NSW Native Vegetation Management Benefits Analyses

Technical report

Acknowledgements:
OEH acknowledges the assistance provided by Professor Brendan Mackey, Fenner School of Environment and Society, Australian National University, and Associate Professor Nick Reid, School of Environment and Rural Sciences, University of New England, both of whom were contracted to undertake a critical review of the analysis approach used in this report.

Main cover photo: D Finnegan, OEH

Suggested citation:
Drielsma, MJ, Howling, G and Love, J 2012, *NSW Native Vegetation Management Benefits Analyses: Technical report*, NSW Office of Environment and Heritage, Sydney.

Published by:
Office of Environment and Heritage
59–61 Goulburn Street, Sydney
PO Box A290
Sydney South NSW 1232

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@environment.nsw.gov.au
See also www.environment.nsw.gov.au/pollution

Ph: (02) 9995 5000 (switchboard)
Ph: 131 555 (information & publications requests)
Ph: 1300 361 967 (national parks, climate change and energy efficiency information and publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

ISBN 978 1 74293 916 2
OEH 2012/0905
January 2013

Contents

List of figures

List of tables

Executive summary

This technical report provides an explanation of spatial analyses undertaken to provide a state-scale context for investment in native vegetation management in New South Wales. An earlier version of the analyses was undertaken for the Draft NSW Biodiversity Strategy (draft Strategy) (DECCW 2010b). These analyses, termed native vegetation management (NVM) benefits analyses, enhance the scope and application of the original analyses in response to comments on the draft Strategy.

NVM benefits analyses predict where native vegetation management will contribute highest benefit to terrestrial biodiversity at a state scale. The analyses focus on improving the condition, extent and connectivity of vegetation formations.

The NVM benefits analyses recognise that the type of management that returns greatest benefit for biodiversity varies across the state. They were designed to inform investment across a range of activities, and as such consider four types of benefit:

- ‘Manage’ benefits are areas of existing native vegetation in good condition and where emphasis on management would be on maintaining this high condition.
- ‘Improve’ benefits also relate to areas of existing native vegetation, and while they are generally better examples of more heavily altered vegetation types, they nonetheless require some form of active management to improve their condition.
- ‘Revegetate’ benefits are cleared areas where replanting or natural regeneration of species that previously occurred at the site would return the highest benefit.
- ‘Consolidate’ benefits highlight areas where emphasis on linking, or retaining the current connectivity values of core remnants, would provide greatest benefit.

The modelling techniques described in this report use data and methodologies that were available and practical at the time of the analyses. They represent a significant evolution in techniques previously applied to state-scale biodiversity benefits modelling. The techniques used also reflect the analytical problems in accommodating varied issues and management needs in different landscape contexts across NSW.

Two approaches were used:

1. ‘Manage’, ‘improve’ and ‘revegetate’ benefits

These benefits were developed through application of the Biodiversity Forecasting Tool (BFT). The BFT adopts a ‘general approach to modelling the persistence of biodiversity’, using vegetation communities (or ecosystems) as surrogates for overall biodiversity, with the biodiversity of a region represented by the remaining extent, condition and spatial configuration of the original (pre-clearing) vegetation of the region. Individual benefits layers were derived based on four criteria:

i) vegetation communities that have been ‘highly cleared’, ‘degraded’ and/or ‘fragmented’

ii) vegetation communities that are floristically distinct

iii) vegetation condition of sites

iv) neighbourhood connectivity of sites.

The overall conservation status of vegetation communities is assessed based on floristic distinctiveness and levels of clearing. This information is then relayed to a regional analysis where local vegetation condition and neighbourhood connectivity are included in determining benefits for each location. The approach assumes that higher benefit from management will accrue where the analysis identifies sites that would respond well to the relevant management applied (manage, improve or revegetate).

2. 'Consolidate' benefits

Consolidate benefits were developed using Landscape Value analysis techniques. The Landscape Value of a site or location refers to:

i) how well that location is connected to habitat, and

ii) how well it contributes, by virtue of its landscape position, to habitat connectivity of other locations.

Landscape Value analysis was undertaken for a study region that includes the Eastern and Central Divisions of NSW. The Western Division was excluded from the Landscape Value mapping process as it is not fragmented in the same sense as the eastern parts of the state.

Three broad vegetation structural classes (VSC) were modelled across the study area: closed forest, open forest and woodland. VSC surfaces were initially derived through applying transformation functions to raw foliage projected cover values derived from existing literature. Each of the VSC layers was then modified by a 'condition' layer with values hierarchically assigned to a combination of land tenure, land-use and land cover classes.

Two modelling techniques were applied to each of the three VSCs, corresponding to two aspects of connectivity:

i) Habitat Links Analysis was used to identify habitat linkages between and through patches of habitat.

ii) Neighbourhood Habitat Area analysis was used to assess the level of connected habitat of each site.

The NVM benefits map outputs are designed to inform investment across a range of users, including:

- CMAs, to inform the upgrade of their catchment action plans
- other public land management agencies, including local government, to target investment in native vegetation management
- non-government organisations and landholders, to apply for funding or target investment.

The outputs are intended as a guide only, as their accuracy is limited by the scale of data used. The spatial outputs from this project are based on 6.25 ha (250 m by 250 m) gridcells and can be reliably mapped to a cartographic scale of 1:100,000. NSW Government agencies, catchment management authorities and others may hold additional data and mapping, in many cases developed with or by OEH, which is more spatially precise. Having a broader, big-picture perspective, the state-scale NVM benefits complement this more localised and detailed data. Where state-scale NVM benefits and catchment-scale priorities overlap, users are encouraged to adopt these areas as their highest priority for investment. The more precise data may also be used to better match management actions to locations, while maintaining a focus on the big picture.

The NVM benefits analyses are static and should be reviewed at a future date. As investment translates into improvements on the ground, the benefits areas will change. Future improvements in vegetation type and condition mapping will also provide an opportunity to enhance the analyses. In addition, the adoption of this model will provide lessons in how better to approach integration of state, regional and local-scale assessments in the future.

1 Scope and purpose

This technical report provides an explanation of spatial analyses undertaken to provide a state-scale context for investment in native vegetation in New South Wales. The analyses were undertaken to assist NSW catchment management authorities (CMAs) and others to consider state-scale benefits to terrestrial biodiversity through development of catchment action plan (CAP) upgrades in 2012 and 2013.

The report addresses five aspects of the spatial analytical process:

1. the purpose and intent of the analysis of state-scale native vegetation management benefits (Section 2)
2. methods used to derive four state-scale native vegetation management benefits layers:
    - ‘manage’, ‘improve’ and ‘revegetate’ benefits, developed through the application of the terrestrial Biodiversity Forecasting Tool (Section 3)
    - ‘consolidate’ benefits, developed through the application of Landscape Value analysis techniques (Section 4)
3. steps taken to apply areas with highest state-scale native vegetation management benefits to NSW ecosystems to inform investment in native vegetation management (Section 5)
4. methods used to model vegetation classes and vegetation condition, which were used to evaluate the relative state-scale benefit for biodiversity expected from native vegetation management (Appendices 2–3)
5. additional steps taken to support the analyses (Appendices 4–6).

A brief discussion on the usefulness of the techniques, their use in informing regional investment and the need for continued refinement of approaches is included in a brief discussion section (Section 6).

The layers derived from the analyses described here are intended to inform development of investment priorities for native vegetation management. The NVM benefits map described in this report is based on these layers, and should not be considered separately from the individual layers. Maps of the four state-scale native vegetation management benefits layers are provided in Appendix 7.

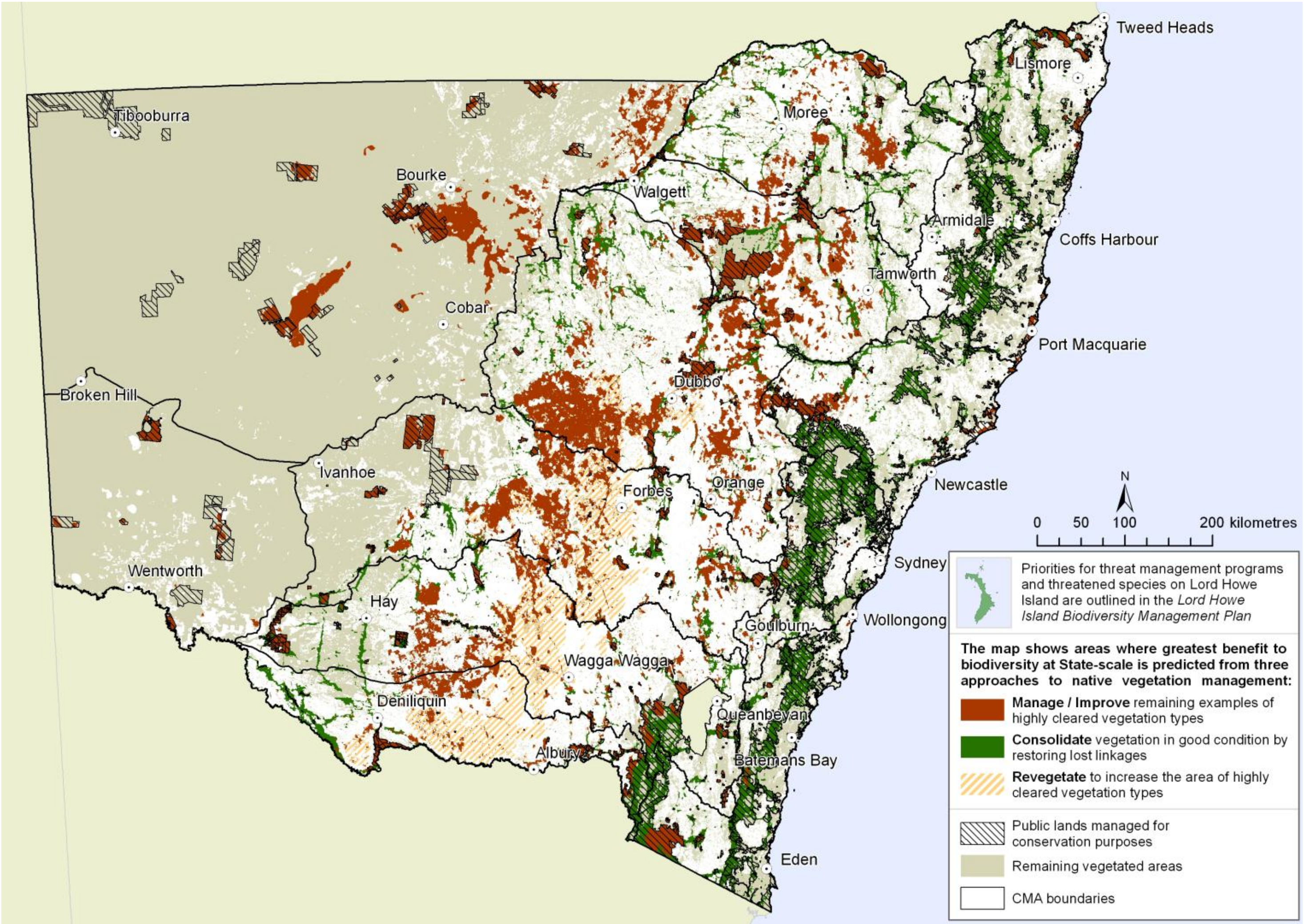


Figure 1: The NVM benefits map

The map shows areas where native vegetation management will contribute highest benefit to terrestrial biodiversity through improvement in the condition, extent and connectivity of native vegetation formations at the state scale.

2 State-scale native vegetation management benefits

2.1 Native vegetation management benefits and the NVM benefits map

Where investment is directed toward improving native vegetation condition, the NSW Office of Environment and Heritage (OEH) recommends that investment be directed to where it will contribute highest benefit to terrestrial biodiversity by improving the condition, extent and connectivity of vegetation formations at the state scale. Native vegetation management (NVM) benefits analyses predict where native vegetation management will contribute highest benefit to terrestrial biodiversity through improvement in the condition, extent and connectivity of native vegetation at the state scale.

2.2 Intent and purpose in considering NVM benefits

The map in Figure 1 shows areas where, all considerations being equal, the greatest benefit to biodiversity at the state scale is predicted to be achieved from management of native vegetation (including revegetation of previously cleared areas). The map and analyses used to develop it recognise that no single type of management will necessarily have the same level of importance in all parts of the state. The map was therefore designed to inform investment across a range of activities, including: protecting and improving the condition of the most important areas of depleted vegetation classes, revegetating cleared areas (particularly where this will increase the area of the most depleted types), and linking efforts to create networks of 'green corridors'. The analyses consider four types of benefit:

- 'Manage' benefits relate to areas of existing native vegetation which are generally in good condition and where the emphasis of management would be on maintaining this high condition. A number of highest 'manage' benefit areas occur in protected areas, reflecting the importance of their continued management where pressures are exerted by adjacent land uses.
- 'Improve' benefits also relate to areas of existing native vegetation, and while generally the best examples of more heavily altered vegetation types, they nonetheless require some form of active management to improve their condition.
- 'Revegetate' benefits are cleared areas where re-establishment of species that previously occurred at the site (through replanting or natural regeneration) would contribute to improving the condition of terrestrial biodiversity at the state scale. The analysis highlights the most extensively cleared vegetation types, notably in the sheep–wheat belt.
- 'Consolidate' benefits were derived through a different form of analysis to the other three benefit layers, and provide a state-scale cross-regional connectivity analysis. The layer highlights where emphasis on linking, or retaining the current connectivity values of core remnants, would provide greatest benefit. This includes a combination of (a) monitoring and targeted removal of threats (weeds, inappropriate fire regimes, etc.), notably in large protected areas; and (b) revegetation to buffer and/or link native vegetation where this will maintain the internal viability of otherwise isolated vegetation remnants.

Individual maps depicting each of these four layers are included in Appendix 7.

Box 1: Overview of how to interpret areas mapped as comprising high NVM benefit

	Manage / Improve	Consolidate	Revegetate*
Colour on map	Brown	Green	Hatched orange
What the mapping depicts	Areas where management to maintain or improve condition within existing vegetation would contribute most benefit to biodiversity at the state scale	Areas that are well connected to existing vegetation or are part of an important habitat link or corridor	Cleared areas where revegetation would contribute most benefit to biodiversity at state scale
Outcome	Maintain or improve condition within the best remaining examples of heavily cleared vegetation classes	Maintain vegetation in good condition and improve its connectivity across a larger area	Increase the area of vegetation types which have been most heavily cleared
Approach	Protect and manage existing native vegetation	Monitor, control threats and enhance connectivity within and between areas in good condition	High quality mixed species plantings (using locally-appropriate provenance) or natural regeneration on cleared areas

* The intention of the mapping is to depict where revegetation, if undertaken, would provide greatest benefit to terrestrial biodiversity at the state scale. It is acknowledged that a large proportion of these mapped areas are productive agricultural lands. As such, it is likely that only a small proportion of these areas will be revegetated, notably where this contributes to ecosystem services that support farm productivity.

2.3 Features of the NVM benefits map

The broad management interventions depicted by the NVM benefits map are not mutually exclusive. Native vegetation involves a combination of activities including active removal of pressures (e.g. grazing), encouraging natural regeneration, targeted replanting, and monitoring to trigger management of emergent threats in high condition areas. The map is intended to convey a simple message about the differences in the relative emphasis on types of management across the state. It is intended to complement the individual benefits layers.

Of the four management benefits layers, greatest overlap occurs between the ‘manage’ and ‘improve’ layers. Both were derived from the same type of spatial analysis technique, and relate to existing native vegetation. They have been combined in Figure 1 to reduce the complexity of the map.

The map was developed by combining the top five per cent of benefits that would be achieved from each of the ‘revegetate’ and ‘manage/improve’ areas. The top 10 per cent of benefits from the ‘consolidate’ areas layer was used in a basic attempt to have a similar area of native NVM benefit depicted from the analyses based on the Biodiversity Forecasting Tool (‘revegetate’ and ‘manage/improve’) and Landscape Value analysis (‘consolidate’).

While the NVM benefits map depicts areas where highest benefit is predicted to accrue from investment, OEH does acknowledge that significant benefit would nonetheless accrue from investing in areas outside the highest benefit bracket depicted in Figure 1.

The management benefits layers and NVM benefits map are not intended to be interpreted as maps of 'high conservation value' native vegetation. Instead, they show the relative benefits expected from investment in one area relative to others, and are intended to be used in addition to information on national, regional and state-scale priorities for investment in threatened species recovery, threat abatement, and maintenance of ecosystem services such as water quality and carbon sequestration. CMAs and other investors are encouraged to consider each of the management benefits layers in Appendix 7 when developing investment priorities, and seek to maximise the state-scale benefit to biodiversity that can be achieved from native vegetation management in conjunction with other practical considerations (investor preferences, delivery capacity, community support, etc.).

The scale at which the NVM benefits have been presented precludes their direct use in assessing applications to clear native vegetation under the *Native Vegetation Act 2003*, or evaluate proposals for funding to support native vegetation rehabilitation. They should be considered indicative, and should be validated by field assessment.

2.4 Two approaches to predicting NVM benefits

The analysis techniques used reflect the analytical problems posed by needing to accommodate varied issues and management needs in different landscape contexts across NSW. Two approaches were used to predict biodiversity benefits as part of the process shown in Figure 2:

- 'Manage', 'improve' and 'revegetate' benefits were developed through application of the Biodiversity Forecasting Tool (see Section 3).
- 'Consolidate' benefits where developed using Landscape Value analysis techniques (see Section 4).

