# Investigating the distribution of *Acacia longifolia* ssp. *sophorae* in south-west Victoria using satellite remote sensing and GIS

**Jennifer Emeny**[A], **Gordon Duff**[B], **Dianne Simmons**[C] and **Anne Wallis**[A]
[A] School of Ecology and Environment, Deakin University, PO Box 423, Warrnambool, Victoria 3280, Australia.
[B] CRC for Tropical Savannas Management, Charles Darwin University, Darwin, Northern Territory 0909, Australia.
[C] School of Ecology and Environment, Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia.

## Summary

**Mapping and analysis of the distribution of environmental weeds is an important component of strategic weed management. Such information is particularly important in managing 'native invaders', where invasion characteristics must be clearly understood prior to any management action being taken. This paper reports on an investigation of the current distribution of the native invader *Acacia longifolia* ssp. *sophorae* (Labill.) Court (coast wattle) in south-west Victoria, using remote sensing and Geographic Information Systems (GIS). Coast wattle was successfully mapped from Landsat ETM imagery using a supervised classification procedure, with 82% of coast wattle shown on the map accurately depicting coast wattle on the ground. An estimated 11 448 ha were classified as supporting coast wattle, representing 12% of native vegetation in the study area. A more detailed GIS analysis in the Lower Glenelg National Park revealed coast wattle has invaded a limited number of vegetation types, and is more prevalent close to roads and within management zones associated with disturbance. The current regional extent of the species means widespread control is unlikely; hence the immediate focus should be on preventing further spread into areas where it is currently absent. Landsat imagery also proved to be a successful tool for mapping large scale coast wattle distribution, and could be used in long-term monitoring of the species.**

## Introduction

Over the last two decades there has been increasing recognition that some Australian plants can behave as environmental weeds beyond their original range (Carr *et al.* 1992, Rose 1997, Carr 2001, Groves 2001, Keighery 2002), and that impacts of these species can equal that of any exotic weed (Mullet and Simmons 1995, McMahon *et al.* 1996, Rose and Fairweather 1997, Costello *et al.* 2000, Mullet 2001). In Victoria, most coastal and near-coastal reserves now contain at least one Australian plant species which has become invasive beyond its traditional range (Burrell 1981, Molnar *et al.* 1989, Bennett 1994, McMahon *et al.* 1996, Parks Victoria 1998, 1999, 2001, Coutts 2001, McMahon and Brighton 2002). In most cases, the current impact, extent, spread over time, and factors promoting invasions remain largely unknown. Yet a clear understanding of invasion characteristics is required for 'native weeds', as management actions require stronger justification than for most exotic weeds (Rose 1997, Mullet 2001, Howell 2003). Accordingly, the threat of a species must be demonstrated on a case-by-case basis.

*Acacia longifolia* ssp. *sophorae* (Labill.) Court (coast wattle) is recognized as one of the more serious native invaders in Australia (Carr 2001), and is invasive both within and beyond its original biogeographical range (Groves 2001). In south-west Victoria, coast wattle has spread extensively over the past 40 years, from coastal foredune vegetation into inland vegetation types. Studies in the region (McMahon *et al.* 1996, Clay and Schneider 2000, Rees and Paull 2000, Mitchell and Wilson 2005) and elsewhere in southeastern Australia (Costello *et al.* 2000) have suggested coast wattle can have significant impacts on biodiversity and faunal habitat. McMahon *et al.* (1996) recorded an average loss in plant diversity of 60% 10 to 15 years after coast wattle invasion in coastal heathland in south-west Victoria, which is supported by recent findings by Mitchell and Wilson (2005). Similarly, Costello *et al.* (2000) recorded an average decline in plant diversity of 36% just 10 years after coast wattle invasion in coastal grasslands of New South Wales, increasing to 76% after 20 years. Further studies in coastal heathland of south-west Victoria have demonstrated negative impacts on ant diversity (Clay and Schneider 2000) and loss of suitable mammal habitat (Rees and Paull 2000, Mitchell and Wilson 2005). Yet despite the probable impacts, relatively little is known about the inland invasion of coast wattle in south-west Victoria, including the current extent of invasion and factors involved in the invasion process. It is difficult to assess the threat of the species and develop appropriate management strategies without such information. Field assessment of coast wattle in south-west Victoria has been made difficult by the extent and remoteness of vegetation in the region (Baldock *et al.* 1995 b).

There has been considerable interest in the use of geospatial technologies in environmental weed management. Of particular interest is the potential use of remote sensing for mapping weed distribution (e.g. Everitt *et al.* 1991, 1992, 1999, 2001, Pitt and Miller 1988, Ullah *et al.* 1989a,b, Everitt and Escobar 1996, Frazier 1998, Bulman 2000, Crossman and Kochergen 2002, Underwood *et al.* 2003, van Klinken 2005, Lass *et al.* 2005, Fuller 2005, Emeny *et al.* 2005), and GIS for weed distribution analysis (e.g. Lass and Callihan 1993, Kerr and Westbrooke 1996, Wilcock and Westbrook 1996, Siderov and Ainsworth 2004). Where successfully applied, remote sensing can provide a large-scale, cost-effective and repeatable alternative to traditional field-based mapping (Frazier 1998), and GIS can be used to investigate spatial relationships between weed distribution and environmental/cultural factors (Kerr and Westbrooke 1996, Wilcock and Westbrooke 1996). However, whilst mapping and analysis of weeds has been undertaken independently using these technologies, integration of the two is less common. Although weed distribution maps produced from remotely sensed data are useful in their own right, analysis of distribution patterns is limited to visual assessment. Likewise, whilst GIS is often used to analyse weed distribution data collected in the field, its application is limited by the coverage and accuracy of the data, which can be biased by site accessibility (Kerr and Westbrooke 1996). By integrating the two, the utility of remotely sensed distribution maps could be increased by quantitative analysis within a GIS, and GIS analysis could benefit from the complete coverage of a study area using remote sensing.

This paper reports on an investigation of the current distribution of coast wattle in south-west Victoria using a combination of remote sensing and GIS. The investigation had two primary objectives. The first objective was to map the current distribution of coast wattle in south-west Victoria using satellite imagery. Race and Rollings (1992) have successfully mapped coast wattle from Landsat imagery at a spatial scale of 31 $km^2$ in coastal vegetation in the region. This study aimed to determine whether Landsat imagery could be used to map coast wattle over a much larger spatial extent and range of environments. The use of Landsat imagery as a mapping and monitoring tool for coast wattle is also discussed. The second objective was to analyse the distribution of coast wattle in the Lower Glenelg National Park using GIS. The park was of particular interest due to its size (27 300 ha), conservation status, and concern about rapid proliferation of coast wattle in recent decades. Two broad vegetation types occur in the park, heathy woodland and lowland forest (Parks Victoria 2000), which are further divided into a number of Ecological Vegetation Classes (EVCs). The total area and spatial arrangement of coast wattle in the park are currently unknown. Hence four basic patterns of distribution were investigated: the total area, and the distribution according to management zones, proximity to roads, and EVC. By increasing our understanding of the current distribution of coast wattle in south-west Victoria, management of the species can be better informed and a baseline established for future monitoring.

