uncoloured areas fell below the 0.1 threshold.

Figure 2  Habitat suitability for lantana after a temperature increase of 1°C
Note: Blue Mountains City Council local government area is outlined in white. Suitability ranges from marginally suitable (blue; near the threshold of 0.1) to very suitable (red; approaching 1.0). Uncoloured areas fell below the 0.1 threshold.

Figure 3  Habitat suitability for lantana after a temperature increase of 2°C
Note: Blue Mountains City Council local government area is outlined in white. Suitability ranges from marginally suitable (blue; near the threshold of 0.1) to very suitable (red; approaching 1.0). Uncoloured areas fell below the 0.1 threshold.

Figure 4  Habitat suitability for lantana after a temperature increase of 3°C
Implications

Although six environmental variables were included in the final model, maximum temperature accounted for more than 90 per cent of the variation in lantana presence that was explained by the model. Habitat suitability was positively correlated with temperature, a finding supported by past research suggesting that, although lantana thrives in a wide variety of environments under broad climatic conditions, it is intolerant of cooler temperatures (Sharma et al. 2005). Cilliers (1983) found that lantana rarely occurs where temperatures frequently fall below 5°C because its growth is prevented by the freezing and death of its shoots.

It has also been suggested that canopy cover is an important determinant of whether lantana will establish. Fensham et al. (1994) found a negative correlation between lantana density and tree cover, and Gentle and Duggin (1997) concluded that shading plays a greater role in limiting lantana than other environmental factors such as soil nutrient levels. One might therefore have expected the canopy cover predictor variable used in this research to explain a substantial amount of the variation in lantana presence. That it explained very little variation—3.01 per cent as described by the model—does not necessarily mean that local canopy cover is an unimportant predictor of whether or not the weed will establish; rather, it probably results from the temperate climate of the study area.

Fensham et al. (1994), who suggested that canopy cover is an important determinant of lantana presence or absence, studied lantana in a tropical environment where the mean maximum temperature ranged from 26.5°C in July to 35.1°C in November (BOM 2009a). Such high temperatures stand in stark contrast to those of the Blue Mountains, where even in the warmer Lower Blue Mountains, winter maxima reach only 16°C and minima often fall below 0°C with frequent frosts (BOM 2009b). Given lantana's sensitivity to frosts and low temperatures, the weed's distribution in the Blue Mountains is therefore more likely to be restricted by temperature than in tropical areas. In tropical areas, where lantana is not stressed by low temperatures, other variables such as canopy cover might become more important as predictors of the weed's presence or absence.

Adding 1, 2 and 3°C to the maximum temperature values of the prediction extent dramatically increased the amount of habitat suitable for lantana in the Blue Mountains and shows how forecast warmer climates might greatly facilitate the weed’s spread into the area. The model predicts that the amount of the local government area that is suitable for lantana will increase from 15 per cent at present to 58 per cent after a 3°C rise in temperature, so it is highly likely that the cooler climate of the region is management’s best ally for restricting the weed’s distribution. The habitat suitability map for lantana after a 3°C rise in temperature classifies almost all of the lower Blue Mountains as suitable habitat (see Figure 4). If the region’s relatively cool climate is lost after a 3°C rise in temperature by 2050, as predicted (IPCC 2007), the lower Blue Mountains might look more like the heavily infested Hawkesbury region to the north-east.

By overlaying the habitat suitability model with vegetation community layers and assessing these communities for the presence of endangered species, we were able to assess which biodiverse areas are at greatest threat from lantana’s further progress into the Blue Mountains. Armed with a knowledge of the biodiversity at greatest threat from lantana, land managers can target for lantana control areas where the benefits for biodiversity are the greatest.

Lantana presents one of the worst threats to native species in Australia (Thorp & Lynch 2000), and the present research has directly responded to calls for the integration of weed management with biodiversity conservation. Just as the methods for developing the habitat suitability model can be adapted to other weeds where presence and absence data are available, so can the strategy for integrating biodiversity conservation be adapted. If these techniques are extended to other weed species, an assessment of the collective threat Australia’s worst weeds pose for the country’s native biodiversity is possible.
Recommendations

As can be seen through the mapping of suitable habitat, many potential invasion pathways for lantana are similar in that suitable habitat lies along riparian areas. Although in this study the preference for riparian areas appears to result from the relatively higher maximum temperatures experienced in these areas, research suggests that lantana might establish small populations along the shores of waterways (van Oosterhout et al. 2004). Furthermore, management agencies have expressed concern about lantana along river shores because the rivers can act as dispersal corridors for the weed (ARMCANZ et al. 2000). Although water is not thought to be a major dispersal agent for the weed, riparian areas are generally characterised by interruptions in the forest canopy and higher soil temperature and moisture—conditions that are ideal for lantana germination, growth and seed production (Duggin & Gentle 1998). In addition, Bluespace surveys and this project’s fieldwork found the weed along riparian areas near the eastern border of the Blue Mountains City Council local government area.