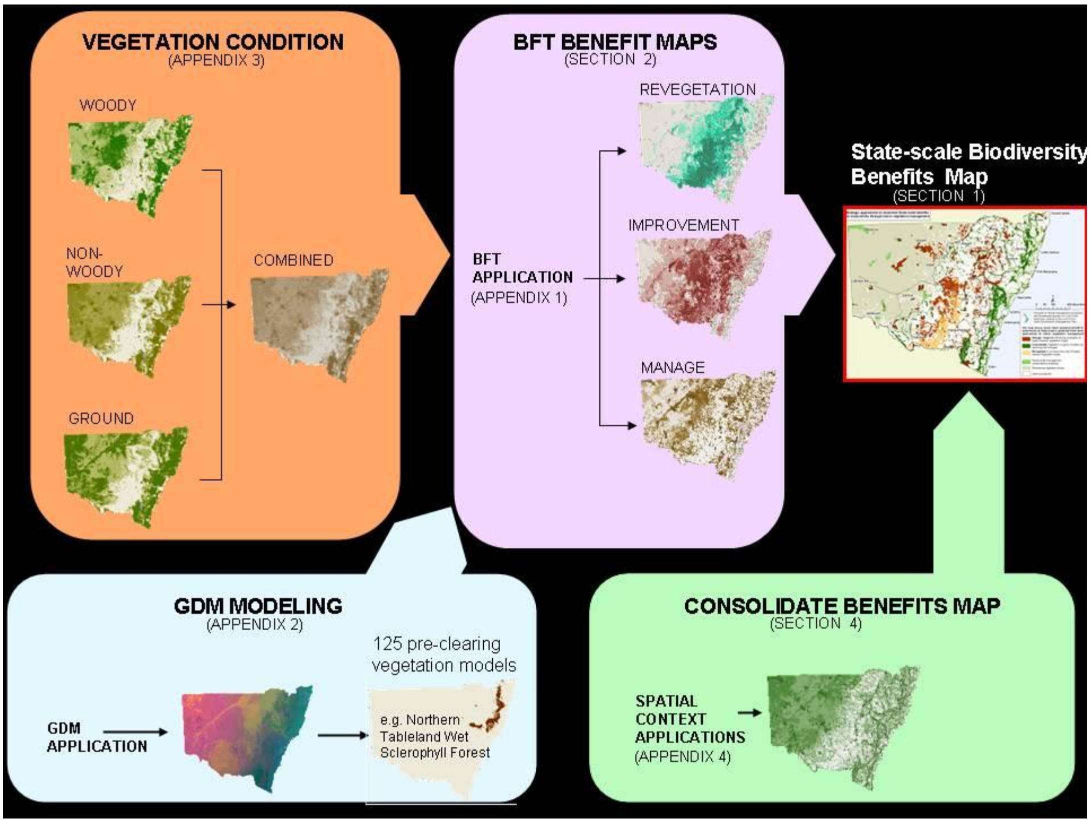


Figure 2: Overall approach to deriving native vegetation management benefits layers and the NVM benefits map

2.5 Ecosystems not fully addressed in the analysis of NVM benefits

2.5.1 Aquatic ecosystems

Aquatic ecosystems other than forested wetlands were not expressly considered in the biodiversity benefits analyses. At the time the analysis was undertaken, OEH intended that priorities for aquatic ecosystems would be determined in consultation with other NSW Government agencies.

2.5.2 Arid shrubland ecosystems

Previous attempts to model state-scale 'priority areas' for native vegetation management (e.g. DECCW 2010a, 2010b) were not able to reliably model differences in predicted condition of arid shrubland ecosystems. This was largely the result of limitations caused by the coarse scale of vegetation condition mapping and a paucity of spatial data for total grazing pressure. Improvements in the use of modelled vegetation classes and use of an improved state-scale vegetation condition model have enabled predicted differences in the relative benefits from improved management of arid shrubland ecosystems to be modelled in eastern parts of their distribution.

However, the lack of data on total grazing pressure, combined with the analytical techniques currently available, still limited the predictive capacity of the analyses, such that only about 40,000 ha of the total 8.8 million hectares of arid acacia shrublands, and 317,000 ha of the total 6.9 million hectares of arid chenopod shrublands were predicted to have very high NVM benefit. CMAs are encouraged to consider the likely benefits of investment in the mapped areas with highest state-scale NVM benefit when undertaking assessments to guide investment across their wider extent.

2.6 Modifications to the NVM benefits map in Growth Centres

The metropolitan and regional strategies developed by the NSW Department of Planning have identified areas known as 'Growth Centres', where new development will be focused, to meet the needs of expanding populations. A small proportion of high priority cells occur in these Growth Centres. As these lands will be developed it is not appropriate to consider them as areas likely to be managed to contribute higher benefit to biodiversity, and cells comprising high NVM benefit were removed. Exceptions were made for parts of the North West and South West Growth Centres in Western Sydney where native vegetation is expected to be retained and restored.

3 Predicting biodiversity benefits – ‘manage’, ‘improve’ and ‘revegetate’

3.1 Criteria for predicting biodiversity benefit

The ‘manage’, ‘improve’ and ‘revegetate’ benefit layers were derived using a form of the Biodiversity Forecasting Tool (BFT), a general overview of which is presented in Appendix 5. The BFT adopts a general approach to modelling the persistence of biodiversity, using vegetation communities (or ecosystems) as surrogates for overall biodiversity (Figure 3); that is, the biodiversity of a region is represented by the remaining extent, condition and spatial configuration of the original (pre-clearing) vegetation of the region (Ferrier & Drielsma 2010). This approach is appropriate as a broad-brush assessment which is often supplemented at the regional scale with species- or assemblage-level analysis.

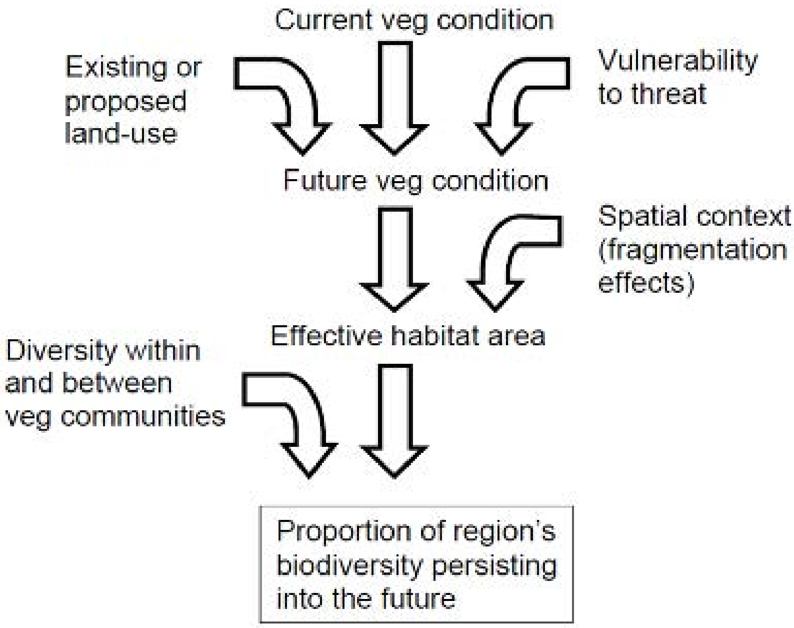


Figure 3: Illustration of the general framework for modelling biodiversity persistence

A process modelling approach is used that integrates condition, spatial context and vegetation community representation into a measure of biodiversity persistence. In the case of the native vegetation management benefits, the community types were mapped as a ‘probability stack’ of 125 classes (Resource & Conservation Assessment Council 2004)

For the purposes of developing the NVM benefits map, the individual benefits layers were derived based on the following four criteria.

Criterion A – vegetation communities that have been highly cleared, degraded and/or fragmented

Some types of vegetation have experienced higher rates of clearing, degradation and fragmentation in the past than others. Criterion A seeks to invest in these types of vegetation because:

1. further pressure would lead to disproportionately high rates of biodiversity loss
2. investment in management would lead to greater improvements in biodiversity retention, and
3. they are generally located in landscapes also facing greater future pressures.

In some cases areas are identified as having high native vegetation management benefit not because of the type of vegetation at the site itself, but because of its proximity to vegetation with a high benefit. In such cases investment in these areas for their buffering, infilling and linkage values would be expected to yield higher benefits than investing in the neighbouring priority sites alone.

Criterion B – vegetation communities that are floristically distinct

Vegetation communities that are particularly distinctive in terms of their species composition but are not well conserved are an obvious priority for maximising biodiversity outcomes. This is particularly important for communities that are highly cleared and which comprise species that are not well conserved in other vegetation communities.

Criterion C – vegetation condition of sites

The benefits of investing in native vegetation of moderate to very good condition are likely to be high, relative to other areas. This is largely because vegetation in moderate to very good condition already has important biodiversity values that can be maintained or enhanced for a modest investment, and management actions to address threats are likely to be more successful than management of areas in low condition. Some degraded areas may be identified as having high ‘manage’ benefits (as well as higher ‘improve’ benefits) if they contain vegetation that scores highly across the other criteria (A, B and D).

Areas with high ‘manage’ benefit are intended to highlight the best remaining examples of vegetation communities that address the other three criteria. The analysis assigns a higher benefit to sites that are in better condition. However, once other attributes are taken into account in the analysis, high manage benefit areas can range in condition from moderate to very good.

The areas identified as having high ‘improve’ benefit are typically areas with vegetation that is in moderate condition and scores highly across the other criteria. With appropriate management, areas such as these can provide improved biodiversity outcomes within a relatively short timeframe and with a modest level of effort.

Areas with high ‘revegetate’ benefit are predominantly cleared or highly degraded examples (i.e. in very low condition) of either existing or original vegetation types that score highly across the other criteria.

Criterion D – neighbourhood connectivity of sites

It is widely understood that native vegetation which is well connected to other native vegetation tends to retain more biodiversity over time and appears more resilient to pressures such as weed invasion than areas of vegetation that are more fragmented (Merriam 1984, Hanski 1999, Soule et al. 2004, Nicholson et al. 2006, Doerr et al. 2010, Mackey et al. 2010). Areas of native vegetation which are better connected internally and with adjacent areas are also considered to be more likely to adapt and persist under predicted climate change scenarios (Heller & Zavaleta 2009). The analysis described in this report therefore assumes the principle that maintaining and increasing internal patch connectivity leads to biodiversity benefits across NSW, particularly where it relates to vegetation that scores highly for the other three criteria.

3.2 Applying the criteria

The BFT applied the above criteria at two levels: (1) vegetation community level, and (2) landscape level. In the first instance, the overall conservation status of vegetation communities is assessed based on Criteria A–D (Section 3.1). This information is then relayed to a landscape-level analysis where local vegetation condition and neighbourhood connectivity (Criteria C and D, Section 3.1) are included in determining benefits individually for each location.

The methodology assumes that higher benefit from management will accrue where the analysis identifies sites that would respond well to the relevant management (manage, improve or revegetate), are relatively well-connected and floristically distinctive, and belong to a vegetation community that has been highly cleared, degraded and/or fragmented. There is considerable flexibility in how the BFT is applied. In each application of the BFT to a particular project, the most suitable data inputs available are identified in consultation with relevant experts.

The spatial configuration component of the BFT requires the selection of mobility parameters (denoted as 1/α – a distance, in metres, see Technical Note 1) (Hanski 1999) corresponding to each possible vegetation condition value. These parameters describe the relative connectivity between habitat provided by a range of conditions, from cleared to pristine.

When biodiversity is considered in total, as with the analyses described here, a single set of generic mobility parameters are assigned to reflect the average movement abilities of vertebrates and mobile invertebrates. The variables chosen for the analyses to derive for the NVM benefits map are summarised in Table 6, in appendix 5.

The BFT comprises three steps, to: (a) calculate effective habitat area of vegetation classes, (b) derive a measure of regional biodiversity, and (c) map biodiversity benefits.

Technical Note 1: BFT connectivity measure (Criterion D) and colonisation potential

Colonisation potential (Hanski 1999), is calculated as:

$$C_i = \left(\sum_j H_i H_j e^{-\alpha d_{ij}} \right)^{1/y}$$

where:

H_i is the vegetation condition of the focal cell

H_j is the vegetation condition of a neighbourhood location j

d_{ij} is the effective distance from the focal cell i to j

1/α is the movement parameter

y sets the relative influence of spatial context and site attributes

e is Euler's constant

Mobility parameters range from 1/α = 2000 m for cleared cells to 1/α = 5000 m for high condition cells (see Table 6). This range translates to permeability values of between 0.88 and 0.95 for each cell. (Permeability values are multiplied along least cost paths to calculate the effective distance between cells; see Drielsma et al. 2007a for description of the method).

Intermediate condition cells were scaled between these values. The y parameter acts to balance the influence of fragmentation and condition within the BFT. In this analysis y = 4. This meant that locations supporting over-cleared vegetation were not as 'penalised' (i.e. given lower priority) for being part of small, isolated or fragmented patches, as would otherwise be the case if y were a lower value.

Step A: Calculate effective habitat area of vegetation classes

The effective habitat area (EHA) is calculated as the proportion of remaining colonisation potential (Hanski 1999, Drielsma et al. 2007a; see Technical Note 1), summed across the region. Compared to vegetation extent alone, EHA was considered a truer representation of the proportion of the original biodiversity that can potentially be supported (by a location or vegetation class) as it accounts for the extent remaining (Criterion A), its condition (Criterion B;) (Oliver & Parkes 2003, Thackway & Lesslie 2005) and its fragmentation (Criterion D; Andrén 1994, Sisk et al. 2000, Fahrig 2002).

Step B: Derive a measure of regional biodiversity

For this project this measure does not explicitly consider climate change or uncertain risks to biodiversity such as possible new mining projects. This measure is termed the regional biodiversity index (or 'BDI_R').

Compositional overlap (Faith & Walker 1996) is an important consideration in this step as it allows for the distinctiveness of communities to be factored into the calculations of conservation benefits. By including this consideration, species that occur across a range of communities are assumed to be buffered from losses associated with one of those communities; species associated with only one or a very few communities are considered more vulnerable. Technical Note 2 describes a refined approach developed in collaboration with CSIRO to calculate the state's biodiversity index through consideration of overlap of communities (S Ferrier pers. comm. 2011).

Step C: Map biodiversity benefits

To keep these calculations tractable, estimated changes to BDI_R are calculated at the 'landscape' scale within 'neighbourhood windows' (see Technical Notes 3 and 4). The change to the BDI_R in each case is incremented to the corresponding cells in an output 'benefit' grid.

'Manage' and 'improve' benefits

'Manage' benefits apply to extant native vegetation and are derived by systematically switching the condition of (petal) locations to simulate clearing of native vegetation (see Technical Note 3). At each step the altered petal's habitat and permeability are set to the minimum values ($H = 0$; $1/\alpha = 2000$ m) and the change to BDI_R is re-calculated. The switching process has the effect of reducing the BDI_R through direct loss of habitat at the focal cell when it is altered in the moving window analysis, and by reducing the habitat of neighbourhood sites, when they are part of an altered petal.

The magnitude of the loss in regional BDI_R caused by clearing equates to the relative benefit of preventing that loss. Clearing an area that reduces connectivity and condition of a poorly protected vegetation community will result in a relatively large decrease in regional BDI_R (although the absolute value will be very low), and therefore translate to a high benefit for management of that location.

'Improve' benefits apply mostly to partly degraded extant native vegetation, where the alternative land use involves allowing the current vegetation condition to improve passively by removing the pressures, such as grazing, that otherwise prevent such improvement in the long term. Twenty years was selected as an arbitrary, but still prolonged, timeframe for improvement.

'Revegetate' benefits

'Revegetate' benefits apply to degraded extant and cleared native vegetation and are derived by systematically changing the condition of each location to simulate it being returned to its pre-cleared state ($H = 1000$; $1/\alpha = 5000$ m). The increase in BDI_R caused by revegetating the gridcell or petal becomes the relative benefit for revegetation.

Revegetating an area that improves connectivity and improves condition of a poorly protected vegetation community will result in a relatively large increase in regional BDI_R and translate into a high priority for revegetation.

A schematic overview of the overall process for deriving native vegetation management benefits as described above is illustrated in Figure 4. Configuring the technique involved sourcing and deriving best available data and choosing parameters and options that suited the purpose and spatial scale of the analyses. The major choices for the configuration of the BFT and data inputs are provided in Tables 6 and 7 of Appendix 5.

Technical Note 2: Calculating the state's biodiversity index considering compositional overlap of communities

The regional biodiversity index for the region (BDI_R) classified into *n* communities is calculated using the following formula:

$$BDI_R = \frac{\sum_{i=1}^{n} \sum_{k=0.1}^{0\rightarrow 1.0} \frac{o_i \left(\sum e_j \big/ \sum o_j \right)^z}{\sum o_j}}{\sum_{i=1}^{n} \sum_{k=0.1}^{0\rightarrow 1.0} \left(\frac{o_i}{\sum o_j} \right)} \qquad s_{ij} \geq k \,,$$

where the original EHA of community *j* was o_j; and the current EHA is e_j. A value of z = 0.25 was applied (z defines the species–area relationship; see Table 7 in Appendix 5). The compositional similarity between communities *i* and *j* is s_{ij}. For each community *i*, 11 iterations are calculated within the numerator and denominator (k = 0, 0.1,..,1.0).