## Methods

*Study area*

The study area for the mapping exercise was a 60 × 60 km section of south-west Victoria (Figure 1), chosen to cover the distribution of coast wattle in the region. The pre-European distribution of coast wattle in this area is unknown. However historic distributions are believed to have been restricted to the narrow foredune zone along the coast (Baldock *et al.* 1995a).

A number of parks and reserves occur within the study area. The Lower Glenelg National Park is the largest set aside primarily for conservation (Figure 1). The second component of the study focused on the Lower Glenelg National Park only, where the spatial distribution of coast wattle was analysed in greater detail.

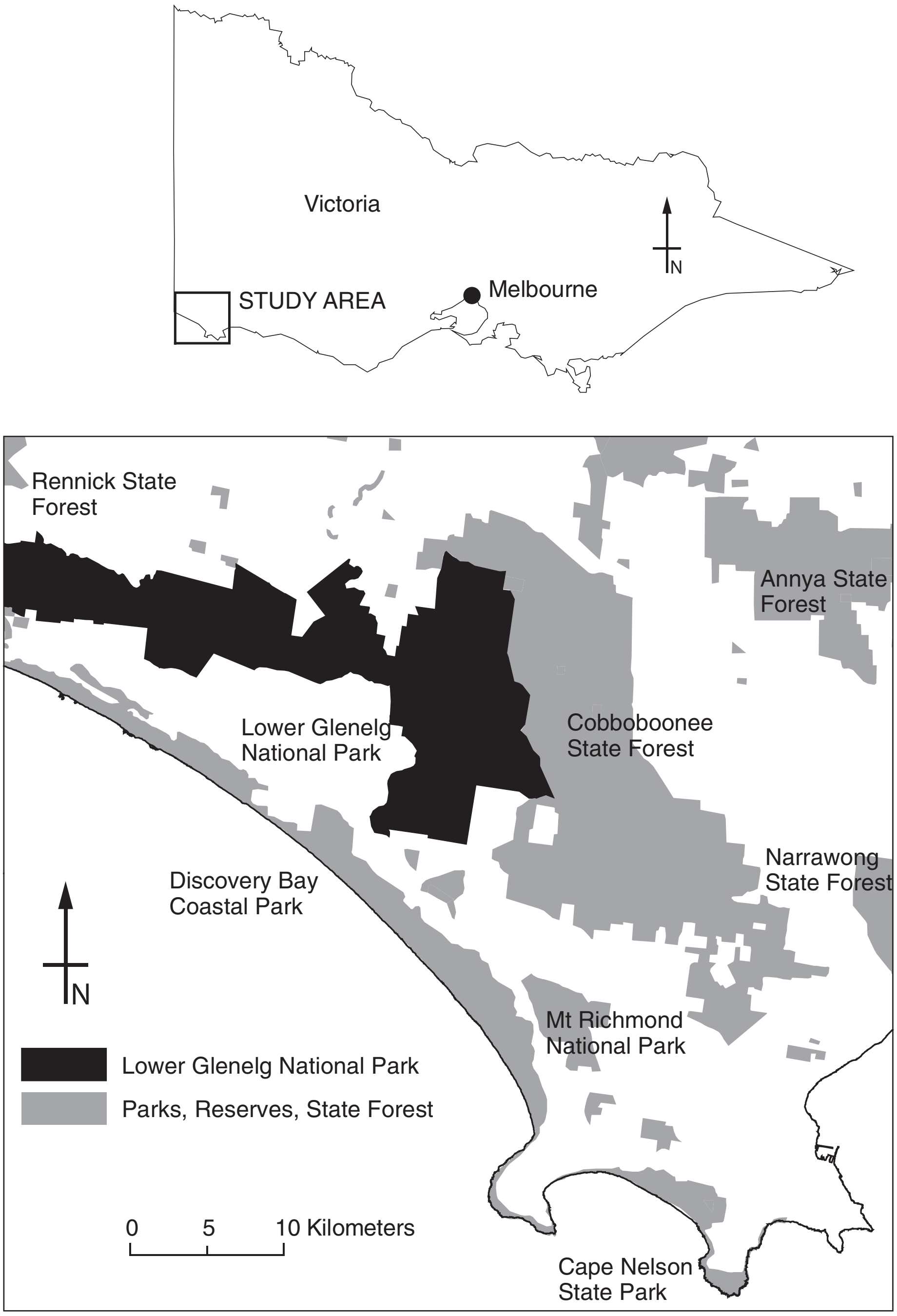


**Figure 1. Study area, showing the 60 × 60 km area used for the regional mapping exercise, and the Lower Glenelg National Park, which was the focus of further distribution analysis.**

*Mapping coast wattle distribution in south-west Victoria using satellite imagery*

The first step in the investigation was to establish the current distribution of coast wattle in south-west Victoria. Satellite imagery was chosen for the mapping exercise due to the extent of the region, which made field-based mapping or mapping from aerial photographs impractical and cost-prohibitive.

Mapping of coast wattle from satellite imagery followed standard image classification procedures, including: image selection and pre-processing; unsupervised classification to identify spectrally distinct land cover categories; supervised classification, and; a classification accuracy assessment. All image analysis was undertaken in ER Mapper 6.3 (Earth Resource Mapping Ltd 2002).

**Image selection and preparation** Landsat Enhanced Thematic Mapper 7 was chosen as the imagery source due to its availability, its cost-effectiveness for the study area size, and the previous success of coast wattle mapping by Race and Rollings (1992). Landsat 7 imagery consists of eight spectral bands, including seven thematic bands and one panchromatic band. Bands one to five and seven were used in the image analysis, spanning the visible, near infrared and middle infrared regions of the electromagnetic spectrum, with an approximate ground resolution of 30 m. The thermal band (band six) and panchromatic band (band eight) were excluded as these were of different spatial resolution.

Geometrically corrected Landsat quarter scenes were obtained on August 3rd 2001 and January 10th 2002. These corresponded with the period immediately prior to flowering of coast wattle and the post-flowering/seed production phase, respectively. Images were acquired on more than one date as several weed mapping studies have found time of year to influence weed detectability (Everitt and Escobar 1996). Cloud-free imagery was not available during the peak flowering period of late August to early September. Images from previous flowering periods were not considered appropriate due to the length of time between image acquisition and collection of ground-truth data. Prior to analysis the images were clipped to the 60 × 60 km study area, and a standard contrast stretch applied to enhance the display of the image.

**Image analysis and production of coast wattle distribution map** Supervised classification was used as the primary image analysis technique for mapping coast wattle. Supervised classification uses the spectral properties of pre-defined land-cover categories to classify each pixel in an image into one of these categories, forming a land cover map (Richards and Jia 1999).