As a result—considering that lantana is known to establish along the shores of rivers and that the present study identified such areas as the most suitable habitat for the weed to progress westward into the Blue Mountains—these areas should be accorded priority for monitoring and management. If lantana is allowed to establish and persist in these areas it might continue to propagate itself westward along the rivers, expanding its range with detrimental consequences for World Heritage biodiversity. The river shores might in fact become the focal places for lantana to disperse seed into the intact wilderness, waiting for the next disturbance—for example, fire or tree damage caused by feral animals such as pigs and horses (Fensham et al. 1994)—to make its inroads into the now relatively undisturbed eucalypt forests.

Climate change will have major consequences for the spread of invasive species because changing conditions will destroy existing niches and create new, empty ones (Hellmann et al. 2008). Some experts have expressed concern that these new niches will be most easily colonised by invasive species that can easily adapt to new environments and for which migration is an insignificant barrier (Woodward & Kelly 2008). Since the forecast temperature increases will serve only to make conditions more suitable for lantana in the Blue Mountains, the weed might take advantage of any niche changes a warmer world bestows on the region. The region is high in endemism and is on the World Heritage List for its conservation values (UNESCO 2001), and climate change might well bring permanent loss of native species with restricted ranges, with weeds such as lantana taking their place.

In view of the changes probably in store for the climate of the Blue Mountains, it is imperative that management make efforts to reduce lantana’s population while it still has the help of cool winters and frequent frosts: such assistance might not be available for much longer. Furthermore, since is it thought that native species will be slower to adapt to changes in temperature, rainfall and carbon dioxide availability (Hellmann et al. 2008; Woodward & Kelly 2008), lantana control will buy the area’s native biodiversity valuable time to adapt to new conditions it might face.
## Appendix A  Lantana habitat and simulated temperature increases

Table A1  Percentage of each vegetation community classified as suitable habitat for lantana at present and under simulated temperature increases of 1, 2 and 3°C

<table>
<thead>
<tr>
<th>Code</th>
<th>Vegetation community</th>
<th>+0°C</th>
<th>+1°C</th>
<th>+2°C</th>
<th>+3°C</th>
<th>Priority condition</th>
<th>Distance to lantana (m)</th>
<th>Threatened ecological community</th>
</tr>
</thead>
<tbody>
<tr>
<td>2C</td>
<td>Sydney Turpentine–Ironbark Forest</td>
<td>44.1</td>
<td>45.4</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>2D</td>
<td>Shale/Sandstone Transition Forest</td>
<td>26.9</td>
<td>31.8</td>
<td>88.8</td>
<td>97.0</td>
<td>20% now</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>2I</td>
<td>Sun Valley Cabbage Gum Forest</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>110</td>
<td>Yes</td>
</tr>
<tr>
<td>2K</td>
<td>Blue Gum Riverflat Forest</td>
<td>52.5</td>
<td>80.2</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>2L</td>
<td><em>Casuarina cunninghamiana</em> River Oak Forest</td>
<td>63.5</td>
<td>67.0</td>
<td>99.2</td>
<td>99.6</td>
<td>20% now</td>
<td>30 500</td>
<td>Yes</td>
</tr>
<tr>
<td>1C</td>
<td>Megalong Granite Dry Rainforest</td>
<td>25.6</td>
<td>46.1</td>
<td>78.1</td>
<td>99.7</td>
<td>20% now</td>
<td>31 900</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><em>Melaleuca linariifolia</em> Low Open-forest</td>
<td>71.7</td>
<td>89.6</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>876</td>
<td></td>
</tr>
<tr>
<td>4B</td>
<td><em>Eucalyptus sclerophylla</em> Bench Woodland</td>
<td>50.3</td>
<td>54.3</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>279</td>
<td></td>
</tr>
<tr>
<td>4C</td>
<td>Kowmung Wilderness Complex</td>
<td>25.7</td>
<td>29.5</td>
<td>59.0</td>
<td>86.0</td>
<td>20% now</td>
<td>31 300</td>
<td></td>
</tr>
<tr>
<td>5D</td>
<td>Lagoon Vegetation (Glenbrook Lagoon)</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Blue Mountains Riparian Complex</td>
<td>22.5</td>
<td>29.9</td>
<td>47.7</td>
<td>63.8</td>
<td>20% now</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>11B</td>
<td><em>Eucalyptus piperita</em> – <em>Angophora costata</em> Open Forest/Woodland</td>
<td>22.4</td>
<td>34.1</td>
<td>67.3</td>
<td>81.6</td>
<td>20% now</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>11C</td>
<td><em>Corymbia gummifera</em> – <em>Corymbia eximia</em> Open Forest/Woodland</td>
<td>59.2</td>
<td>71.1</td>
<td>100.0</td>
<td>100.0</td>
<td>20% now</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>Blue Mountains Shale Cap Forest</td>
<td>3.5</td>
<td>3.5</td>
<td>86.6</td>
<td>90.4</td>
<td>80% +3°C</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>2O</td>
<td>Riparian Granite Slopes Forest</td>
<td>3.0</td>
<td>6.9</td>
<td>33.9</td>
<td>81.9</td>
<td>80% +3°C</td>
<td>28 700</td>
<td></td>
</tr>
<tr>
<td>11F</td>
<td><em>Corymbia gummifera</em> – <em>Eucalyptus sparsifolia</em> Open Forest/Woodland</td>
<td>12.0</td>
<td>17.0</td>
<td>86.2</td>
<td>99.1</td>
<td>80% +3°C</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>Blue Mountains Swamps</td>
<td>0.8</td>
<td>0.8</td>
<td>1.0</td>
<td>4.8</td>
<td>None</td>
<td>20</td>
<td>Yes</td>
</tr>
<tr>
<td>1A</td>
<td><em>Ceratopetalum apetalum</em> – <em>Doryphora sassafras</em> Rainforest</td>
<td>1.2</td>
<td>2.7</td>
<td>6.0</td>
<td>18.7</td>
<td>None</td>
<td>160</td>
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</tr>
<tr>
<td>1B</td>
<td><em>Backhousia myrtifolia</em> – <em>Ceratopetalum apetalum</em> Rainforest</td>
<td>2.8</td>
<td>3.8</td>
<td>13.4</td>
<td>20.9</td>
<td>None</td>
<td>250</td>
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</tbody>
</table>
### Percentage area considered suitable lantana habitat