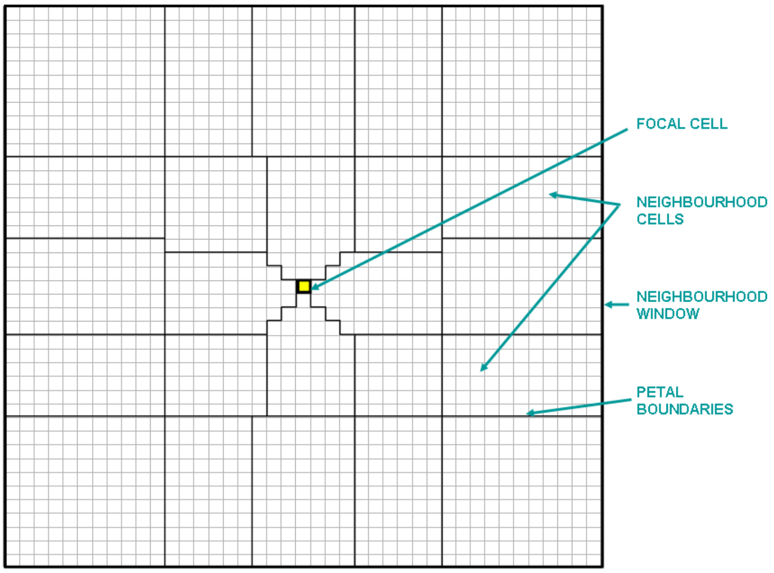
At each step only the communities *j* with similarity to community *i* greater than or equal to k are included in the calculations, i.e. when k = 0, all communities are included; when k = 1, only community *i* itself is included.

This technique was tested and validated within the project and found to provide a greatly improved balance between the concerns of representing biodiversity at both the community and species levels. However to further ensure that the importance of communities as entities in their own right is not overshadowed by concerns for individual species, a balance was effectively achieved by scaling the compositional similarity values involving different communities ($i \neq j$) between 0 and 0.5.

The method is used to calculate values of marginal biodiversity benefit (M_i) for each community *i*, in order to relay community-level context into neighbourhood calculations (see Technical Note 4). M_i is calculated by finding the increase in BDI_R from the current level when e_i is replaced with o_i.

Technical Note 3: Using the neighbourhood window

The 'neighbourhood' around each cell was defined by a 41 x 41 cell window (10.25 km x 10.25 km) (see below).



Within each neighbourhood window, the focal cell is surrounded by other gridcells that are arranged into 'petals' (groups of other gridcells) which become the analysis units for the switching process, making the analysis computationally efficient. For the native vegetation benefits analyses each 41 x 41 window was reduced to a 5 x 5 set of petals, where the focal cell is also treated as a petal. Petals become larger, the further they are from the focal cell. This reflects the lower influence that each individual cell has on the biodiversity status of the focal gridcell, with increasing distance.

Technical Note 4: Calculating benefits for each neighbourhood window

For each window, the BFT initially calculates BDI_R for the current state, based on current land use and management and on the extent and condition of vegetation communities (see Figure 3); then estimated changes to BDI_R arising from localised management changes are systematically recalculated.

1. The current benefit score of a focal cell (denoted f) is calculated as $B_f = M_i \times C_f$.
2. Each set of cells (petals, see Technical Note 3) surrounding the focal gridcell is switched, in turn, to alternative values reflecting changed management corresponding to the three benefit types.
3. Following each switch, the change in benefit is calculated for the window. That value is divided equally among all the cells making up the altered petal and the apportioned values are incremented to the same corresponding cells in the output grid.
4. This process is repeated for all 'petals' within a neighbourhood window.
5. Steps 1–4 are repeated for every gridcell in NSW.

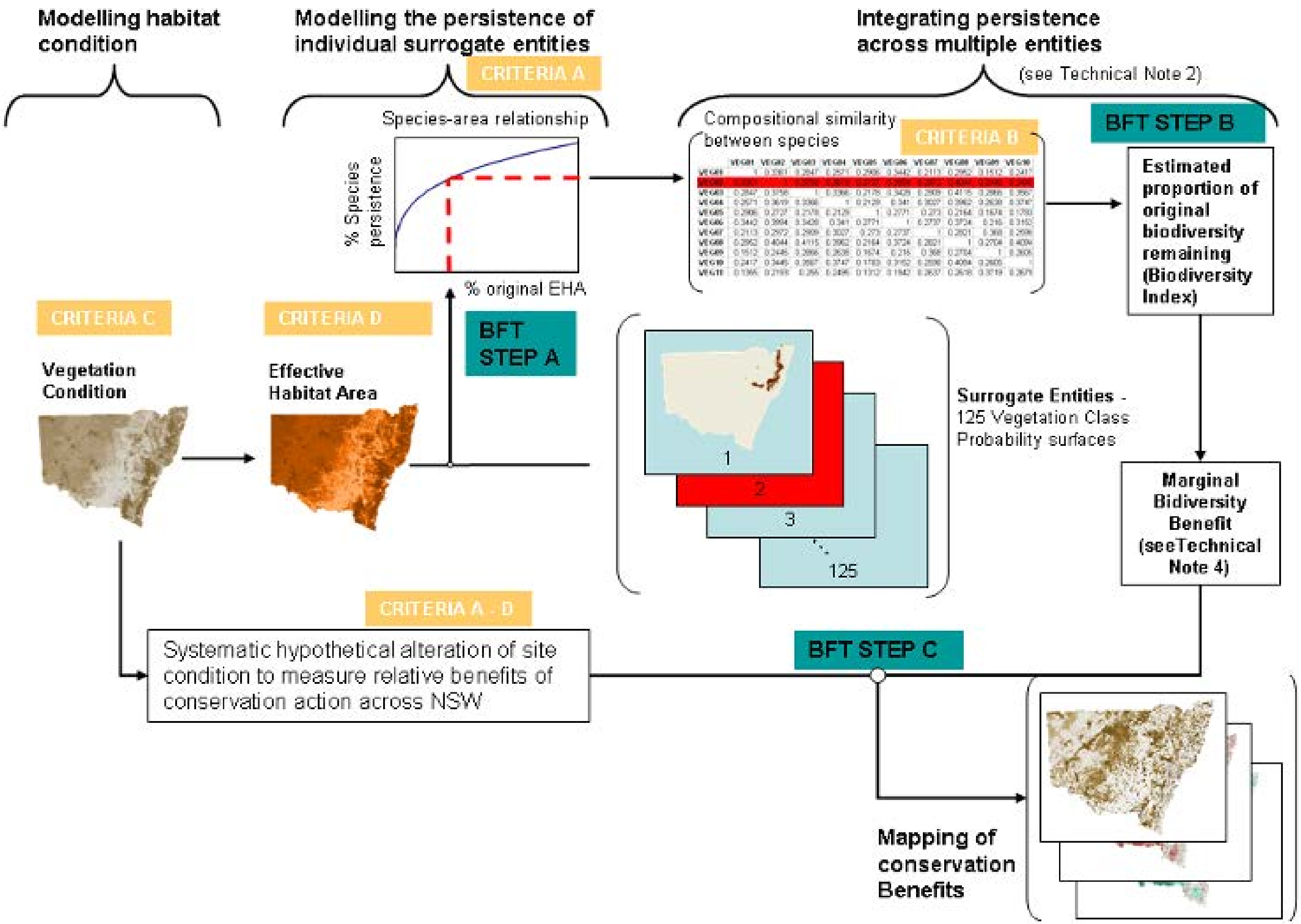


Figure 4: Application of the general framework for modelling conservation benefits

4 Predicting biodiversity benefits – 'consolidate'

4.1 Concepts in Landscape Value analysis

Habitat connectivity is acknowledged as a major factor influencing the persistence of native populations, especially fauna (Noss 1987). Maintaining and enhancing habitat connectivity is also regarded as a major adaptation to climate change (Heller & Zavaleta 2009, Mackey et al. 2012).

The Landscape Value of a site or location refers to (1) how well that location is connected to habitat, and (2) how well it contributes, by virtue of its landscape position, to habitat connectivity of other locations (see Figure 5). Landscape Value mapping highlights areas where conservation of existing vegetation, condition improvement of degraded vegetation, or rehabilitation of cleared areas are most likely to contribute to maintaining or enhancing connectivity across a region. While the analysis uses similar principles and approaches to the connectivity measure within the BFT, which considers regional (window) connectivity (Section 3), Landscape Value is designed to consider connectivity across a larger area.

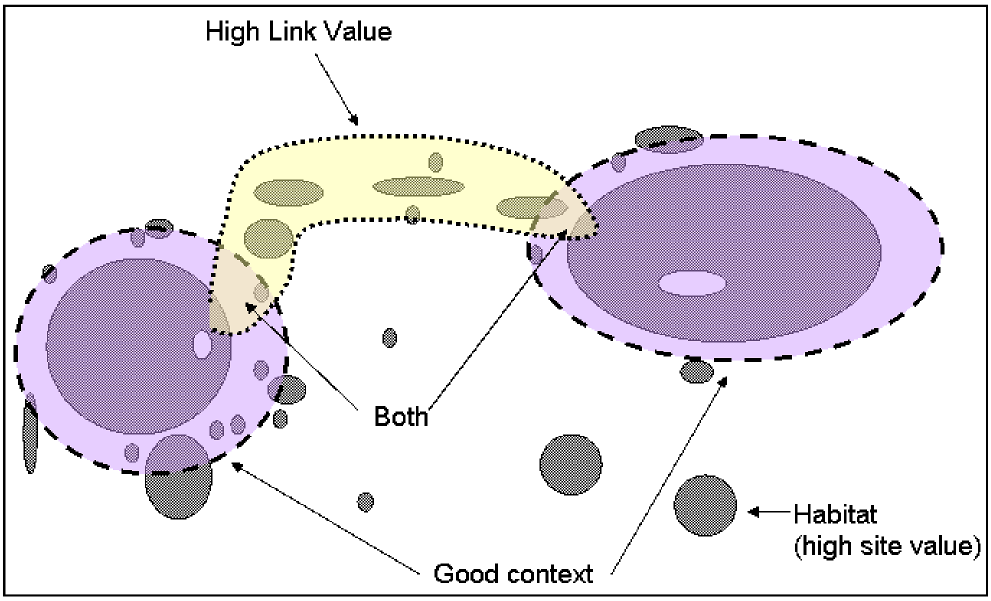


Figure 5: Assigning Landscape Value for locations of good spatial context and/or link value

Landscape Value can be due to link value, context or both. In all cases the appropriate management action will largely depend on site condition.

Landscape Value was derived using graph theoretical approaches (Drielsma et al. 2007a, 2007b). It systematically models habitat linkages across a broad range of ecological scales, from local (i.e. connections that affect the day-to-day movements of fauna with limited movement ability, such as small birds and reptiles), to regional (i.e. dispersal and/or migration across tens or hundreds of kilometres). The connectivity measures employed depict colonisation potential (based on spatial links mapping, see Technical Note 1) and Neighbourhood Habitat Area (for spatial context mapping, see Technical Note 6). The process was repeated for three broad vegetation structures: wet forest, dry forest and woodland/grassland, then combined.

Landscape Value is intended to complement other assessment methodologies, such as the BFT, which explicitly focuses on the complementarities of sites from a vegetation community representation perspective, but which does not map habitat links. Not all sites with high Landscape Value will have high representation value or site condition (Criteria A–C, Section 3.2). Sites that do possess these other values may deserve attention in their own right, regardless of their Landscape Value. Because of an emphasis on landscape context, high Landscape Value does not generally apply to highly cleared regions. By virtue of the disproportionate loss of the original vegetation types in such regions, these are typically identified as high 'revegetate' benefit.

The single general framework presented here does not attempt to consider every species in its modelling, nor does it attempt to provide conclusive direction for the recovery of individual species. Instead, the aim is to consider a broad range of species' mobility across a range of broad habitat types and promote improved landscape-scale planning for biodiversity generally, including common species and ecosystems as a whole. The promotion of Landscape Value is intended to reduce pressures affecting the viability of populations and to ensure that valued common biota and ecosystem processes remain common.

4.2 Coverage of analysis

Landscape Value analysis was undertaken for a study region that includes the Eastern and Central Divisions of NSW. The Western Division was excluded from the Landscape Value mapping process because although habitat degradation widely affects that region, it is not fragmented in the same sense as the eastern parts of the state where actual clearing is a major feature. In the sense that clearing is minor, the Western Division generally retains high Landscape Value, which has been represented in the 'consolidate' benefits layer by effective habitat area (see Section 3.2, Step A).

Because the analysis is primarily concerned with the connectivity or spatial context of locations, including context viewed at large spatial scales, a 200 km buffer was included which extends the analysis into Queensland, Victoria and the Western Division of NSW. The buffer was included in an attempt to ensure the integrity of the data up to the boundaries of the main study region (see Figure 6). Because the buffer was included only to provide context, its inputs were derived using a less rigorous methodology than that employed for the study region proper. All products from this analysis were subsequently clipped to the Central and Eastern Divisions of NSW.

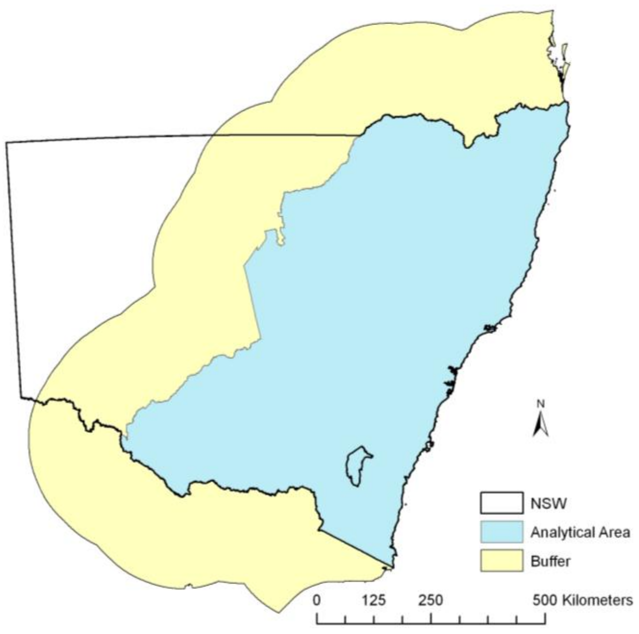


Figure 6: Location of original analytical area and buffer region for Landscape Value

4.3 Building a model to evaluate Landscape Value

Step A: Derive VSC surfaces

Three broad vegetation structural classes (VSCs) were modelled across the study area: closed forest, open forest and woodland. The values of these VSCs were not intended to represent vegetation or habitat condition in relation to its original or pre-1750 state (as does the NSW vegetation condition surface, see Appendix 3). Instead, the surfaces were intended to indicate how well each location, in its current compositional and structural form, conforms to each VSC. Areas that were previously closed forest, but which have since been partly cleared, are unlikely to provide habitat for closed-forest species, but may provide habitat and support movement by open forest or woodland species.

The use of the three non-exclusive classes provides a basis for separately modelling connectivity between locations of similar habitat via routes of similar vegetation, while avoiding the complexity of modelling individual species movements.

The VSCs were structurally defined using foliage projective cover (FPC, see Table 5, Appendix 3). The FPC data was corrected for hill shade and cloud cover.

Step B: Apply a structure classification

VSC surfaces were initially derived through applying transformation functions to raw FPC values based on FPC benchmarks from Gibbons et al. (2008). These functions represent the range of FPC values expected to occur within each of the VSCs. For each location the transformed values indicate to what degree it contributes to each of the VSCs. The transformations use continuous functions with overlap between individual classes. Therefore each location may function as more than one VSC (see Figure 18, Appendix 4).

Step C: Apply a VSC modifier

Each of the VSC layers was then modified by a ‘condition’ layer with values hierarchically assigned to a combination of land tenure, land-use and land cover classes. A land-use derived cropping mask was also applied to the VSC layers in order to remove areas identified as having been cropped, that presented artificially high FPC values (see Figure 17, Appendix 4).

Step D: Model connectivity

Two connectivity modelling techniques were applied to each of the three VSCs to correspond to two aspects of connectivity (see Figure 5):

1. Habitat Links Analysis (Drielsma et al. 2007b) was used to identify habitat linkages between and through patches of habitat.
2. Neighbourhood Habitat Area analysis (Hanski 1999; Drielsma et al. 2007a) was used to assess the level of connected habitat (spatial context) of each site (gridcell).

Details of how these techniques were applied are described below. At the conclusion of the analysis, all links and NHA outputs were merged (summed) into a combined Landscape Value surface.

Links least cost path analysis

Landscape linkages are the parts of the landscape that facilitate connectivity between concentrations of habitat, although they do not necessarily belong to such concentrations themselves and may in fact consist of a mix of low to high habitat value (condition) at the site level. The value of a link is derived not from its weakest part but from the overall connectivity the link provides and the quantity and quality of the habitat it connects.

The links analysis for each VSC was undertaken at a range of scales. The objective was that the final product would not be biased to an arbitrarily chosen scale of connectivity but would cover the range of scales at which various biota are known to move across the landscape (within the constraints of the study region) for processes including day-to-day foraging, dispersal and migration.

Average mobility parameters (1/α, see Table 1 and Figure 7) were derived to match a range of ecological scales considered. These distances define effective distance and decay functions within the colonisation potential and NHA calculations (see Technical Note 5).