Fifteen land cover categories were chosen for inclusion in the supervised classification, based on field observations, existing maps and the results of an unsupervised classification, which was used to identify land categories with clearly distinct spectral signatures (Emeny 2002). The land categories of primary interest in the study were those containing coast wattle (labelled 'coast wattle') and native vegetation free of coast wattle. Native vegetation free of coast wattle was divided into 'heathland', 'woodland' and 'burnt' (of any type) as these were too spectrally distinct to include as a single category. The remaining eleven land categories (e.g. water, pine plantations, urban etc.) will be grouped as 'other' from this point for brevity. The 'coast wattle' category incorporated coast wattle presence in any environment, as initial investigations indicated that separating coast wattle presence according to its environment increased mis-classification errors.

Training areas were identified on the image to develop a spectral signature for each land cover category. These areas were selected on the basis of being relatively homogenous and representative of the land cover category of interest. Coast wattle training areas were selected on the basis of having greater than or equal to 70% coast wattle cover, which was assessed visually following calibration in the field using line-intercept transects (Krebbs 1999). Training area locations were identified in the field using a Trimble Geographic Positioning System (GPS) then transferred to ER Mapper. Field identification was conducted close to the time of image acquisition to minimize errors associated with land cover change. For the inaccessible land cover types of heathland and water (incorporated in the 'other' category), aerial photographs and existing maps were used to select suitable training sites. A total of 408 training areas were used, with an average of 27 per category (due to the large study area). The training areas were distributed as evenly as possible across the study area to account for variability in land cover reflectance that can occur across geographic space.

The spectral signatures of coast wattle, heathland and woodland were compared using line graphs and scattergrams to indicate whether the classes were spectrally distinct and therefore likely to be distinguishable in the supervised classification. The supervised classification procedure was then run using the maximum likelihood classifier. Based on similarity of spectral signature, each pixel was classified into a single land cover class to form an overall land cover map. The total area of coast wattle and coast wattle-free vegetation was then calculated, and the classified image exported to ArcView 3.3 (Environmental Systems Research Institute 2002) for final map production and assessment of classification accuracy.

**Accuracy assessment of the distribution map** Map accuracy was estimated using the method described by Congalton (1991), which compares classification results with the 'true' land cover type on the ground at a number of locations (reference data). Reference data were collected primarily in the field using the GPS, located according to a stratified random sampling strategy (Congalton 1988). Aerial photos and existing maps were used to collect reference data for heathland and water categories which were inaccessible in the field. Whilst it is ideal to collect a minimum of 50 reference points per land cover category, more or less can be collected according to the relative importance and spectral variability of a class (Congalton 1991). Between 28 and 265 reference points were collected for each category (total of 1086 points), with a positive bias towards the most important categories of coast wattle, heathland and woodland. These were compared to classification results and entered into an error matrix to calculate overall accuracy, user's accuracies and producer's accuracies (Congalton 1991). The 'Kappa Coefficient' was also calculated, a standard method for estimating the degree of accuracy achieved above chance alone (Monserud and Leemans 1992).

*Analysis of coast wattle distribution in the Lower Glenelg National Park*

The second component of the investigation aimed to analyse the pattern of coast wattle distribution in the Lower Glenelg National Park. Four distribution parameters were quantified: the total area; distribution according to park management zones; distribution in relation to roads, and; distribution within different EVCs. Analyses were undertaken using ArcView 3.3.

To estimate the total area occupied by coast wattle in the park, the distribution map was converted from raster to vector format, then clipped to the extent of the park boundary. The XTools ArcView extension (Oregon Department of Forestry 2001) was used to calculate the total area of coast wattle and other land cover classes.

The proportion of coast wattle to coast wattle-free land cover was then calculated within each management zone in the park. The Lower Glenelg National Park is divided into four management zones: zone one; two; three, and; 'reference areas'. These zones represent a gradient of human disturbances ranging from minimal in the reference zones through to relatively high in zone three (Table 1).

To examine the spatial relationship between coast wattle and proximity to roads, a buffer tool was used to create 50 m buffers extending out either side of roads in the park to the maximum possible distance of 2300m. The total area of coast wattle in each buffer was calculated using XTools, and the proportion of coast wattle in each buffer plotted against distance from road. Finally, the total area of coast wattle within each EVC was calculated using the ArcView Spatial Analyst extension (Environmental Systems Research Institute, 2000).

## Results

*Mapping coast wattle distribution in south-west Victoria using satellite imagery*

Inspection of spectral signatures created from the mean reflectance values of the training areas revealed that coast wattle was spectrally distinct from all other land cover classes in the January image. Distinction between coast wattle and woodland or heathland was greatest in the near- and middle-infrared regions of the spectrum, in bands four, five and seven (Figure 2). Coast wattle was more spectrally distinct from heathland than woodland. In the August image, coast wattle was not sufficiently distinct from heathland or woodland (Figure 3). Initial attempts at undertaking a supervised classification of this image confirmed this; hence it was excluded from further analysis.

The supervised classification of the January image resulted in 11 448 ha classified as coast wattle, 67 369 ha as coast wattle-free woodland, and 8869 ha of coast wattle-free heathland. A further 9364 ha were classified as burnt vegetation, and 143 872 ha as all other land cover types. Overall, 12% of native vegetation in the study area was classified as currently supporting coast wattle.

The regional distribution map created from the classification indicated that coast wattle is present in virtually all vegetation reserves within the study area, including those as far as 15 kilometres inland. In many instances even the verges of pine plantations and cleared roadsides contain coast wattle. Both visual inspection of the

**Table 1. Description of management zones in the Lower Glenelg National Park, including conservation values and management prescriptions (adapted from Department of Conservation and Environment (1991)). There is an increase in the degree of human influence from zone 1 and the reference areas through to zone 3.**

| Feature | Zone 1/reference areas | Zone 2 | Zone 3 |
|---|---|---|---|
| Conservation values | Highly significant conservation area or reference area | Includes ecological systems and vegetation types not well represented in park and areas of landscape/ archaeological significance | Known conservation values not threatened or are adequately protected |
| Recreation/ facilities | Essentially unmodified, frequency of contact very low, facilities absent | Natural appearing settings, moderate frequency of contact on roads (low to moderate elsewhere), facilities simple and isolated | Natural appearing settings, but may have noticeable modifications, high to moderate frequency of contact, facilities may be complex and cater for large numbers |
| Fragmentation/ roads/ surrounding land use | Minimum 800 ha, width 2 km, minimum 500 m from public roads, pine plantations or private land, management tracks rare and of minimum standard | No size criteria, low use roads acceptable | No size criteria, access by public roads |
| Management actions | Primarily off-site controls | Site controls subtle | Controls obvious but in harmony with the environment |
| Prescribed burning | For vegetation or habitat management only | For protection within defined fire breaks, and for vegetation or habitat management as required | For protection within defined zones, other protection measures near visitor sites and main roads, and for vegetation or habitat management as required |

classification results and ground observations suggest that remnant vegetation with a high edge to area ratio has a greater proportion of area occupied by coast wattle than larger reserves and, around the boundary of the Lower Glenelg National Park, edges adjacent to pine plantations are invaded more often than those adjacent to other native vegetation or agricultural land.