<table>
<thead>
<tr>
<th>Code</th>
<th>Vegetation community</th>
<th>+0°C</th>
<th>+1°C</th>
<th>+2°C</th>
<th>+3°C</th>
<th>Priority condition</th>
<th>Distance to lantana (m)</th>
<th>Threatened ecological community</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td>Moist Basalt Cap Forest</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.7</td>
<td>None</td>
<td>16 700</td>
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</tr>
<tr>
<td>2E</td>
<td><em>Eucalyptus deanei</em> – <em>E. piperita</em> Tall Open-forest</td>
<td>0.0</td>
<td>0.1</td>
<td>13.5</td>
<td>54.6</td>
<td>None</td>
<td>1 180</td>
<td></td>
</tr>
<tr>
<td>2F</td>
<td><em>Eucalyptus cypellocarpa</em> – <em>E. piperita</em> Tall Open-forest</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>10.5</td>
<td>None</td>
<td>6 240</td>
<td></td>
</tr>
<tr>
<td>2G</td>
<td><em>Eucalyptus oreades</em> Open-forest/Tall Open-forest</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>None</td>
<td>13 900</td>
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</tr>
<tr>
<td>2N</td>
<td><em>Melaleuca styphelioides</em> – <em>M. linariifolia</em> Forest</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>18.2</td>
<td>None</td>
<td>26 600</td>
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</tr>
<tr>
<td>2P</td>
<td>Megalong Footslopes Forest</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>28.7</td>
<td>None</td>
<td>23 800</td>
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</tr>
<tr>
<td>2Q</td>
<td>Megalong Granite Forest</td>
<td>13.2</td>
<td>17.3</td>
<td>38.3</td>
<td>79.7</td>
<td>None</td>
<td>27 100</td>
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<tr>
<td>4D</td>
<td>Redgum Swamp Woodland</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>91.7</td>
<td>None</td>
<td>29 400</td>
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</tr>
<tr>
<td>5A</td>
<td>Blue Mountains Heath and Scrub</td>
<td>2.2</td>
<td>3.1</td>
<td>21.8</td>
<td>29.4</td>
<td>None</td>
<td>40</td>
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</tr>
<tr>
<td>7</td>
<td>Blue Mountains Escarpment Complex</td>
<td>0.3</td>
<td>0.3</td>
<td>0.7</td>
<td>3.2</td>
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<td>620</td>
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</tr>
<tr>
<td>11D</td>
<td><em>Corymbia gummifera</em> – <em>Eucalyptus sclerophylla</em> Open Forest/Woodland</td>
<td>0.0</td>
<td>0.0</td>
<td>2.2</td>
<td>21.4</td>
<td>None</td>
<td>2 690</td>
<td></td>
</tr>
<tr>
<td>11E</td>
<td><em>Corymbia gummifera</em> – <em>Eucalyptus sieberi</em> Open Forest/Woodland</td>
<td>0.0</td>
<td>0.0</td>
<td>0.8</td>
<td>18.1</td>
<td>None</td>
<td>2 940</td>
<td></td>
</tr>
<tr>
<td>11G</td>
<td><em>Eucalyptus sclerophylla</em> Open Forest/Woodland</td>
<td>0.0</td>
<td>0.0</td>
<td>0.6</td>
<td>8.5</td>
<td>None</td>
<td>1 950</td>
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</tr>
<tr>
<td>12</td>
<td>Modified Bushland</td>
<td>15.0</td>
<td>16.2</td>
<td>29.5</td>
<td>45.9</td>
<td>None</td>
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</tr>
<tr>
<td>13</td>
<td>Introduced Communities</td>
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<td>0.0</td>
<td>0.0</td>
<td>3.2</td>
<td>None</td>
<td>8 110</td>
<td></td>
</tr>
</tbody>
</table>