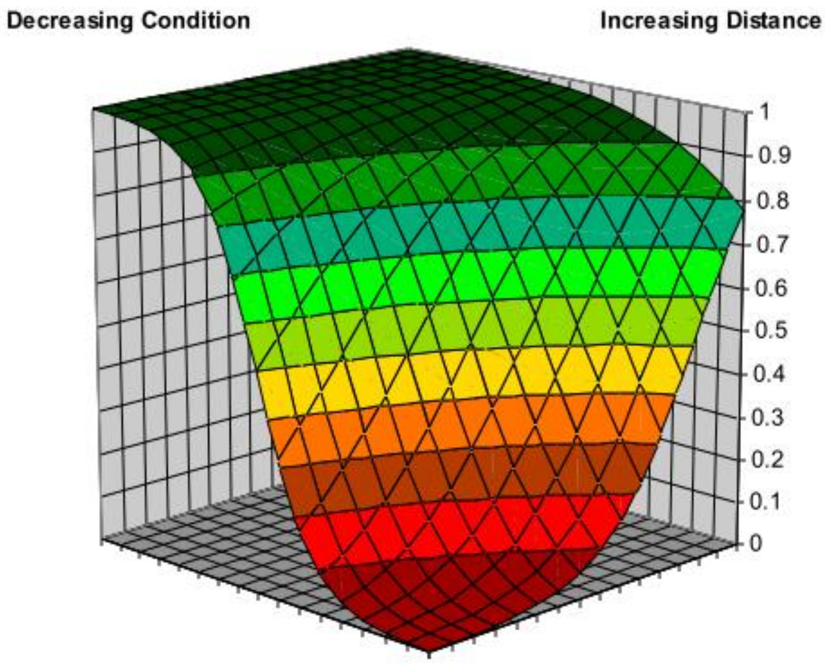
Technical Note 5: Effective distance model for links analysis

Within least cost path analysis used in links analysis, 'effective distance' is calculated for each path. The effective distance between two locations is a function of the permeability to fauna movement of the intervening habitat. The effective distance across an area of good condition is close or equal to Euclidian distance, while the effective distance across a location of poor condition is greater.

A sygmoidal distance-decay function is employed for calculating the permeability (w_{ij}), a weight between 0 and 1, between two sites i and j based on a mobility parameter (1/α).

$$w_{ij} = \frac{e^{-i\left(d_{ij} - 1/\alpha\right)}}{1 + e^{-i\left(d_{ij} - 1/\alpha\right)}}$$

where d_{ij} is the effective distance between sites i and j and e represents Euler's constant. The figure below illustrates how decay functions vary across a range of condition (habitat suitability) values.



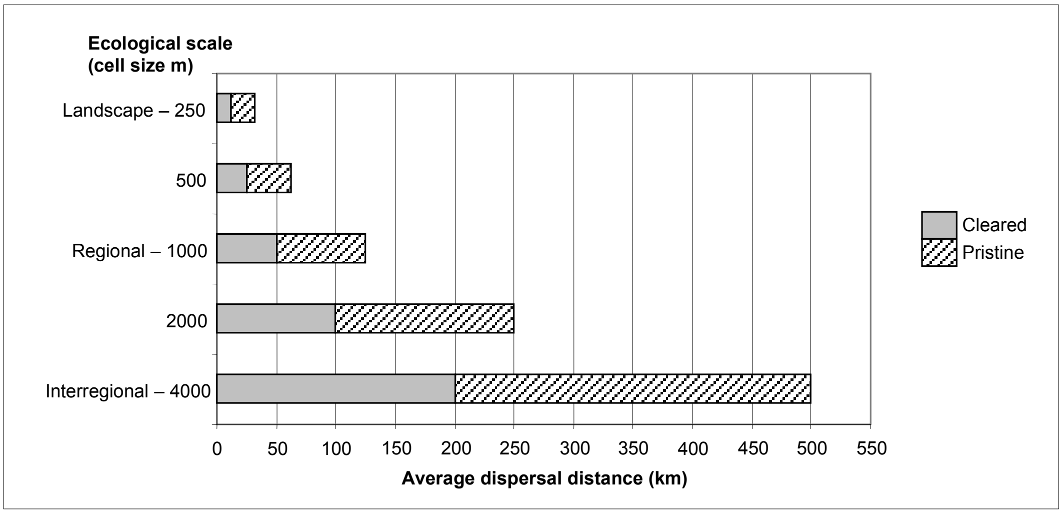


Figure 7: Generic mobility parameters across the range of analysis scales

Each VSC condition surface was re-sampled at various grid resolutions representing a range of ecological scales, and at various grid origins (see Figure 19 in Appendix 4) (the latter was done to capture detail commonly lost through a single re-sampling to an arbitrary origin). The 100 m grid resolution VSC condition surfaces were re-sampled at five different ecological scales ranging from a 'landscape scale', sampled at 250 m resolution, through to 'interregional scale' sampled at 4 km resolution (see Table 1). Each run of the links analysis (Table 1) was therefore configured to apply to a unique combination of VSC, a spatial scale (defined by path distance) and grid resolution, and an origin offset. The number of paths for each run was increased in relation to the resolution (more paths for finer resolution).

This multi-scale approach ensured the connectivity analysis covered movement scales relevant to a majority of fauna species including day-to-day local movements, landscape-scale dispersals and cross-regional migrations.

Table 1: Summary of spatial links runs for each vegetation structural class

A systematic strategy crossing scales (path length and mobility parameter), spatial (gridcell) resolution and origin setting was adopted.

Ecological scale	Grid resolution (m)	No. grid origins	Paths per origins	Total paths	Mobility parameter 1/α (km)	Minimum path distance (km)	Maximum path distance (km)
Within region	250x250	25	4000	100000	31.25	2.5	25
	500x500	25	2000	50000	62.5	5	50
	1000x1000	16	1570	25120	125	10	100
	2000x2000	25	500	12500	250	20	200
Interregional	4000x4000	25	250	6250	500	40	400

Neighbourhood Habitat Analysis

Neighbourhood Habitat Area (NHA) is a measure of the landscape context of each site – the site's connectivity to other habitat or conversely its fragmentation. The NHA value for each site (gridcell) is a measure of the area, condition and connectedness of surrounding habitat (to the focal cell) within a neighbourhood window (see Technical Note 6).

NHA was calculated across the region at five spatial scales and cell resolutions (Table 1), mirroring the multi-scale links analysis described above, using the cost benefit approach (CBA) with the petals technique (Drielsma et al. 2007a).

As the resolution of the gridcells varied (kept a constant proportion to the spatial scale being examined) all other aspects of the analysis remained constant across the various runs, i.e. the range of permeability values and the petal configurations. In each run, the permeability values of each cell (i.e. the multiplicative weight or 'cost' of moving through a cell, where the accumulative cost for a path starts at one) were derived by scaling the habitat values between 0.779 and 0.905. These values were based on 1/α values that range between four times and 10 times the gridcell resolution for each scale of analysis, i.e. across the analysis movement abilities are assumed to be 2.5 times as great for high condition as for poor.

Technical Note 6: Calculation of Neighbourhood Habitat Area

The NHA of a gridcell *i* was calculated as follows:

$$NHA_i = \left(\sum_j H_j e^{-\alpha d_{ij}} \right)$$

where:

H_j is the vegetation condition of a neighbourhood location (petal) *j* (*j* can equal *i*)

d_{ij} is the effective distance from the focal cell to cell j, and

$1/\alpha$ is the mobility parameter.

NHA is closely related to the colonisation potential measure (see Section 2), the difference being that with NHA each neighbourhood component is not weighted by the habitat value (condition) of the focal cell, making it purely a measure of context; with the focal cell not a special case in the calculations.

Step E: Regional balance weightings

The raw output from the connectivity analysis showed results heavily skewed towards the slopes and ranges in the east of NSW that retain large contiguous areas of intact native vegetation. A process was applied to ensure the Landscape Value attributed to a site reflected its relative contribution within a regional context as well as within the context of NSW.

The revised Landscape Value values (Landscape Value_2) were calculated by boosting the initial Landscape Value values (Landscape Value_1) of cells inversely proportional to the NHA at the interregional scale (referred to as '4000_N'), where:

Landscape Value_2 = Landscape Value_1 + (Landscape Value_1 * (1 – (4000_N/4000_N_{max}))).

The overall effect was to accentuate regionally important key habitats and corridors within areas otherwise largely cleared, such as the sheep–wheat belt of central NSW.

5 Relating NVM benefits to the ecosystems of NSW

Three additional analyses were applied to the NVM benefits map to assist interpretation and enable their graphical presentation in ecosystem profiles developed for each vegetation formation. The analyses are important for identifying the potential contribution that public agencies, CMAs, or private land managers can make towards the conservation of different ecosystem types.

The final NVM benefits map was intersected with a map of tenure and an updated version of the Keith (2002) pre-1750 ecosystem map to develop summary statistics on the extent of each type of benefit by ecosystem for each CMA and for each land tenure in NSW (updated map provided by David Keith, pers. comm. 2010). The following data was calculated:

- the private/public split of high NVM benefit extent within each ecosystem type, (including a further split of public and private lands between those managed primarily for conservation purposes and those that have other uses, and
- the extent of each NVM benefit per ecosystem type within each CMA.

A second analysis was undertaken to generate statistics on the public and private land tenure breakdown of NVM benefits. The map was overlain with available tenure data and CMA boundaries to determine the extent of each management benefit in each basic land tenure category for each ecosystem type (Table 2). Table 3 summarises the land tenure categories that were combined to calculate data on the extent of areas with highest NVM benefit on public and private land, plus the data sources from which they were derived.

Information on the average level of fragmentation of each ecosystem type was undertaken using the approach described in Appendix 6. These data are referred to in the profiles. Some ecosystem types, such as dry sclerophyll forests, are generally distributed within much larger remnants than others, such as grassy woodlands. This should be taken into account when deciding whether an area is a priority area. For instance, a smaller grassy woodland remnant may represent a good investment where a dry sclerophyll forest remnant of the same size may not.

The ecosystem profiles developed to provide these data:

- describe the conservation status and biodiversity value of each ecosystem
- provide a map of the distribution of highest NVM benefits to inform development of catchment investment priorities
- describe the pattern of fragmentation and conservation management
- identify the proportion of public and private lands that have highest NVM benefit, including the proportion of public reserves where biodiversity conservation is already the focus of management effort, and
- acknowledge cultural associations with Aboriginal groups.

An example of how NVM benefits are presented for one such ecosystem is provided in Figure 8.

Table 2: Extent of priority investment areas within ecosystems managed by different land management groups

Ecosystem	Benefit areas on public land (ha) (% of total area of benefit area)					Benefit areas on private land (ha) (% of total area of benefit area)			All benefit areas (ha)
	OEH estate	State forests	Crown land	TSR	TOTAL	Freehold	Western Lands Lease	TOTAL	GRAND TOTAL
Grassy woodlands	266,676 (5%)	64,244 (1%)	324,112 (7%)	44,344 (1%)	699,376 (14%)	4,258,720 (86%)	3,476 (0%)	4,262,196 (86%)	4,961,572 (100%)
Grasslands	50,996 (13%)	1,840 (0%)	14,860 (4%)	20,444 (5%)	88,140 (23%)	207,500 (53%)	92,764 (24%)	300,264 (77%)	388,404 (100%)
Semi-arid woodlands	472,936 (14%)	67,864 (2%)	350,460 (11%)	152,032 (5%)	1,043,292 (32%)	1,619,240 (49%)	639,396 (19%)	2,258,636 (68%)	3,301,928 (100%)
Dry sclerophyll forests	2,286,752 (52%)	177,796 (4%)	228,048 (5%)	14,684 (0%)	2,707,280 (62%)	1,672,012 (38%)	0 (0%)	1,672,012 (38%)	4,379,292 (100%)
Wet sclerophyll forests	709,836 (73%)	107,696 (11%)	11,576 (1%)	1,136 (0%)	830,244 (85%)	145,112 (15%)	0 (0%)	145,112 (15%)	975,356 (100%)
Rainforests	218,404 (84%)	17,568 (7%)	2,572 (1%)	196 (0%)	238,740 (92%)	20,588 (8%)	0 (0%)	20,588 (8%)	259,328 (100%)
Forested wetlands	153,592 (28%)	40,148 (7%)	50,796 (9%)	15,644 (3%)	260,180 (48%)	279,812 (52%)	3,228 (1%)	283,040 (52%)	543,220 (100%)
Heathlands	94,472 (92%)	1,100 (1%)	1,568 (2%)	12 (0%)	97,152 (95%)	5,132 (5%)	0 (0%)	5,132 (5%)	102,284 (100%)
Alpine complex	99,372 (100%)	48 (0%)	108 (0%)	4 (0%)	99,532 (100%)	112 (0%)	0 (0%)	112 (0%)	99,644 (100%)
Arid acacia shrublands	22,132 (55%)	0 (0%)	280 (1%)	564 (1%)	22,976 (57%)	408 (1%)	16,636 (42%)	17,044 (43%)	40,020 (100%)
Arid chenopod shrublands	130,188 (41%)	200 (0%)	16,336 (5%)	44,688 (14%)	191,412 (60%)	111,164 (35%)	14,536 (5%)	125,700 (40%)	317,112 (100%)
TOTAL	4,505,356 (29%)	478,504 (3%)	1,000,716 (7%)	293,748 (2%)	6,278,324 (41%)	8,319,800 (54%)	770,036 (5%)	9,089,836 (59%)	15,368,160 (100%)

Table 3: Public and private land tenure categories

Tenure	Categories of land / water managed for conservation purposes	Data source
Public	OEH estate (national parks, nature reserves, state conservation areas)[1]	OEH
	OEH estate (not gazetted)	OEH
	Aquatic reserves[1]	OEH
	State forest flora reserves[1]	DPI
	Travelling stock reserves[2]	DPI
	Crown reserves (with a conservation purpose[3])	DPI
	Marine parks (Sanctuary zones)	Marine Park Authority
	Other Crown lands with a conservation agreement	DPI
Private	Western Lands Lease with a conservation agreement or covenant[4], including conservation covenants held on title (Dept of Lands database). This information overlaps with other data such as wildlife refuges and property vegetation plans. Nature Conservation Trust covenants.	DPI
	Freehold land with a conservation agreement or covenant including wildlife refuges[1], voluntary conservation agreements[1], Crown land conversion covenants (compliance), property agreements (in perpetuity)[1], PVP agreements (in perpetuity)[1]	Miscellaneous including OEH, CMAs, and private organisations

[1] Aligns with the categories found within the Native Vegetation Report Card 'New Conservation Areas' and 'New Restoration/Revegetation of Native Vegetation' categories.
[2] Travelling stock reserves (TSRs) are parcels of Crown land that are reserved under legislation for use by travelling stock and are managed by livestock health and pest authorities (LHPAs). LHPAs manage the land to strike a balance between the needs of travelling or grazing stock and the conservation of native species.
[3] Crown reserve categories are defined in Appendix 1.
[4] Western Land Leases are technically public land, however they are managed privately with few restrictions beyond those that generally apply to private land.

Note that the Native Vegetation Report Card (NVRC) component of the *NSW Annual Report on Native Vegetation* (DECCW 2008) reports on private and public land achievements in the conservation, restoration and management of the native vegetation of NSW under the *Native Vegetation Act 2003*. The land tenure categories presented in Table 3 align where possible with those identified within the NVRC 'New Conservation Areas' and 'New Restoration/Revegetation of Native Vegetation' categories. Not all NVRC tenure categories could be included in this table due to data availability or confidentiality reasons.