According to the accuracy assessment, an overall classification accuracy of 81% was achieved for the January image. The Kappa Coefficient was 0.78, indicating that the classification was 78% better than could be achieved by chance alone. An error matrix including only coast wattle and coast wattle-free vegetation types is shown in Table 2. The user's accuracy for coast wattle, which is a measure of the percentage of coast wattle shown on the image that is actually coast wattle on the ground, was calculated at 82%. The producer's accuracy, a measure of the percentage of coast wattle on the ground actually shown as coast wattle in the image, was 71%. These accuracies are comparable to the results of other Australian weed mapping studies using remote sensing (e.g. Frazier 1998, Abbott *et al.* 1999, Crossman and Kochergen 2002) and were considered acceptable for continuation to the next stage of analysis using GIS.

*Analysis of coast wattle distribution in the Lower Glenelg National Park*

**Overall extent of coast wattle in the park** Coast wattle distribution within the Lower Glenelg National Park is shown in Figure 4. The current distribution of the species appears to be confined largely to the central and southern sections of the park, predominantly close to boundary edges. The far western and eastern sections of the park are relatively free of coast wattle.

Table 3 shows the relative proportions of coast wattle and other cover classes within the Lower Glenelg National Park. Despite appearing to cover a large area, coast wattle-invaded vegetation was found to make up only 7% (1963 ha) of the park. In comparison, heathland and woodland free from coast wattle made up 64% and 19% respectively.

**Distribution of coast wattle according to management zones** The proportion of coast wattle to coast wattle-free vegetation was found to vary considerably between management zones in the park. The proportion of coast wattle-invaded vegetation in each of the zone was: Reference Areas (<1%); Zone 1 (4%); Zone 2 (10%), and; Zone 3 (28%). An increase in the proportion of coast wattle per zone was found to coincide with the increase in the intensity of human disturbances used to define these zones (as outlined in Table 1).

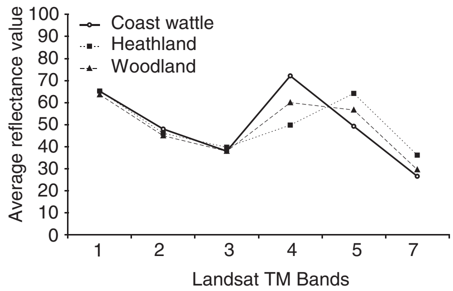


**Figure 2. Spectral signatures of coast wattle, woodland and heathland in the January 2002 Landsat image. Coast wattle is spectrally distinct from both heathland and woodland.**

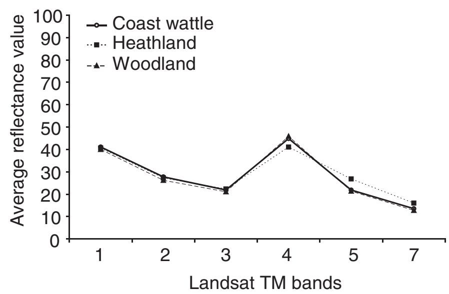


**Figure 3. Spectral signatures of coast wattle, woodland and heathland in the August 2001 Landsat image. Coast wattle is not spectrally distinct from heathland or woodland.**

**Table 2. Error matrix for the classification of the January 2002 Landsat image, showing only coast wattle and coast wattle-free heathland and woodland. 'Other' refers to all other categories in the classification. Diagonal values shown in bold represent correctly classified data.**

| | | Reference data | | | | |
|---|---|---|---|---|---|---|
| | | Coast wattle | Heathland | Woodland | Other | Total |
| Classification data | Coast wattle | **188** | 1 | 28 | 11 | 228 |
| | Heathland | 0 | **43** | 0 | 5 | 48 |
| | Woodland | 36 | 6 | **148** | 10 | 200 |
| | Other | 41 | 1 | 3 | | |
| | Total | 265 | 51 | 179 | | |
| | *Producer's Accuracy* | *71%* | *84%* | *83%* | | |
| | *User's Accuracy* | *82%* | *90%* | *74%* | | |

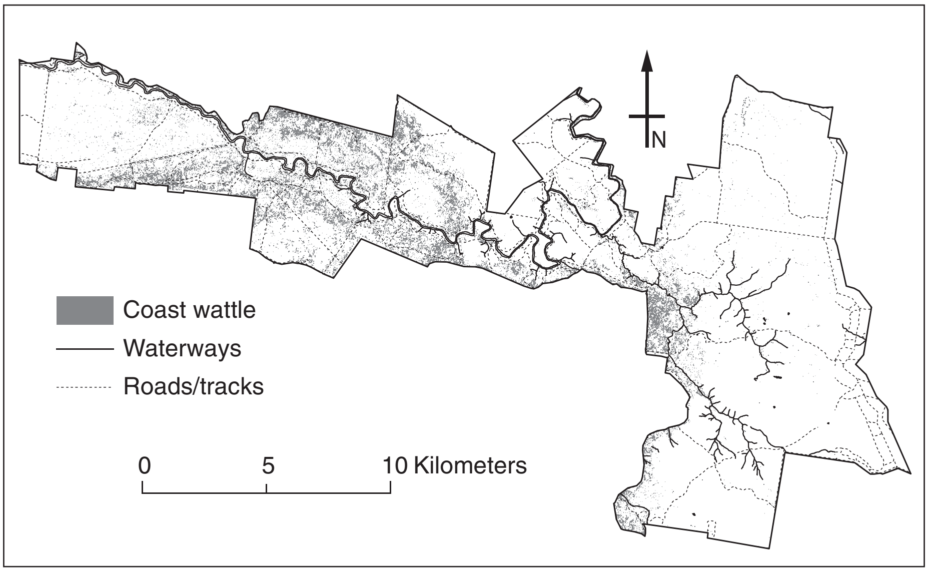


**Figure 4. Coast wattle distribution in the Lower Glenelg National Park according to the supervised classification of the January 2002 image.**

**Table 3. Proportions of different land cover classes in the Lower Glenelg National Park according to the supervised classification of the January 2002 Landsat image.**

| Land cover class | Area classified as land cover class (ha) | Proportion of total park area (%) |
|---|---|---|
| Woodland | 16 685 | 64 |
| Heathland | 4 943 | 19 |
| Coast wattle | 1 963 | 7 |
| Burnt vegetation | 1 366 | 5 |
| Other | 1 287 | 5 |
| Total | 26 244 | |

**Distribution of coast wattle in relation to roads** Coast wattle presence was found to decrease significantly with increasing distance from roads in the park (Figure 5). Of the total area classified as coast wattle in the park, 86% occurred within 500 m of roads. Beyond 1000 m from roads, coast wattle presence was negligible (Figure 5). The results also indicated however that occasionally coast wattle can occur at some distance from roads.