Note: The table also lists the distance from each vegetation community to a lantana sighting (where a distance of 0 indicates the vegetation community contains a sighting) and whether the vegetation community contains, or is itself listed as, a threatened ecological community under the *Threatened Species Conservation Act 1995*. The table is separated into three sections, as specified in the ‘Methods’ section of this report.
## Appendix B  Threatened ecological communities and endangered species

### Table B 1  Endangered species occurring in priority threatened ecological communities

<table>
<thead>
<tr>
<th>Corresponding Department of Environment, Climate Change and Water vegetation community</th>
<th>BMSC Forest</th>
<th>SST Forest</th>
<th>SVCG Forest</th>
<th>CRO Forest</th>
<th>STI Forest</th>
<th>BGR Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Mountains City Council threatened ecological community</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BMSC Forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sydney hinterland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSF (shrubby)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SST Forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern Riverine Hinterland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WSF (grassy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SVCG Forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Hinterland</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>WSF (shrubby)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CRO Forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>STI Forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BGR Forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total communities</strong></td>
<td>21</td>
<td>6</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total unique</strong></td>
<td>13</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Total numbers of species are tabulated for each Department of Environment, Climate Change and Water vegetation community and the number of species unique to that vegetation community. BMSC = Blue Mountains Shale Cap, SST =
Shale/Sandstone Transition, SVCG = Sun Valley Cabbage Gum, CRO = *Casuarina cunninghamiana* River Oak, STI = Sydney Turpentine Ironbark, BGR = Blue Gum Riverflat, DSF = Dry Sclerophyll Forests, WSF = Wet Sclerophyll Forests.
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Integrating Adaptive Weed Management and Biodiversity Conservation in the Blue Mountains

by Alexander Gold

The Australian Government has listed lantana as one of the country's worst weeds. It is expanding its range further south and inland and it is important to understand how it might progress and further compromise Australian landscapes.

The Blue Mountains region was taken as a case study for investigating the potential spread of lantana because Blue Mountains City Council is very interested in maintaining the effectiveness of its weed control operations and better understanding the potential threats new arrivals might pose.

This research aimed to develop a habitat suitability model for lantana in a portion of the Greater Blue Mountains World Heritage Area at present and under forecast warmer climates.

This work identified temperature as the most important environmental variable currently restricting lantana's presence to the lower altitudes along the eastern reaches of the local government area. In view of the changes probably in store for the climate of the Blue Mountains, the research indicates it is imperative that management make efforts to reduce lantana's population while it still has the help of cool winters and frequent frosts.

This project was funded in Phase 1 of the National Weeds and Productivity Research Program, which was managed by the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) from 2008 to 2010. The Rural Industries Research and Development Corporation (RIRDC) is now publishing the final reports of these projects.

Phase 2 of the Program, which is funded to 30 June 2012 by the Australian Government, is being managed by RIRDC with the goal of reducing the impact of invasive weeds on farm and forestry productivity as well as on biodiversity. RIRDC is commissioning some 50 projects that both extends on the research undertaken in Phase 1 and moves into new areas. These reports will be published in the second half of 2012.

This report is an addition to RIRDC's diverse range of over 2200 research publications which can be viewed and freely downloaded from our website www.rirdc.gov.au. Information on the Weeds Program is available online at www.rirdc.gov.au/weeds

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.