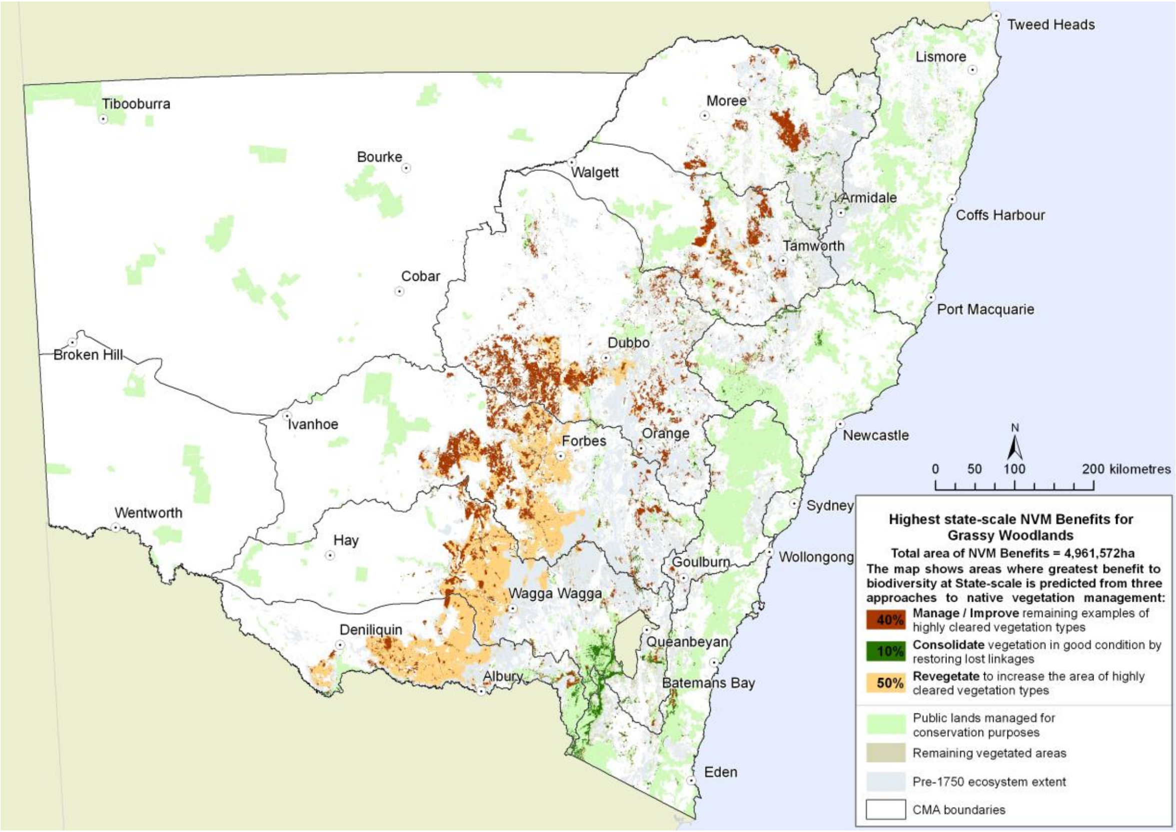


Figure 8: Example of the presentation of NVM benefits mapping for the grassy woodlands ecosystem

6 Discussion

6.1 Comments on the relationship to previous state-scale analyses

Previous attempts to develop state-scale analyses of biodiversity benefits or 'priority areas' have provided the impetus for significant refinements in the theory and application of analyses to inform investment across large areas. The draft NSW Biodiversity Strategy, for example, included mapping of proposed priority areas for investment in native vegetation management (DECCW 2010a).

Feedback from public submissions on the draft Strategy highlighted opportunities to enhance the scope and application of spatial analyses. The analyses described in this report accommodate lessons learned from these early efforts by incorporating several modifications:

1. The analyses include an improved statewide vegetation condition layer incorporating:
    a) improvements in the resolution of available data, and understanding on what influences vegetation condition in western ecosystems (i.e. consideration of groundcover (non-woody) vegetation condition, soil structural stability and foliage projective cover), and
    b) an expansion of the area of the state where investment in native vegetation management is encouraged based on state-scale biodiversity benefit.
2. The analyses replace the early use of Mitchell Landscapes as the main surrogate for biodiversity, with finer-resolution modelled vegetation classes which in turn are consistent with the Keith vegetation formations on which the 'state ecosystems' are based.

6.2 Constraints and future opportunities

The modelling techniques described in this report comprised data and methodologies available and practical for analysis across NSW at this time and within the resources available.

The modelling seeks to provide useful guidance to the kind of natural resource management investment currently being undertaken and anticipated in NSW in the medium term. The models aim at a particular scale of analysis suited to the state of NSW, providing big-picture state-level input which should enhance localised decision-making that invariably draws on additional finer-scale information and direct site inspections.

The pace of methodological and data improvement is such that significant refinements were possible over the period of this project. The current statewide models have incorporated improved vegetation class surrogates and vegetation condition, and the BFT methodology for considering composition overlap has been overhauled. It can be anticipated that the process of undertaking and applying this modelling within NSW will continue to generate lessons on how to better approach this task in the future. In addition it is anticipated that the data limitations that have constrained this analysis, particularly vegetation type and condition mapping, will progressively be addressed, leading to improvements in the future.

6.3 Interpretation and application

The NVM benefits map is intended as a guide to show areas where highest NVM benefits are likely to occur, and where investment in native vegetation management could be directed from a state perspective. The accuracy of maps derived from the analyses are limited by the scale and accuracy of data used to derive each of the benefits layers. The spatial outputs from this project are based on 6.25 ha (250 m x 250 m) gridcells and can be reliably mapped to a cartographic scale of 1:100,000.

It is recognised that NSW Government agencies, catchment management authorities and others may hold additional data and mapping, in many cases developed with or by OEH, which is more spatially precise. Having a broader, big-picture perspective, the state-scale NVM benefits complement this more localised and detailed data. Where state-scale NVM benefits and catchment-scale priorities overlap, users are encouraged to adopt these areas as highest priority for investment. The more precise data may also be used to better match management actions to locations, while maintaining a focus on the big-picture.

To accommodate these data, two aspects of the biodiversity forecasting analysis for 'manage', 'improve' and 'revegetate' benefits are highlighted as being amenable to use of finer-resolution catchment-scale data:

a) Utilise finer-resolution vegetation mapping inputs to more accurately predict the occurrence of vegetation types that represent clear priority for investment (e.g. vegetation types that have been extensively cleared and where management of any remnants in moderate to good condition would have significant benefit).

b) Utilise regional-scale condition data which more reliably reflects site condition, and/or accommodates additional information on pressures acting at the site (weed infestation, feral predator populations, etc.).

The introduction of state-scale biodiversity benefits models has highlighted the methodological challenges of synthesising this information with regional-scale assessment. It remains an area of current research which will lead to improved multi-scale assessment in the future.

7 References

Andrén, H 1994, ‘Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review’, *Oikos* 71:355–366.

DEC [NSW Department of Environment and Conservation] 2004, *Nandewar WRA Landscape Conservation*, report for the Resource and Conservation Assessment Council (RACAC), NSW Western Regional Assessment, coordinated by NSW Department of Infrastructure, Planning and Natural Resources, report no. NAND01, Department of Environment and Conservation (NSW), Coffs Harbour.

DEC [NSW Department of Environment and Conservation] 2006, *Decision Support Tools for Biodiversity Conservation: Biodiversity Forecasting Toolkit* – prepared by DEC for the Comprehensive Coastal Assessment (DoP), Department of Environment and Conservation (NSW), Armidale.

DECC [NSW Department of Environment and Climate Change] 2008, *NSW Interim Native Vegetation Extent* (2008–Version 1), report and data prepared by NSW Department of Environment and Climate Change for the National Land and Water Resources Audit, project no. DONR 000397.

DECCW [NSW Department of Environment, Climate Change and Water] 2010a, *Deriving Priority Areas for Investment – a technical report to accompany the Draft NSW Biodiversity Strategy*, Department of Environment, Climate Change and Water NSW, Sydney.

DECCW [NSW Department of Environment, Climate Change and Water] 2010b, *Draft NSW Biodiversity Strategy 2010–2015*, Department of Environment, Climate Change and Water NSW, Sydney.

Department of Natural Resources and Water 2007, *Land cover change in Queensland 2004–2005: a State-wide Landcover and Trees Study (SLATS) Report*, Department of Natural Resources and Water, Brisbane.

Dillon, M, McNellie, M and Oliver, I 2009, *Technical Background Report NSW State of the Catchments 2008: Native Vegetation*, Scientific Services Division, Department of Environment and Climate Change, Sydney.

Doerr, VAJ, Doerr, ED and Davies, MJ 2010, *Does structural connectivity facilitate dispersal of native species in Australia’s fragmented terrestrial landscapes?*, CEE review 08–007 (SR44), CSIRO Sustainable Ecosystems, Canberra.

Drielsma, MJ 2000, ‘Derivation of GIS terrain variables for use in Comprehensive Regional Assessments’, in possession of author, Armidale.

Drielsma, MJ, Love, J, Manion, G and Barrett, T 2010, *Great Eastern Ranges Vegetation Condition Modelling Project Report*, Spatial Analysis of Conservation Priorities in the Great Eastern Range, Armidale, NSW Department of Environment, Climate Change and Water.

Drielsma, M, Love, J and Barrett, T unpub., Eastern NSW Landscape Value Mapping Project.

Drielsma, MJ and Ferrier, S 2006, ‘Landscape scenario modelling of vegetation condition’, *Ecological Management and Restoration* 7:45–52.

Drielsma, MJ, Ferrier, S and Manion, G 2007a, ‘A raster-based technique for analysing habitat configuration: The Cost–Benefit Approach’, *Ecological Modelling* 202:324–332.

Drielsma, MJ, Manion, G and Ferrier, S 2007b, ‘The Spatial Links Tool: Automated mapping of habitat linkages in variegated landscapes’, *Ecological Modelling* 200:403–411.

Fahrig, L 2002, ‘Effect of habitat fragmentation on the extinction threshold: A synthesis’, *Ecological Applications* 12:346–353.

Faith, DP and Walker, PA 1996, ‘Environmental diversity: on the best-possible use of surrogate data for assessing the relative biodiversity of sets of areas’, *Biodiversity and Conservation* 5:399–415.

Ferrier, S 2002, ‘Mapping spatial pattern in biodiversity for regional conservation planning where to from here?’ *Systematic Biology* 51:331–363.

Ferrier, S 2005, *An integrated approach to addressing terrestrial biodiversity in NRM investment planning and evaluation across state, catchment and property scales*, NSW Department of Environment and Conservation, Armidale.

Ferrier, S and Drielsma, MJ 2010, ‘Synthesis of pattern and process in biodiversity conservation assessment: a flexible whole-landscape modelling framework’, *Diversity and Distributions* 16:386–402.

Ferrier, S, Faith, DP, Arponen, A and Drielsma, MJ 2009, ‘Community-Level Approaches to Spatial Conservation Prioritization’, in A Moilanen, KA Wilson and HP Possingham (eds), *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools*, Oxford University Press, Oxford.

Ferrier, S, Manion, G, Elith, J and Richardson, K 2007, ‘Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment’, *Diversity and Distributions* 13:252–264.

Ferrier, S, Watson, G Pearce, J and Drielsma, MJ 2002, ‘Extended statistical approaches to modelling spatial pattern in biodiversity in north-east New South Wales: I, Species-level modelling’, *Biodiversity and Conservation* 11:2275–2307.

Fuller, RA, Drielsma, MJ, Watson, JEM, Taylor, R, Shushinsky, J, Smith, J and Possingham, HP 2011, *Priorities for ecological restoration in the Western Woodlands Way*, report commissioned by the four catchment management authorities of the Western Woodlands Way: Border Rivers / Gwydir, Central West, Lachlan, and Namoi, Spatial Ecology Laboratory, University of Queensland, Brisbane, and the GIS Research and Development Unit, NSW Department of Environment and Climate Change, Armidale.

Gibbons, P, Ayers, D, Seddon, J, Doyle, S and Briggs, S 2008, *BioMetric 2.0: A Terrestrial Biodiversity Assessment Tool for the NSW Native Vegetation Assessment Tool*, *Operation Manual*, NSW Department of Environment and Climate Change, Sydney.

Hanski, I 1999, ‘Habitat connectivity, habitat continuity, and metapopulations in dynamic landscapes’, *Oikos* 87:209–219.

Harte, J, McCarthy, S, Taylor, K, Kinzig, A and Fisher, ML 1999, ‘Estimating species-area relationships from plot to landscape scale using spatial-turnover data’, *Oikos* 86:45–54.

Heller, NE and Zavaleta, ES 2009, ‘Biodiversity management in the face of climate change: A review of 22 years of recommendations’, *Biological Conservation* 142:14–32.

Keith, DA 2002, *A compilation map of native vegetation for New South Wales*, New South Wales National Parks and Wildlife Service, Hurstville.

Keith, DA 2004, *Ocean shores to desert dunes*, Department of Environment and Conservation (NSW), Hurstville.

Landcare NSW 2010, *Travelling Stock Route sites*, Landcare NSW Inc, retrieved 02/07/12, from www.landcarensw.org.au/node/1365.

Logan, V, Ferrier, S and Manion, G 2009, ‘Using modelling of continuous gradients of community composition to assess vulnerability of biodiversity to climate change in New South Wales’, poster presentation to INTECOL conference.

Mackey B, Berry S, Hugh S, Ferrier S, Harwood, T and Williams, K 2012, ‘Ecosystem greenspots: identifying potential drought, fire and climate change micro-refuges’, *Ecological Applications* 22:1852–1864.

Mackey, BG, Watson, J and Worboys, GL 2010, *Connectivity Conservation and the Great Eastern Ranges Corridor*, a report to the Department of Environment and Climate Change NSW, ANU enterprises, Canberra.

Margules, CR and Sarkar, S 2007, *Systematic Conservation Planning*, Cambridge University Press, New York.

Merriam, G 1984, 'Connectivity: a fundamental ecological characteristic of landscape pattern', pp. 5–15 in M Ruzicka, T Hrnciarova and L Miklos (eds), *Proceedings of the First International Seminar on Methodology in Landscape Ecological Research and Planning, Roskilde, Denmark*, International Association for Landscape Ecology.

Nicholson, E, Westphal, MI, Frank, K, Rochester, WA, Pressey, RL, Lindenmayer, DB and Possingham, HP 2006, 'A new method for conservation planning for the persistence of multiple species', *Ecology Letters* 9:1049–1060.

Noss, R 1987, 'Corridors in real landscapes: a reply to Simberloff and Cox', *Conservation Biology* 1:159–164.

Noss, RF 1990, 'Indicators for monitoring biodiversity: a hierarchical approach', *Conservation Biology* 4:355–364.

Oliver, I and Parkes, D 2003, *A prototype toolkit for scoring the biodiversity benefits of land use change*, NSW Department of Infrastructure, Planning and Natural Resources, Parramatta.

Pressey, RL, Watts, ME, Barrett, TW and Ridges, MJ 2009, 'The C-Plan conservation planning system: origins, applications, and possible futures', in A Moilanen, KA Wilson and HP Possingham, (eds), *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools*, Oxford University Press.

Resource and Conservation Assessment Council 2004, *Bioregional Landscape Conservation Framework: Biodiversity Component*, NSW Western Regional Assessments, Brigalow Belt South, Resource and Conservation Assessment Council, Sydney.

Ridges, MJ 2010, *Aboriginal Sites Decisions Support Tool (ASDST), State-wide product outline and technical summary*, NSW Department of Environment, Climate Change and Water, Sydney.

Sisk, TD, Noon, B and Hampton, HM 2000, 'Estimating the effective area of habitat patches in heterogeneous landscapes', pp. 713–726 in JM Scott, PJ Hegland, ML Morrison, JB Haufler, MG Raphael, WA Wall and FB Samson, (eds), *Predicting Species Occurrences: Issues of Accuracy and Scale*, Island Press, Washington DC.

Soule, ME, Mackey, BG, Recher, HF, Williams, JE, Woinarski, JCZ, Driscoll, D, Dennison, WC and Jones, ME 2004, 'The role of connectivity in Australian conservation', *Pacific Conservation Biology* 10:266–279.

Thackway, R and Lesslie, R 2005, *Vegetation Assets, states, and transitions: accounting for vegetation condition in the Australian landscape*, Australian Department of Agriculture, Fisheries and Forestry, Canberra.

Walker, PJ 1991, *Land Systems of Western NSW*, Technical Report No. 25, Soil Conservation Service of NSW, Sydney.

Appendix 1: Categories of Crown reserve with a conservation purpose

Addition~Water Supply
Camping~Preservation of Water Supply
Camping~Public Recreation~Water Supply
Camping~Water Supply
Catchment Area
Catchment Area~Soil Conservation
Coastal Environmental Protection~Public Recreation
Community Purposes~Environmental Protection
Community Purposes~Environmental Protection~Heritage Purposes
Community Purposes~Environmental Protection~Public Recreation
Conservation of Native Flora~Fauna
Crossing~Preservation of Native Flora
Drainage~Environmental Protection~Public Recreation
Drainage~Preservation of Fauna~Preservation of Native Flora
Environmental Protection
Environmental Protection~Future Public Requirements
Environmental Protection~Future Public Requirements~Public Recreation
Environmental Protection~Heritage Purposes
Environmental Protection~Heritage Purposes~Public Recreation
Environmental Protection~Preservation of Scenery~Public Recreation
Environmental Protection~Public Recreation
Environmental Protection~Public Recreation~Rural Services
Environmental Protection~Public Recreation~Tourist Facilities and Services
Environmental Protection~Public Recreation~Water
Environmental Protection~Public Recreation~Water Supply
Environmental Protection~Rural Services
Extension~Preservation of Water Supply
Extension~Water Supply
Fauna~Preservation of Native Flora
Future Public Requirements
Future Public Requirements~Preservation of Fauna~Preservation of Native Flora
Future Public Requirements~Preservation of Trees
Heritage Purposes~Public Recreation and Coastal Environmental Protection
Native Birds~Preservation of Fauna
Native Fauna~Preservation of Native Flora
Native Fauna~Preservation of Native Flora~Public Recreation
Other Public Purposes~Preservation of Timber~Water Supply
Other Public Purposes~Preservation of Water Supply
Other Public Purposes~Water Supply
Preservation and Growth of Native Flora
Preservation and Growth of Timber
Preservation of Aboriginal Carvings and Drawings
Preservation of Aboriginal Cultural Heritage

Preservation of Aboriginal Relics~Preservation of Trees
Preservation of Caves
Preservation of Caves~Preservation of Native Flora and Fauna
Preservation of Fauna
Preservation of Fauna~Preservation of Native Flora
Preservation of Fauna~Preservation of Native Flora~Public Recreation
Preservation of Fauna~Public Recreation
Preservation of Native Birds
Preservation of Native Fauna~Preservation of Native Flora
Preservation of Native Fauna~Preservation of Native Flora~Public Recreation
Preservation of Native Flora and Fauna
Preservation of Native Flora and Fauna~Preservation of Timber
Preservation of Native Flora and Fauna~Preservation of Trees
Preservation of Native Flora and Fauna~Public Recreation
Preservation of Native Flora and Fauna~Public Recreation~Resting Place
Preservation of Native Flora~Preservation of Native Flora and Fauna~Public Recreation
Preservation of Native Flora~Preservation of Scenery
Preservation of Native Flora~Protection from Sand Drift~Public Recreation
Preservation of Native Flora~Public Baths~Public Recreation
Preservation of Native Flora~Public Recreation
Preservation of Native Flora~Public Recreation~Reservoir
Preservation of Native Flora~Water Supply
Preservation of Scenery
Preservation of Scenery~Public Recreation
Preservation of Trees~Public Recreation
Preservation of Trees~Recreation
Preservation of Trees~Soil Conservation
Preservation of Water Supply
Promotion of the Study and Conservation of Native Flora and Fauna
Promotion of the Study and Preservation of Native Flora
Promotion of the Study and the Preservation of Native Flora and Fauna
Promotion of the Study and the Preservation of Native Flora and Fauna~Public Recreation
Promotion of the Study and the Preservation of Native Flora and Fauna~Public School Purposes
Protection of Fossil Trees
Public Purposes~Water Supply
Public Recreation and Coastal Environmental Protection
Public Recreation and Coastal Environmental Protection~Tourist Facilities and Services
Public Recreation and Preservation of Aboriginal Cultural Heritage
Public Recreation~Water Supply
Scenic Protection
Soil Conservation
Water Supply

Appendix 2: Process to generate an input layer for 'modelled vegetation classes'

This appendix describes how a generalised dissimilarity model (GDM) (Ferrier et al. 2007) was used to derive a vegetation community surrogate for NSW. The GDM was used in the Biodiversity Forecasting Tool (BFT) analysis undertaken to derive 'manage', 'improve' and 'revegetate' benefit surfaces as described in Section 3. The analytical process was extended to produce a distance table (matrix) that was used in the BFT to consider the compositional overlap of vegetation classes.