**Distribution of coast wattle within Ecological Vegetation Classes** GIS calculations highlighted that some Ecological Vegetation Classes are more vulnerable to invasion by coast wattle than others. As can be seen in Table 4, 48% of the area classified as coast wattle in the Lower Glenelg National Park occurred in a single Ecological Vegetation Class (EVC), damp sands herb-rich woodland (EVC 3). Approximately 85% occurred in just four EVCs: damp sands herb-rich woodland (EVC 3), herb-rich heathy woodland (EVC 179), and two mosaic EVCs which included damp sands herb-rich woodland (EVCs 881 and 740) (Table 4). In addition to having the highest total area of coast wattle invasion, these EVCs also tended to have the highest proportion of their area invaded when taking into consideration the area occupied by different EVCs (Table 4).

EVCs with a relatively low proportion and total area of coast wattle invasion included forest EVCs (EVC numbers 16 and 23), heathland EVCs (6 and 8), heathy woodland EVCs (48, 737 and 793), shrubland EVCs (675 and 133), and freshwater marshes (200 and 681).

## Discussion

The results of this investigation confirm the anecdotal estimate reported by McMahon *et al.* (1996) that coast wattle now occurs across more than 10 000 ha of native vegetation in south-west Victoria. It appears that coast wattle is now a significant component of native vegetation in the region, and has spread considerably in recent decades. This is particularly evident in the Lower Glenelg National Park. It is believed that as an early dune colonizer, the species did not originally occur in the park. Even prior to the 1970s coast wattle was sparse in what is now the National Park, occurring over no more than a few hundred hectares (Baldock *et al.* 1995b). This study estimates that almost 2000 ha of the park are now occupied by coast wattle, representing a significant expansion in the species' range.

Examination of distribution patterns in the Lower Glenelg National Park indicates that coast wattle invasion has not been uniform, tending to be concentrated in particular areas. This patchiness may reflect the particular environmental or disturbance factors required to create a suitable environment for invasion (provided a ready supply of propagules). The present study quantified some basic distribution patterns according to units relevant to management, and suggests hypotheses for further testing.

It appears that coast wattle is not invading all vegetation types in the Lower Glenelg National Park, but is concentrated mainly in the herb-rich woodlands. Damp-sands herb-rich woodland has a particularly high degree of invasion (25%

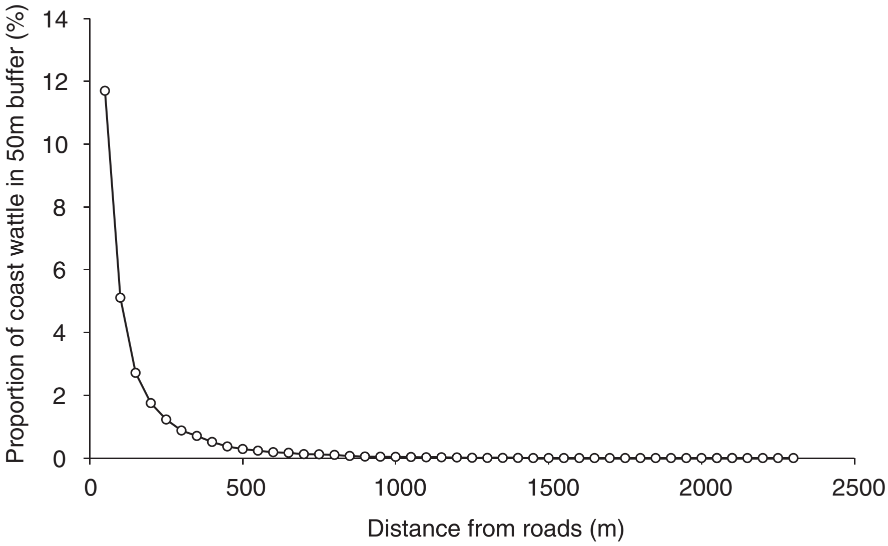


**Figure 5. Relationship between proximity to roads and coast wattle occurrence in the Lower Glenelg National Park. Coast wattle is shown as a proportion of 50 m buffers extending out from roads.**

of the total EVC, and 48% of total coast wattle distribution in the park), and is the second most extensive vegetation type in the park. Conversely, there is relatively little coast wattle in forest and heathland areas, which also cover a considerable proportion of the park. These results are consistent with roadside observations by Baldock *et al.* (1995b). Previous observations have found coast wattle to be more prolific in high light environments (Baldock *et al.* 1995a), and on sandy soils, and rarely on dark clay, peat or waterlogged soils (Stevens 1983, Tame 1992, Costermans 2000). The herb-rich woodlands in which coast wattle is most prevalent tend to be fairly open, with relatively sparse canopy cover, low to moderate shrub cover, and occur on either sandy or loamy soils. Those EVCs where coast wattle invasion has been low generally have higher tree or shrub cover than the herb-rich woodlands, and many occur on heavy or waterlogged soils (e.g.

**Table 4. Area of coast wattle according to Ecological Vegetation Class in the Lower Glenelg National Park, including the proportion of EVC invaded, total area of coast wattle, and proportion of coast wattle in the park.**

| EVC No. | EVC Description | Proportion of EVC invaded by coast wattle (%) | Total area of EVC in park (ha) | Total area of coast wattle in EVC (ha) | Proportion of total coast wattle in park (%) |
|---|---|---|---|---|---|
| 3 | Damp sands herb-rich woodland[AB] | 25 | 3535 | 914 | 48 |
| 179 | Herb-rich heathy woodland | 15 | 859 | 128 | 7 |
| 740 | Damp sands herb-rich woodland/ heathy woodland/ sand heathland | 13 | 974 | 126 | 7 |
| 881 | Damp sands herb-rich woodland/ heathy woodland | 12 | 3490 | 428 | 23 |
| 669 | Escarpment shrubland/ damp sands herb-rich woodland/ riparian woodland | 9 | 272 | 24 | 1 |
| 725 | Damp sands herb-rich woodland/ riparian woodland/ swamp scrub | 8 | 389 | 31 | 2 |
| 23 | Herb-rich foothill forest[AB] | 6 | 232 | 14 | 1 |
| 191 | Riparian scrub | 5 | 323 | 15 | 1 |
| 645 | Wet heathland/ heathy woodland | 4 | 2821 | 101 | 5 |
| 675 | Escarpment shrubland/ damp sands herb-rich woodland/ swamp scrub | 4 | 46 | 2 | <1 |
| 737 | Heathy woodland/ limestone woodland | 2 | 1953 | 48 | 3 |
| 16 | Lowland forest | <1 | 3712 | 34 | 2 |
| 8 | Wet heathland | <1 | 3454 | 10 | 1 |
| 48 | Heathy woodland | <1 | 2499 | 9 | <1 |
| 200 | Shallow freshwater marsh[AB] | <1 | 29 | <1 | <1 |
| 681 | Deep freshwater marsh[B] | 0 | 5 | 0 | 0 |
| 6 | Sand heathland | 0 | 39 | 0 | 0 |
| 133 | Limestone pomaderris shrubland | 0 | 60 | 0 | 0 |
| 793 | Damp heathy woodland[A] | 0 | 340 | 0 | 0 |

[A] Threatened in Glenelg Plains Bioregion (encompassing the western section of the Lower Glenelg National Park)
[B] Threatened in Victorian Volcanic Plains Bioregion (encompassing the eastern section of the Lower Glenelg National Park)

wet heathlands and damp heathy woodland).