The description provided here outlines the processes undertaken to produce:

1. 125 raster surfaces (also known as a probability 'stack'), each of which represents the probability of each Keith Vegetation Class occurring across NSW, and
2. the associated distance table (matrix) defining the compositional similarity between each pair of classes (see Figure 9).

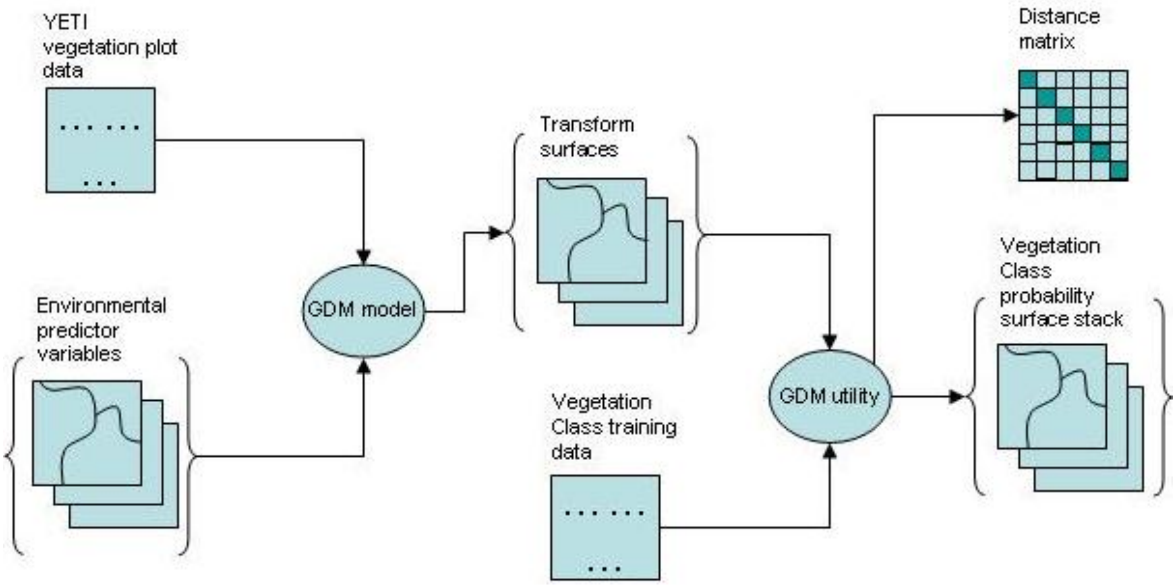


Figure 9: Overall process for deriving the vegetation class probability surfaces and the distance matrix

Deriving the GDM

The GDM was used as the primary software to generate the probability grids. Site data and a number of spatial predictors were obtained from Logan et al. (2009) which provided a single statewide source. This data comprised 36,230 site records for 4845 native flora species in the form of a site by species table, extracted from the YETI flora database and filtered for reliability. The model used a sub-sample of 750,000 site pairs.

The collection of abiotic, topographic and modelled spatial predictors (grids), was augmented with additional terrain variables developed by Mal Ridges (pers. comm. 2011) using a 100 m Digital Terrain Model for NSW. Predictors and their relative level of importance in the model are shown in Table 4 and Figure 10. The model fit is illustrated in Figures 12 and 13. The resulting model explained 39.5% of the deviance in the site data.

The significant predictors were transformed according to the coefficients derived by the GDM model. The transformation functions for the predictors are shown in Figure 11.

Table 4: Predictors and data sources used to derive the GDM (listed in order of influence on the model)

Id.	Variable	Source*	Code
1	Mean annual temperature	ANUCLIM (Logan et al.)	BP01
2	Mean annual moisture index	ANUCLIM (Logan et al.)	BP28
3	Mean annual precipitation	ANUCLIM (Logan et al.)	BP13
4	Mean annual radiation	ANUCLIM (Logan et al.)	BP20
5	Mean moisture index for wettest quarter	ANUCLIM (Logan et al.)	BP34
6	Topographic index 0.5 km radius	Curvature within a 5 x 5 cell neighbourhood window. ArcView map calculation (Ridges 2010)	TP05
7	Multidimensional scaling in SPlus of data derived in ArcMap (axis 2)	(Ridges 2010)	SoilAv2
8	Multidimensional scaling in SPlus of data derived in ArcMap (axis 3)	(Ridges 2010)	SoilAv3
9	Mean diurnal temperature range	ANUCLIM (Logan et al.)	BP02
10	Temperature seasonality (C of V)	ANUCLIM (Logan et al.)	BP04
11	Clay percentage of topsoil	(Logan et al.)	Clpk1
12	Standard deviation of elevation within 1 km diameter	ArcView map calculation (Ridges 2010)	Rugg1
13	Standard deviation of elevation within 3 km diameter	ArcView map calculation (Ridges 2010)	Rugg3
14	Available water capacity in topsoil	(Logan et al.)	Whpk1
15	Proximity to drainage lines	Terrain damped pedestrian cost–distance model (Ridges 2010)	Drncst
16	Proximity to rivers	Terrain damped pedestrian cost–distance model (Ridges 2010)	Rivcst
17	Aspect	ArcView map calculation (Ridges 2010)	Aspect

*Sources: Logan et al. 2009; Ridges 2010

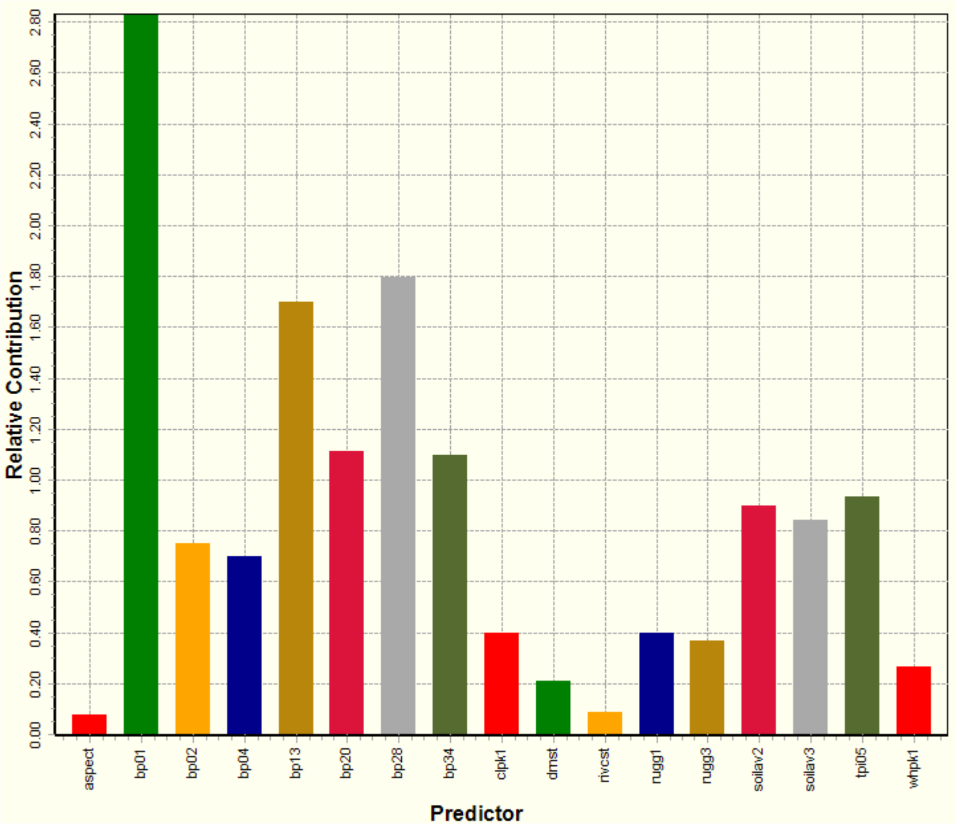


Figure 10: Relative contribution of each predictor variable to the GDM model

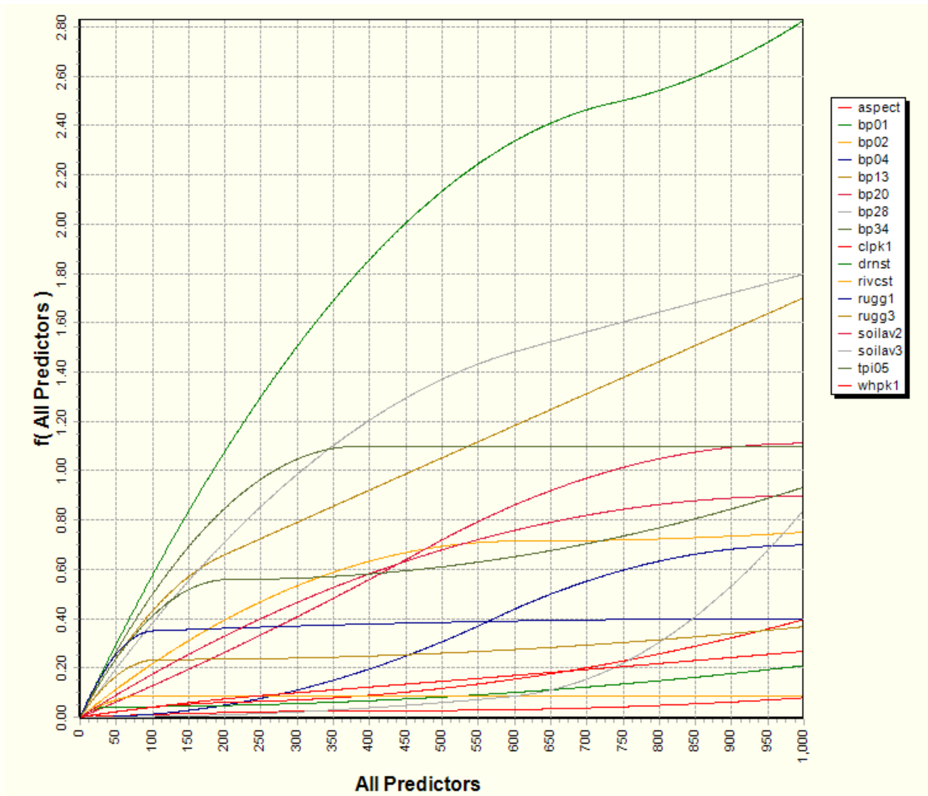


Figure 11: Transformation coefficients

Each significant predictor was transformed according to the coefficients derived by the GDM model. The transformed values (y-axis) describe the rate of species turnover associated with each predictor.

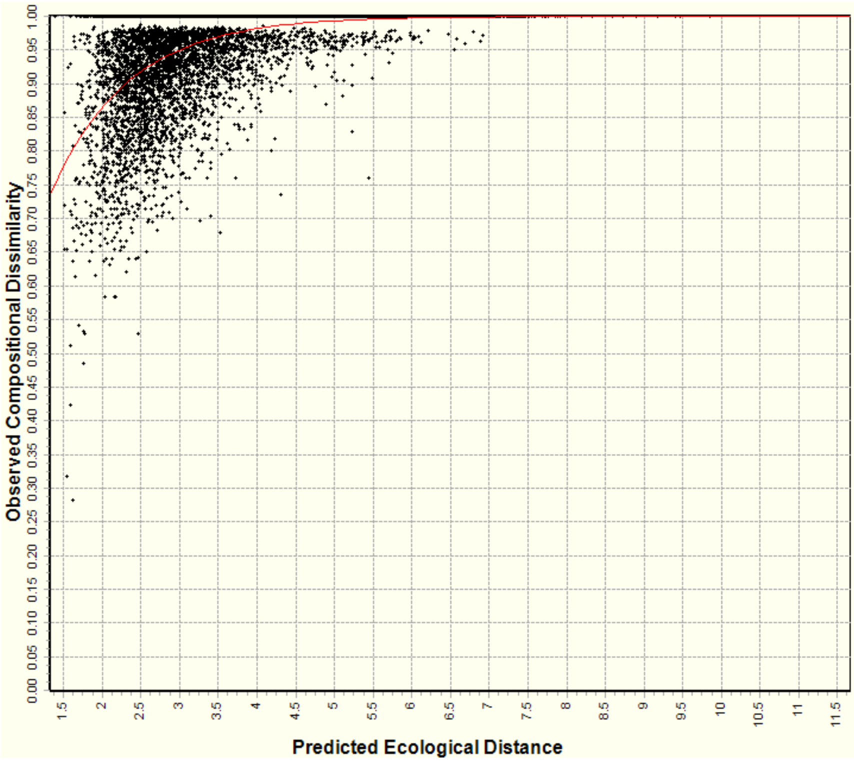


Figure 12: A plot of predicted ecological distance and observed compositional dissimilarity for a randomly selected set of point pairs

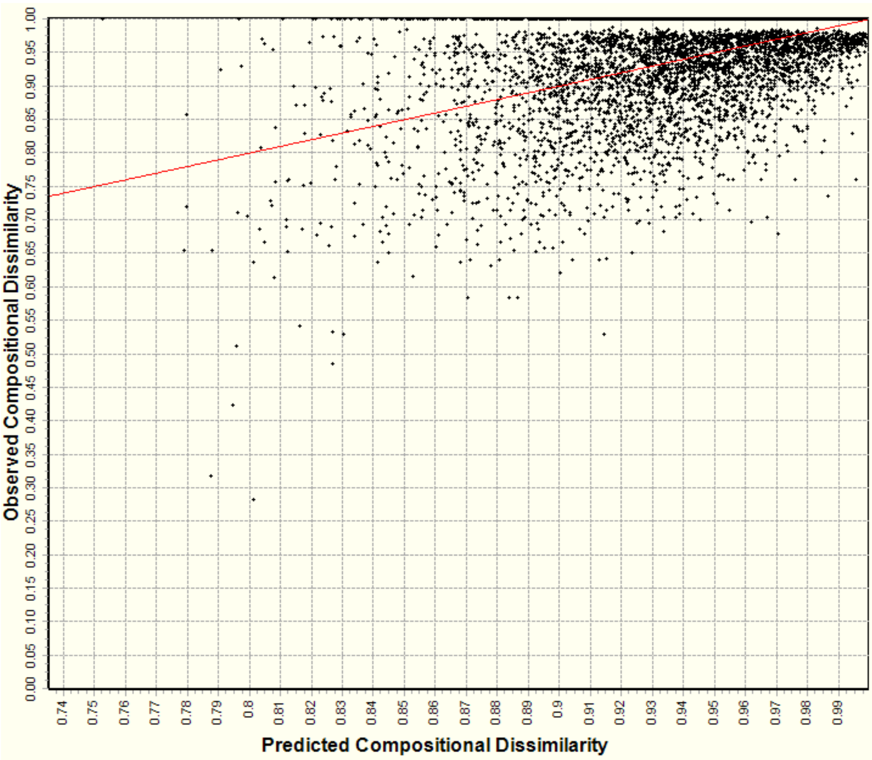


Figure 13: A plot of predicted and observed compositional dissimilarity for a randomly selected set of point pairs

The GDM model can be visualised spatially by classifying the model into classes and using the colouring of each class to display the compositional similarities. To produce Figure 14, 100 classes were automatically generated (not Keith Classes). A Principal Component Analysis was used to derive values for three axes. These values were used to define the level of red, blue and green values attributed to each class.