Coast wattle is not typically a component of these inland woodland vegetation types, and has only invaded in recent decades. Parendes and Jones (2000) suggest that invasion of a species into a new environment occurs when a previous barrier to invasion is removed. The initial and ongoing causes for the invasion of coast wattle into the Lower Glenelg National Park and surrounding region are poorly understood. However, they are often attributed to anthropogenic disturbances or a change to pre-European disturbance regimes, particularly fire and grazing (McMahon *et al.* 1996, Baldock *et al.* 1995b, Costello *et al.* 2000). GIS analysis in this study revealed an increase in coast wattle prevalence in areas with higher levels of human influence, such as vegetation close to roads and management zones with higher levels of human access and management control. The increase in coast wattle with proximity to roads in the Lower Glenelg National Park supports similar observations by Baldock *et al.* (1995b). The increased light, space and soil disturbance typical of roadsides is likely to allow establishment by coast wattle, which is an early-dune colonizer. This effect may be amplified when a road is adjacent to a land use in which regular disturbance occurs. Although not quantified, visual inspection of classification results of coast wattle distribution at the boundary of the Lower Glenelg National Park indicated that sections adjacent to pine plantations (which have regular disturbance during establishment, harvest and road maintenance) were more likely to be invaded than those adjacent to grazing land or other native vegetation.

The increase in coast wattle with a general increase in disturbance in management zones may reflect the influence of a complex range of factors associated with disturbance. When considering the distribution of coast wattle within management zones, it is apparent that a gradient from low occurrence to relatively high occurrence occurs from the Reference Areas and Zone 1 through to Zone 3. The human disturbance factors used to determine management zones vary along a similar gradient. For example, the level of fragmentation, proximity to roads, recreational use and level of management control all increase from the Reference Areas and Zone 1 to Zone 3 (see Table 1). It is also likely that prior disturbances such as logging and grazing would have increased in intensity according to a similar trend, as a function of proximity to roads. Further analysis is required to determine the relative importance of various environmental and disturbance factors in explaining the current distribution of coast wattle, including the role of changes to fire and grazing regimes as suggested by McMahon *et al.* (1996) and Costello *et al.* (2000). The variation in coast wattle distribution according to vegetation type suggests that environmental factors in part determine susceptibility to invasion by coast wattle. It appears that a combination of disturbance and environmental factors may determine its inland distribution.

The invasion of EVCs typically open in structure with relatively low shrub cover suggests that significant structural and compositional change may be taking place. Damp-sands herb-rich woodland is currently classified as 'vulnerable' (i.e. 10 to 30% pre-European extent remains) in the regions in which the Lower Glenelg National Park falls (Glenelg Hopkins Catchment Management Authority 2000). The degree of coast wattle invasion in this EVC should therefore be of considerable concern, and be prioritized in any management programs.

### *The effectiveness of Landsat imagery for mapping and monitoring coast wattle*

Landsat imagery proved to be a successful means of mapping coast wattle at the regional scale in south-west Victoria, comparing well to the accuracy of other weed mapping attempts (e.g. Frazier 1998, Crossman and Kochergen 2002, Underwood *et al*. 2003). As with a number of other studies where a single species is mapped from remotely sensed imagery (Everitt and Deloach 1990, Everitt *et al.* 1991, Everitt *et al.* 1992), successful mapping of coast wattle was found to depend on time of year and corresponding phenological stage. In this case, coast wattle was successfully mapped during the post-flowering, seed production phase of mid-January, but not during the pre-flowering phase of early August. The successful mapping of coast wattle by Race and Rollings (1992) was also during the post-flowering phase (February). Although coast wattle detection was not assessed during peak flowering, it is unlikely that more accurate result would be achieved using a single image due to the extended period over which individual coast wattle plants come in and out of flower (July to November) and as such, it is doubtful that all coast wattle infestations would be detectable in one image. However, further investigation during the flowering period, possibly using multiple images, would be worthwhile.

An important outcome of this study is that it confirms the repeatability of Landsat imagery as a tool for mapping coast wattle, with the success of this and the previous study in the same region by Race and Rollings (1992). There have been relatively few Australian examples where environmental weeds have been mapped using satellite remote sensing (Crossman and Kochergen 2002), and even fewer examples of successful repeat mapping (Bulman 2000). To be useful in practice, mapping techniques need to be robust and repeatable, preferably across sites of varying scales and environmental conditions. This is essential if the technique is to be useful in ongoing monitoring, which is often stated as a primary objective in weed mapping trials (Emeny *et al*. 2005).

The overall mapping accuracy and accuracy of mapping coast wattle in this study was slightly lower than that reported by Race and Rollings (1992). This is probably due to the much larger study area and range of environments in the present study, which tends to increase spectral variability within individual land classes. Mapping accuracy at the regional scale might be improved by mapping coast wattle separately within different vegetation types or smaller geographical units, to decrease the effect of spatial variability. However, for the purpose of this study, which was to provide a relatively rapid assessment of coast wattle distribution across a large area, the accuracy was considered adequate.

The distribution map produced in this study provides a baseline for future monitoring of coast wattle spread in south-west Victoria. Landsat imagery has proven to be a repeatable and relatively robust means for mapping coast wattle, and is currently the only feasible means for mapping the species at the regional scale. By undertaking an accuracy assessment, an estimate of the reliability of distribution maps can also be gauged. The relative coarseness of Landsat imagery limits detection of coast wattle to mature plants and larger stands of the species. It is recommended that regional-scale mapping from satellite imagery be considered as a component of long-term coast wattle monitoring, alongside ground observations used to assess densities and detect recent invasions into new areas.

## Conclusion

By integrating satellite remote sensing and GIS technologies, the current distribution of coast wattle in south-west Victoria has been established, and some basic distribution patterns identified in the Lower Glenelg National Park. When compared to pre-1960 anecdotal estimates, the present extent of the species suggests a rapid expansion of range inland. Analysis of coast wattle patterns in the Lower Glenelg National Park indicates this invasion has not been uniform, and is at this stage restricted to a limited number of vegetation types. There is also some evidence that coast wattle invasion may be associated with anthropogenic disturbances; however, GIS analysis in the study considered only a small number of factors potentially associated with coast wattle distribution. The senior author of this paper is continuing this study by further investigating the relative importance of various factors in explaining current distribution, and whether factors such as vegetation type and disturbance history interact to increase likelihood of invasion.