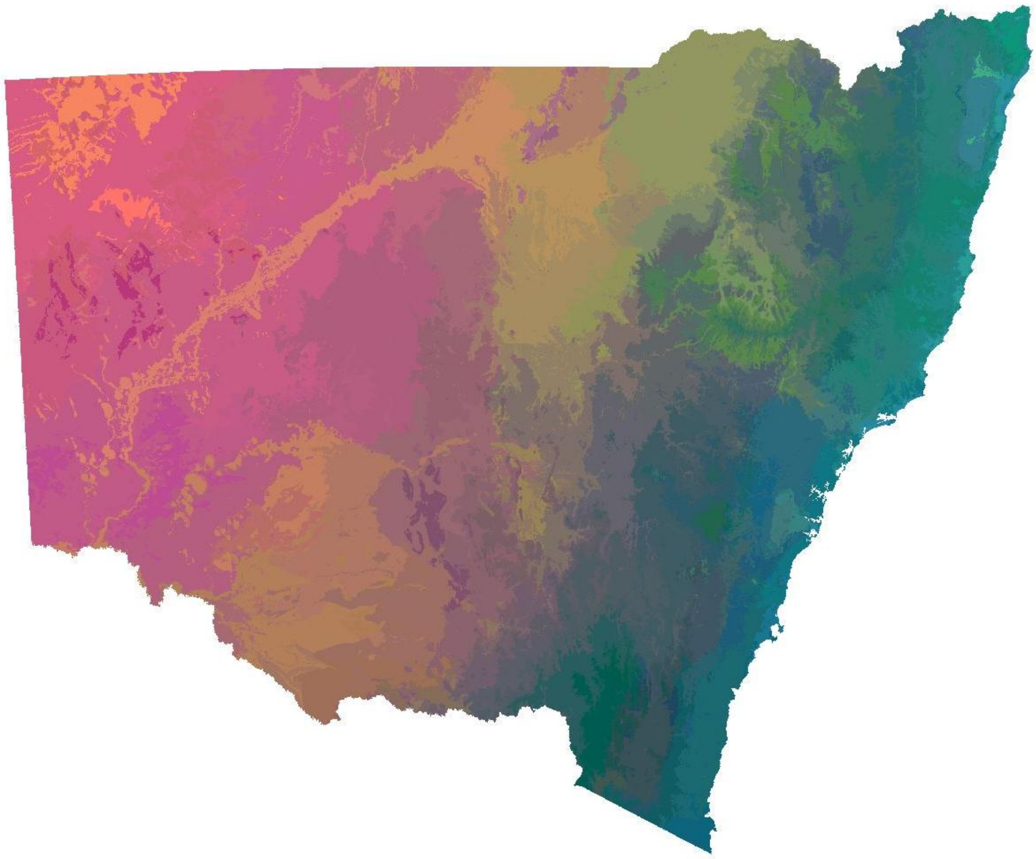


Figure 14: Compositional turnover based on a three-axis ordination of the unconstrained classification of the GDM model

A set of training data of know vegetation class was derived from high certainty points on the map of native vegetation for NSW (Keith 2002). This data was used in conjunction with the GDM model to create a set of unconstrained probability grids for all NSW, each of which contains the probability of each cell belonging to one of the 125 Keith vegetation classes.

The unconstrained grids were processed further to produce a new set of probability grids that were constrained to belong only to those classes described in the attribute table attached to the David Keith Polygon Coverage. The remaining probabilities were then rescaled so that the sum of probabilities through any cell was always 1.0. The constrained version of Figure 14 is shown in Figure 15.

Deriving the distance matrix

The probabilities in the constrained grids were used to weight a collection of approximately 48 x 10^6 site pair records derived from the Keith class training data sites (used to generate the unconstrained grids). These site-pair records were used with the GDM model to predict the compositional similarities between classes.

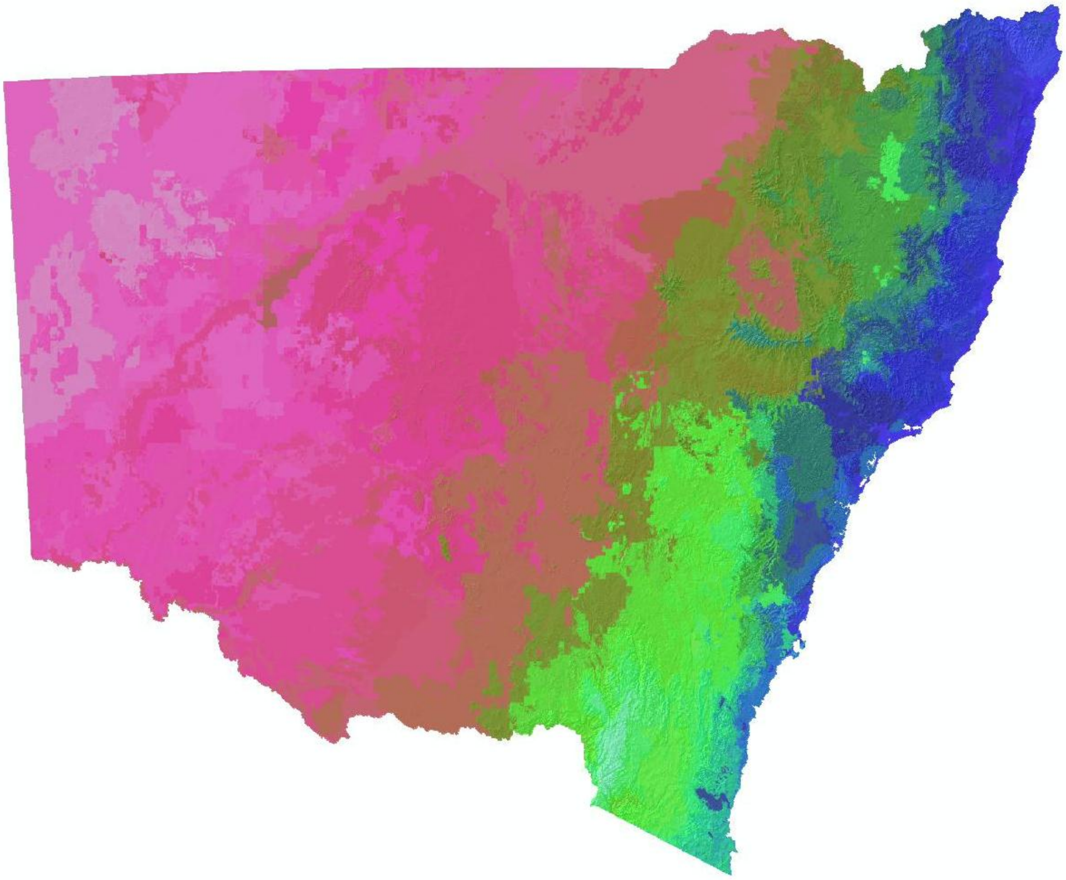


Figure 15: Compositional turnover based on a three-axis ordination of the constrained classification of the GDM model

Appendix 3: Process to generate a statewide vegetation condition model

High precision spatial data on vegetation condition is typically not available at regional scales and greater. However, vegetation condition mapping is an essential spatial input to the Biodiversity Forecasting Tool (BFT) and strongly influences the mapping of conservation benefit.

While an exhaustive process of vegetation condition modelling was not possible, it was considered that some refinement of the 'State of the Catchments' vegetation condition layer (Dillon et al. 2009) could be achieved by integrating recent work undertaken to support the Landscape Value analysis. This was done by incorporating the latest available remote sensing products and through the process of expert knowledge elicitation described below.

The resultant layer was intended as an interim product, providing the best available product for current decision-making. The resolution of the data is 250 m x 250 m (6.25 ha) gridcells and is suitable for viewing at scale of 1:100 000 or greater. The data should not be used to map information beyond this limit or to produce or display information at finer resolutions. The value attributed to each gridcell is an estimate of the average vegetation condition within the cell, where any cell could contain considerably diverse values when viewed in more detail.

Methodology

A probabilistic approach was used for predicting vegetation condition based on the best available set of statewide surrogates, data covering parts of NSW and where necessary, through expert knowledge input.

Based on expert knowledge provided by OEH and CMA staff, each spatial input was assigned probability weights and condition scores. The actual values were based wherever possible on expert OEH and CMA staff input. Responses from experts were initially sought in relation to the selection of inputs and then to the weight attached to each.

In each case the weights given to inputs were a combination of the intrinsic strength of the relationship between each input and condition, and the confidence held in the accuracy of the layers, in the same way that data is used with Bayesian Belief Networks. The strength of the approach adopted, in the context of scarce and incomplete data, is that all relevant data (evidence) can be used to influence the output to some degree, the level of influence being tempered by expert understandings of correlations and data reliability.

The set of predictor variables and a modelling framework were initially developed by the modelling team. This set was iteratively refined in response to input from a wider stakeholder group during two workshops (involving staff from OEH and CMA with expert knowledge in semi-arid and arid environments). These were augmented with follow-up conversations via phone and email.

At a later stage the inputs were further reviewed in the light of their influence on the output condition map and on the priority maps for NSW. The latter reviews were considered tests, rather than a way to apply significant modification to the model. The intention was to ensure that low-level decisions (on inputs) that seemed reasonable when viewed in isolation, did not combine to produce unintended consequences at the higher level (outputs).

The issues raised at the workshops and out of session were incorporated as far as practicable within the constraints of the project. However, it is recognised that much work remains to be done in the area of condition mapping at the state scale to ensure ongoing improvement in the provision of statewide biodiversity assessment capacity. Further work is especially required in relation to the Western Division, to quantify the spatial impacts of grazing.

Detailed information about the predictor variables is provided in Table 5.

Components

Three components of resource condition were modelled separately. They are: woody vegetation condition; non-woody vegetation condition; and soil resilience. The three components were then combined into a single resource condition layer. The contribution of the woody and non-woody components was first combined into a vegetation condition score based on the 'woodiness' layer produced as part of this project, i.e. the woody component contributed nothing to areas predicted to be grasslands; woody and non-woody components contributed to woodlands; and forests were predominantly driven by the woody component. The overall score was made up 2/3 by the vegetation components and 1/3 by the soil resilience.

Results

The predictor variables, the component outputs, and the combined vegetation condition model used to derive the manage, improve and revegetation benefits layers are presented below (Figure 16).

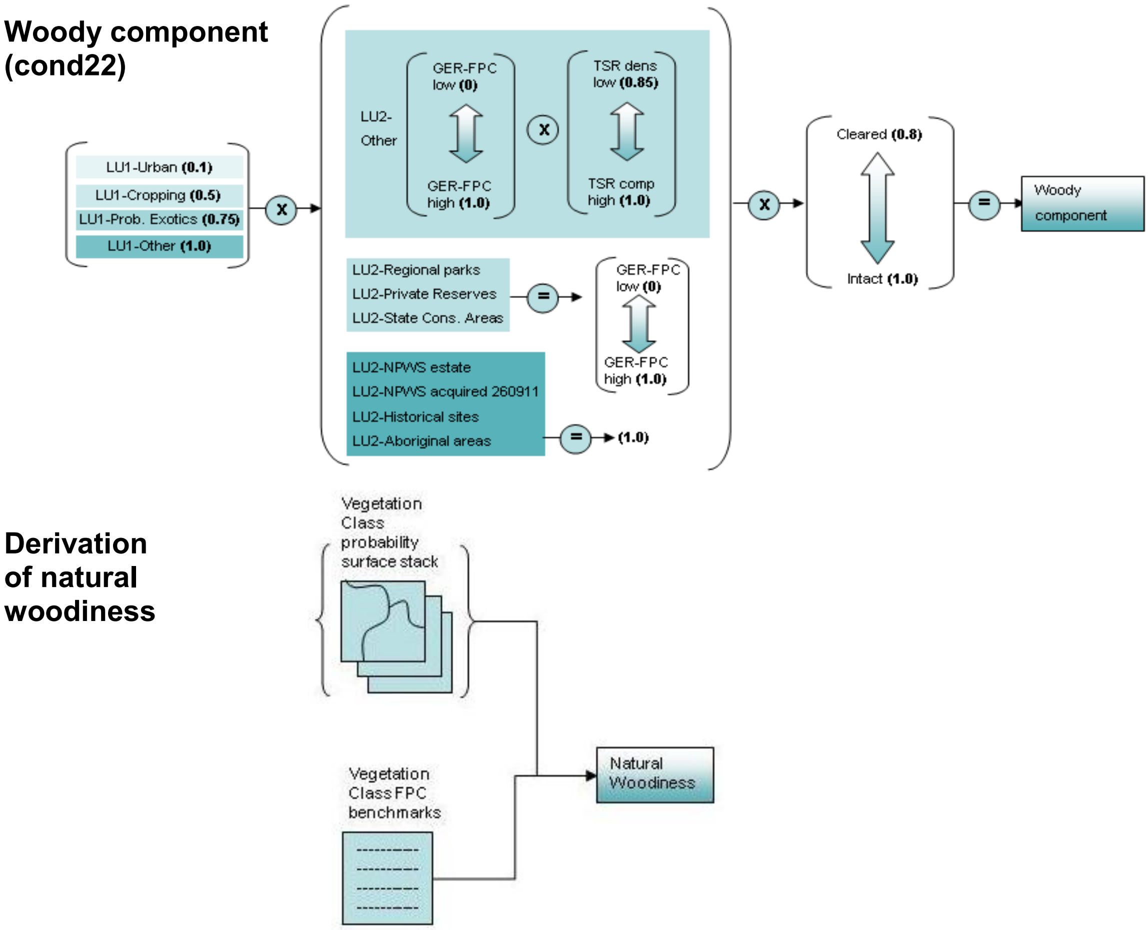
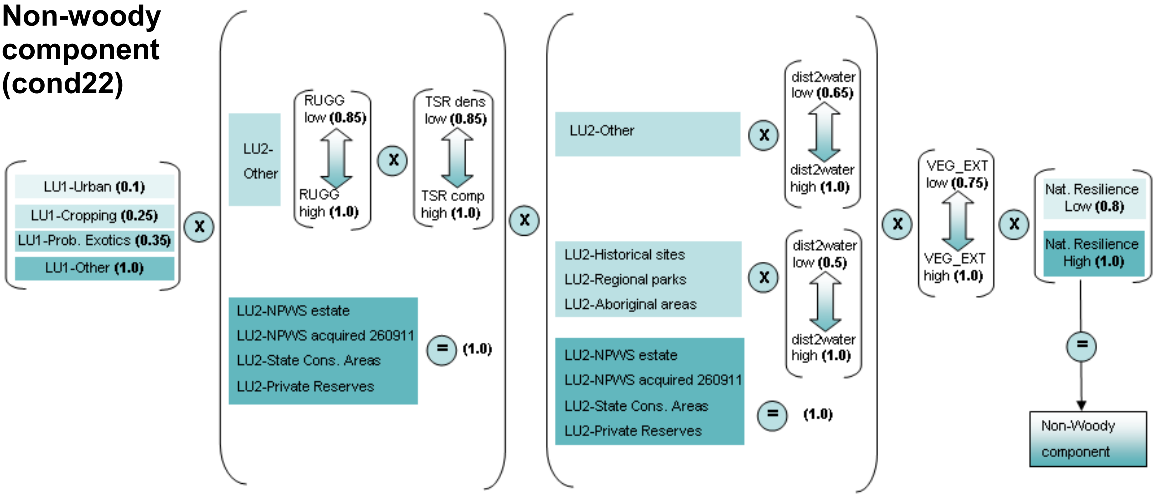
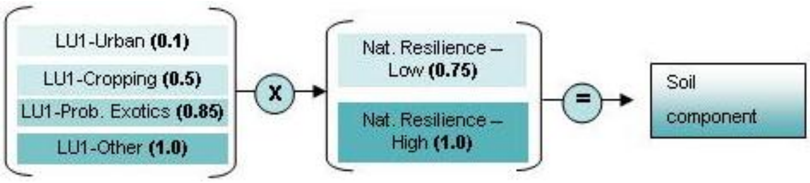


Figure 16a: Models derived for mapping vegetation condition

Non-woody component (cond22)



Soil resilience component (cond22)



Combining the three components

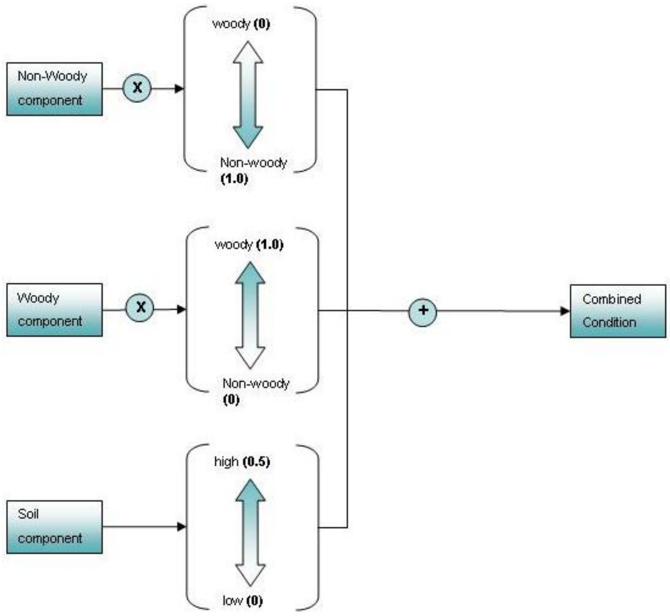


Figure 16b: Models derived for mapping vegetation condition, continued

For each component a set of spatial predictors were attributed with weights (shown in brackets) and multiplied. For discrete predictors (e.g. LU1) each class is weighted separately. For continuous predictors (e.g. RUGG), indicated by block arrows, weight ranges are stretched across the range of variable values. See Table 5 for variable descriptions.