The current extent of coast wattle in the region means widespread control is not feasible in the short term. Management should focus on prevention of further coast wattle spread into environmentally significant areas from which it is currently absent, and close monitoring of further spread. Of particular concern should be prevention of further spread within damp-sands herb-rich woodland, which is regionally vulnerable and already significantly invaded by coast wattle. The regional distribution map created in this investigation provides both a baseline for monitoring future spread of the species, and a data source for investigating factors associated with the current distribution of the species. Whilst it does not eliminate the need for ground monitoring and observations, Landsat imagery has also proven to be a relatively robust means for mapping coast wattle at large scales, and could play an important role in long-term monitoring of the species.

## Acknowledgements

The authors wish to acknowledge funding provided by the Australian Research Council and Parks Victoria for this project, which was carried out as part of an Honours Degree at Deakin University by the first author. Thanks also to Parks Victoria staff for their advice, particularly David Ryan and Cathy Allan, and to John Adams and Paul Emeny for assistance in the field. Thank you to Daniel Ierodiaconou for assistance with the spatial analysis during this project.

## References


Abbott, B., Grice, A.C. and Bastin, G.N. (1999). Low-level aerial photography can detect infestations of the invasive woody vine *Cryptostegia grandiflora* in northern Australia. Proceedings of the 6th International Rangelands Congress, pp. 602-3.

Baldock, R., Martin, D., Gibbs, J. and Gill, F. (1995a). Ecology and control of coast wattle in native forest areas. Introduction: Literature survey. (University of South Australia, Adelaide).

Baldock, R., Martin, D., Gibbs, J. and Milne, S. (1995b). Ecology and control of coast wattle in native forest areas. Distribution and abundance. (University of South Australia, Adelaide).

Bennett, L.T. (1994). The Expansion of *Leptospermum laevigatum* on the Yanakie Isthmus, Wilson's Promontory, under changes in the burning and grazing regimes. *Australian Journal of Botany* 42, 555-64.

Bulman, D. (2000). Is the application of remote sensing to weed mapping just 'S-pie in the Sky'? *Plant Protection Quarterly* 15, 127-32.

Burrell, J.P. (1981). Invasion of coastal heaths of Victoria by *Leptospermum laevigatum* (J.Gaertn.) F.Muell. *Australian Journal of Botany* 29, 747-64.

Carr, G.W. (2001). Australian plants as weeds in Victoria. *Plant Protection Quarterly* 16, 124-5.

Carr, G.W., Yugovic, J.V. and Robinson, K.E. (1992). 'Environmental weed invasions in Victoria: conservation and management implications', p. 5. (Department of Conservation and Environment and Ecological Horticulture Pty. Ltd., Melbourne)

Clay, R.E. and Schneider, K.E. (2000). The ant (Hymenoptera: Formicidae) fauna of coastal heath in south-west Victoria: effects of dominance by *Acacia sophorae* and management actions to control it. *Pacific Conservation Biology* 6, 144-51.

Coutts, S. (2001). Native plants as environmental weeds on the Mornington Peninsula. *Plant Protection Quarterly* 16, 127-8.

Congalton, R. (1988). A comparison of sampling schemes used in generating error matrices for assessing the accuracy of maps generated from remotely sensed data. *Photogrammetric Engineering and Remote Sensing* 54, 593-600.

Congalton, R. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37, 35-46.

Costello, D.A., Lunt, I.D. and Williams, J.E. (2000). Effects of invasion by the indigenous shrub *Acacia sophorae* on plant composition of coastal grasslands in south-eastern Australia. *Biological Conservation* 96, 113-21.

Costermans, L.F. (2000). 'Native trees and shrubs of south-eastern Australia', p. 304. (Reed New Holland, Sydney).

Crossman, N.D. and Kochergen, J. (2002). Mapping environmental weeds in the Mount Lofty Ranges, South Australia, using high resolution infrared aerial photography. Proceedings of the 13th Australian Weeds Conference, eds H. Spafford Jacob, J. Dodd and J.H. Moore, pp. 579-82 (Plant Protection Society of Western Australia, Perth).

Department of Conservation and Environment (1991). Lower Glenelg National Park Management Plan, p. 26. (Department of Conservation and Environment, Melbourne).

Earth Resource Mapping Ltd. (2002). ER Mapper Version 6.3.

Emeny, J. (2002). Integrating remote sensing and GIS for strategic weed management: mapping and analysing the distribution of *Acacia sophorae* in the Lower Glenelg National Park and surrounding region, south-west Victoria', B.Sc. Honours Thesis, Department of Science and Technology, Deakin University.

Emeny, J., Simmons, D. and Wallis, A. (2005). Using geospatial technologies to map and monitor environmental weeds. Proceedings of the Second Victorian Weed Conference, pp. 56-62 (Weed Society of Victoria, Frankston).

Environmental Systems Research Institute (2000). Spatial Analyst for Arcview. Environmental Systems Research Institute, Redlands, California.

Environmental Systems Research Institute (2002). ArcView 3.3. Environmental Systems Research Institute, Redlands, California.

Everitt, J.H., Alaniz, M.A., Escobar, D.E. and Davis, M.R. (1992). Using remote sensing to distinguish common (*Isocoma coronopifolia*) and Drummond goldenweed (*Isocoma drummondii*). *Weed Science* 40, 621-8.

Everitt, J.H. and Deloach, C.J. (1990). Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. *Weed Science* 38, 273-8.

Everitt, J.H. and Escobar, D.E. (1996). Use of spatial information technologies for noxious plant detection and distribution on rangelands. *Geocarto International* 11, 63-80.

Everitt, J.H., Escobar, D.E., Alaniz, M.A. and Davis, M.R. (1991). Light reflectance characteristics and video remote sensing of pricklypear. *Journal of Range Management* 44, 587-92.

Everitt, J.H., Yang, C., Escobar, D.E., Webster, C.F., Lonard, R.I. and Davis, M.R. (1999). Using remote sensing and spatial information technologies to detect and map two aquatic macrophytes. *Journal of Aquatic Plant Management* 37, 71-80.

Everitt, J.H., Yang, C., Racher, B.J., Britton, C.M. and Davis, M.R. (2001). Remote sensing of redberry juniper in the Texas rolling plains. *Journal of Range Management* 54, 254-9.

Frazier, P. (1998). Mapping blackberry thickets in the Kosciusko National Park using airborne video data. *Plant Protection Quarterly* 13, 145-148.

Fuller, D.O. (2005). Remote detection of invasive Melaleuca trees (*Melaleuca quinquenervia*) in South Florida with multispectral IKONOS imagery. *International Journal of Remote Sensing* 26, 1057-63.

Glenelg Hopkins Catchment Management Authority (2000). Draft Glenelg Hopkins Native Vegetation Plan, pp. 76-9. (Department of Natural Resources and Environment, Hamilton).

Groves, R.H. (2001). Can Australian native plants be weeds? *Plant Protection Quarterly* 16, 114-17.

Howell, J. (2003). *Pittosporum undulatum* as a case study for native species that change range – how to avoid inappropriate responses? *Cunninghamia* 8, 153-5.

Keighery, G. (2002). The enemy within: native environmental weeds of Western Australia. Proceedings of the 13th Australian Weeds Conference, eds H. Spafford Jacob, J. Dodd and J.H. Moore, pp. 93-5 (Plant Protection Society of Western Australia, Perth).

Kerr, M.K.C. and Westbrooke, M.E. (1996). The application of GIS to weed survey. Proceedings of the 11th Australian Weeds Conference, ed. R.C.H. Shepherd, pp. 485-8 (Weed Science Society of Victoria, Frankston).

Krebbs, C.J. (1999). 'Ecological Methodology, 2nd Edition', p. 139. (Benjamin/Cummings, California).

Lass, L.W. and Callihan, R.H. (1993). GPS and GIS for weed surveys and management. *Weed Technology* 7, 249-54.

Lass, L.W., Prather, T.S., Glenn, N.F., Weber, K.T., Mundt, J.T. and Pettingill, J. (2005). A review of remote sensing of invasive weeds and example of the early detection of spotted knapweed (*Centaurea maculosa*) and babysbreath (*Gypsophila paniculata*) with a hyperspectral sensor. *Weed Science* 53, 242-51.

McMahon, K. and Brighton, M. (2002). Anglesea Heath Management Plan, p. 55. (Parks Victoria and Alcoa World Alumina Australia, Melbourne).

McMahon, A.R.G., Carr, G.W., Bedggood, S.E., Hill, R.J. and Pritchard, A.M. (1996). Prescribed fire and control of coast wattle (*Acacia sophorae* (Labill.) R.Br.) invasion in coastal heath south-west Victoria. *In* Fire and biodiversity: biodiversity series Paper No. 8 (Biodiversity Unit, Department of the Environment, Sport and Territories, Canberra).

Mitchell, E. and Wilson, B.A. (2005). The response of small mammals to the invasion of coast wattle (*Acacia sophorae*) in a fragmented heathland, southwest Victoria. Fifty first Australian Mammal Society Conference, Albany, Western Australia.

Molnar, C.D., Fletcher, D. and Parsons, R.F. (1989). Relationships between heath and *Leptospermum laevigatum* scrub at Sandringham, Victoria. *Proceedings of the Royal Society of Victoria* 101, 77-87.

Monserud, R.A. and Leemans, R. (1992). The comparison of global vegetation maps. *Ecological Modelling* 62, 275-93.

Mullet, T.L. (2001). Effects of the native environmental weed *Pittosporum undulatum* Vent. (sweet pittosporum) on plant biodiversity. *Plant Protection Quarterly* 16, 117-21.

Mullet, T.L. and Simmons, D. (1995). Ecological impacts of the environmental weed sweet pittosporum (*Pittosporum undulatum* Vent.) in dry sclerophyll forest communities, Victoria. *Plant Protection Quarterly* 10, 131-8.

Oregon Department of Forestry (2001). XTools Extension for ArcView.

Parendes, L.A. and Jones, J.A. (2000). Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. *Conservation Biology* 14, 64-75.

Parks Victoria (1998). Port Campbell National Park and Bay of Islands Coastal Park Management Plan, pp. 80-3. (Parks Victoria, Melbourne).

Parks Victoria (1999). Angahook-Lorne State Park Management Plan, p. 20. (Parks Victoria, Melbourne).

Parks Victoria (2000). State of the Parks 2000, Volume 2, Edition 1, p. 145. (Parks Victoria, Melbourne).

Parks Victoria (2001). Langwarrin Flora and Fauna Reserve Management Plan, p. 31. (Parks Victoria, Melbourne).

Pitt, J.L. and Miller, I.L. (1988). A review of survey techniques for the detection of weeds with particular reference to *Mimosa pigra* L. in Australia and Thailand. *Plant Protection Quarterly* 3, 149-55.

Race, G.J. and Rollings, N. (1992). Mapping *Acacia sophorae* using remotely sensed data – an integrated land management approach. Proceedings of the 6th Australasian Remote Sensing Conference', pp. 2.2-2.8. (Committee of the 6th Australasian Remote Sensing Conference, Wellington New Zealand).

Rees, M. and Paull, D.J. (2000). Distribution and status of the southern brown bandicoot *Isoodon obesulus* in the Portland region of southwestern Victoria. *Wildlife Research* 27, 539-45.

Richards, J.A. and Jia, X. (1999). 'Remote sensing digital image analysis, 3rd edition' (Springer-Verlag, Berlin).

Rose, S. (1997). Integrating management of *Pittosporum undulatum* with other environmental weeds in Sydney's urban bushland. *Pacific Conservation Biology* 3, 350-65.

Rose, S. and Fairweather, P.G. (1997). Changes in floristic composition of urban bushland invaded by *Pittosporum undulatum* in Northern Sydney, Australia. *Australian Journal of Botany* 45, 123-49.

Siderov, K. and Ainsworth, N. (2004). Invasion of bridal creeper (*Asparagus asparagoides*) in a remnant vegetation patch: methodology and initial results. Proceedings of the 14th Australian Weeds Conference, eds B.M. Sindel and S.B. Johnson, pp. 115-18 (Weed Society of New South Wales, Sydney).

Stevens, R.M. (1983). 'Coast wattle on roadsides in south east of South Australia.' (Roadside Vegetation Committee, Adelaide).

Tame, T. (1992). 'Acacias of south eastern Australia', (Kangaroo Press, Kenthurst, Australia).

Ullah, E., Field, R.P., McLaren, D.A. and Peterson, J.A. (1989a). Use of airborne thematic mapper (ATM) to map the distribution of blackberry (*Rubus fruticosus* agg.) (Rosaceae) in the Strzelecki Ranges, south Gippsland, Victoria. *Plant Protection Quarterly* 4, 149-54.

Ullah, E., Shepherd, R.C.H., Baxter, J.T. and Peterson, J.A. (1989b). Mapping flowering Paterson's Curse (*Echium plantagineum*) around Lake Hume, north eastern Victoria, using Landsat TM data. *Plant Protection Quarterly* 4, 155-7.

Wilcock, P.J. and Westbrooke, M.E. (1996). Factors influencing woody weed distribution in the proposed Creswick Regional Park, Victoria. Proceedings of the 11th Australian Weeds Conference, ed. R.C.H. Shepherd, pp. 451-3 (Weed Science Society of Victoria, Frankston).

Underwood, E., Ustin, S.L. and DiPietro, D. (2003). Mapping non-native plants using hyperspectral imagery. *Remote Sensing of Environment* 86, 150-61.

van Klinken, R., Kolomeitz, S., Robinson, T., Metternicht, G., Pullar, D. and Sheperd, D. (2005). Spatial sciences and the management of rangeland weeds in Northern Australia. North Australian Remote Sensing and GIS Forum, Darwin, Australia.

Wilcock, P.J. and Westbrooke, M.E. (1996). Factors influencing woody weed distribution in the proposed Creswick Regional Park, Victoria. Proceedings of the 11th Australian Weeds Conference, ed. R.C.H. Shepherd, pp. 451-3. (Weed Science Society of Victoria, Frankston).