Table 5: Predictor variables used for modelling vegetation condition

Name	Description	Filename	Models / tools	Source	Metadata	References
Ruggedness (RUGG)	ruggedness – variability (using STD) of altitude within a 1250 m radius circle	rugg5c	Used approach from Drielsma 1998 in an Arcview Neighbourhood Statistics calculation: radius = 5cells; window, a circle	DEM_250_NSW		Drielsma 2000
Weighted distance to water (dist2water)	The distance to water – weighted sum of each stream order	d_water2	2 arcview scripts: ‘distance to water A’ and ‘distance to water B’ in ‘west_cond.apr’. A Euclidean distance grid for each stream order is calculated in A; in B each grid from A is transformed with (stream_order ^ 1.5) / A grid and summed	river_250topo_ordered	Downloaded from OEH corporate data 200911	
Great Eastern Ranges adjusted foliage projective cover (GER-FPC)	A woody-centric view of vegetation condition for NSW with tenure effects removed	ger_cond3			A report produced for the Great Eastern Ranges condition modelling project. For derivation of FPC the influence of tenure was removed	Drielsma et al. 2010; Department of Natural Resources and Water 2007; DECCW 2008

Name	Description	Filename	Models / tools	Source	Metadata	References
Natural woodiness	An index from 0–100 of the original proportion of woody vegetation	woodiness2	arcview script: ‘woodiness’ within the .apr ‘west_cond.apr’	NSW vegetation class probability stack; Biometric FPC bench-marks		
NSW mask	1 – for study area; otherwise no data	NSW250	Derived using Arcview map calculator	OEH corporate data (accessed, June 2011)		
Nativeness (LU1)	Urban areas class added to primary source	nw_comp2	Derived using Arcview map calculator	2008 NSW Native Vegetation Extent ver0.1 MODISfpc classification	Converted from 25 m to 250 m gridcell resolution and aligned to the vegetation and condition grid origin	
Vegetation extent (VEG_EXT)	An indication of the level of clearing	veg_ext		NSW Interim Native Vegetation Extent 2008 version1 – the ‘cond_x’ field of the ‘veg_ext_nsw_1’	Aligned with the NSW250 mask	Dillon et al. 2009

Name	Description	Filename	Models / tools	Source	Metadata	References
Attribution of Western Land Systems and Mitchell Landscapes (Nat. resilience)	Evaluation of the resilience of NSW soils by attributing Western Land Systems for the Western Division of NSW and for the Central Division of NSW, where Western Land Systems are not available, using Mitchell Landscapes	Drob_ml8		Western Land System mapping	The attribution was led by Dave Robson from OEH. For the Western Division, each WLS was classed as high or low 'resilience' (its ability to support revegetation following disturbance). For the Eastern Division, Mitchell Landscapes that included reference to cracking grey clays, Quaternary alluvium, or similar. Otherwise, terrain descriptions including watercourses, channels, floodplains, meander plains – these are the active fluvial elements and are composed of grey clays; otherwise landscapes are classed as low. Following this method landscapes coded. Baf, Bap, Bop, Clc, Byc, Gyp, Nac, Tef, Tep were classed as high. The Eastern Division was classed as high.	Walker 1991
TSR density (TSR dens)	A layer indicating the area of TSR in each 250 m cell, i.e. because many TSRs are very narrow a simple gridcell conversion of source data would miss these	TSR250a	The source data was converted to a 50 m resolution grid, then aggregated (arcview grid request) to a 250 m grid using the 'sum' option	TSR polygons provided by A. Zelnik OEH project	Zelnik, A 2009, TSR conservation value – metadata	Landcare NSW 2010

Name	Description	Filename	Models / tools	Source	Metadata	References
NP estate (LU2)	All current NP, NR and recent acquisitions not gazetted; historic sites, regional parks and Aboriginal areas	np_estate4		Sourced from the OEH corporate database 260911; some private reserves from the Southern Mallee added		Else Foster OEH and Lower Murray–Darling CMA project pers. comm. 2007
Vegetation class raster probability surfaces (vegetation class probability surface stack)	A probability surface of the likelihood of finding each vegetation class (Keith 2004) across NSW		GDM model based on YETI vegetation sites (Logan et al. 2009) and GDM utilities using high probability sample points from Keith map as training data	OEH YETI database, Veg. class map (Keith 2002)		Keith 2004; Logan et al. 2009; Keith 2002

Appendix 4: Additional technical information on deriving ‘consolidate’ benefits

Vegetation structural class (VSC) surfaces were initially derived through applying transformation functions to raw foliage projective cover (FPC) values (see Figure 18). The transformation function for deriving the VSC values P(x) is as follows:

$$P(x) = \frac{1}{\delta\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\delta^2}\right) \cdot \left(1 + \varepsilon \Big/ \frac{1}{\delta\sqrt{2\pi}}\right)$$

if P(x) > 1, then P(x) = 1, where x is the FPC value.

The parameters for the three VSCs are as follows:

VSC	μ	δ	ε
Woodland	120	15	0.2
Open forest	160	15	0.2
Closed forest	200	15	0.2

These functions represent the range of FPC values expected to occur within each of the VSCs. For each location the transformed values indicate to what degree it contributes to each of the VSCs. The transformations use continuous functions with overlap between individual classes so that each location may function as more than one VSC.

Derivation of the condition score modifier

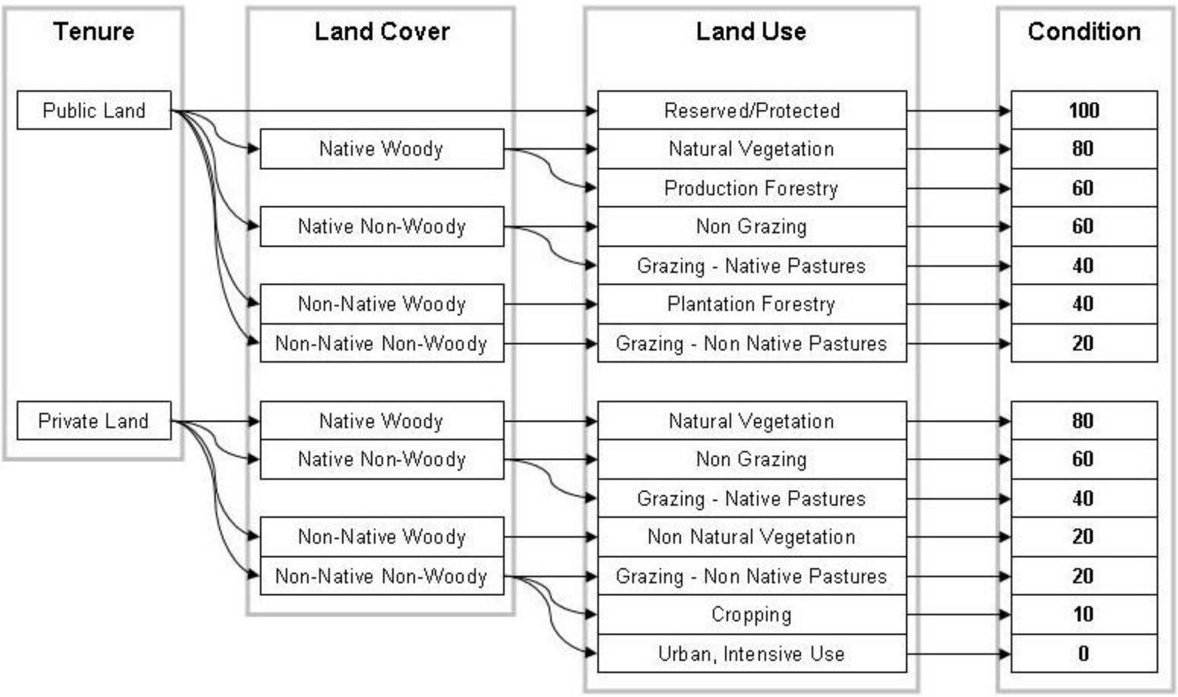


Figure 17: Derivation of refined condition scores based on condition modifiers

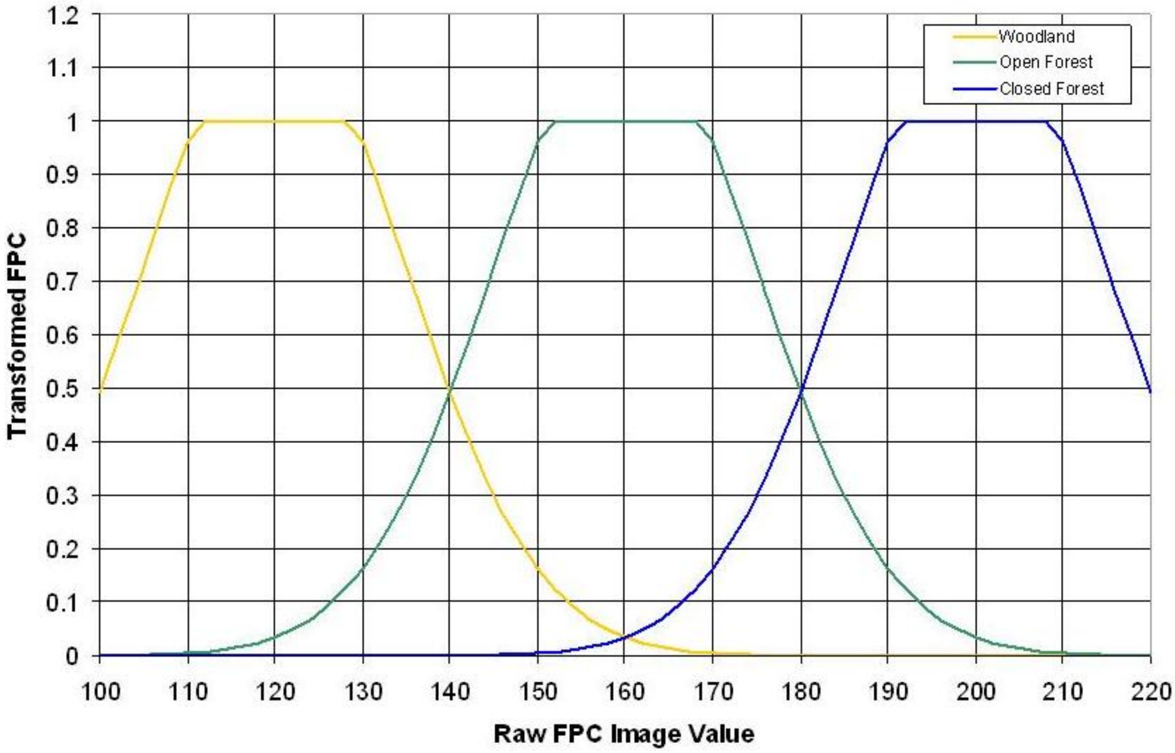


Figure 18: Transformation functions for three vegetation structural classes (VSCs)

To minimise artifacts in the Landscape Value models due to arbitrary selection of grid alignment, analysis at each resolution was distributed across a range of grid origins when re-sampling the baseline data to a coarser resolution (see Table 1 in main text). The distribution of origins is presented below.

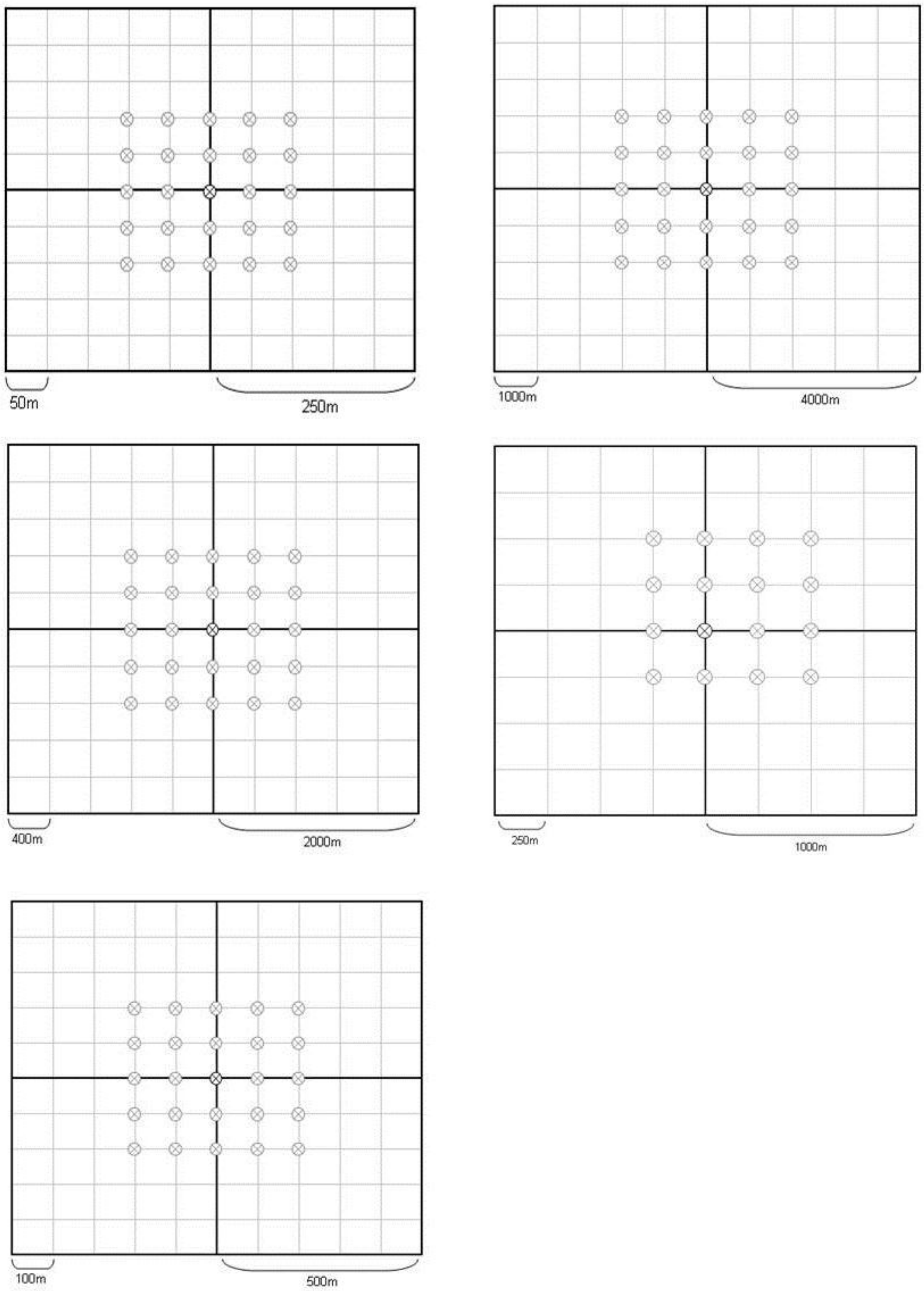


Figure 19: Representation of the system of grid origin off-sets applied at each resolution for which the spatial links tool was applied

From top to bottom, left to right: 250 m, 500 m, 1000 m, 2000 m, and 4000 m, see Table 1. In each case the original 100 m grid (represented by the faint lines) was re-sampled to the coarser resolution with each of the alternative origins, represented by the crossed circles. The bold lines represent one of the re-sampled grids, where the bold origin is adopted. The size of the individual offsets is shown at the bottom-left, and the re-sampled resolution at the bottom-right of each. Additional information on the Landscape Value mapping project is available upon request from OEH (Drielsma et al. unpub.).

Appendix 5: Data input and configuration options for the Biodiversity Forecasting Tool methodology

The Biodiversity Forecasting Tool

The Terrestrial Biodiversity Forecasting Tool (BFT) (DEC 2004, 2006) is an example of systematic conservation assessment designed to address the conservation objective of 'maximising the long-term persistence of compositional diversity at a collective level' (Margules & Sarkar 2007, Ferrier & Drielsma 2010). It was designed to perform two functions that correspond with two broad levels of systematic conservation assessment:

1. assess the conservation effectiveness of any specified configuration of land use and management, i.e. iteratively design and test scenarios (Drielsma & Ferrier 2006, Ferrier & Drielsma 2010) arising from a proposed single action or suite of management actions (or alternatively, to report on the cumulative impacts of a range of past management actions)
2. explore alternative management configurations through optimisation, benefits analysis or through interactive scenario analysis (Ferrier et al. 2009).

The BFT uses a model that incorporates many concepts widely recognised as fundamental to contemporary conservation planning (Ferrier 2005, Ferrier et al. 2009), such as:

1. the effect of multiple land-use and management regimes on habitat retention
2. complementarity (i.e. each location complements overall conservation by representing different features or assets)
3. spatial configuration (i.e. connectivity or, inversely, fragmentation), and
4. population viability.

The BFT was developed to address the mounting complexities being encountered within biodiversity assessment as it attempted to include landscape heterogeneity, landscape processes, vegetation dynamics, multiple land uses and conservation mechanisms, large numbers of biological entities, and uncertainty.

Earlier manifestations of systematic conservation assessment (Pressey et al. 2009) were developed around the less complex aim of maximising the representation of biodiversity in reserves (Ferrier & Drielsma 2010). Hence a binary view of the world was initially adopted, where each location was considered as either being in (reserved) or out; also each part of the landscape was considered either part of a habitat 'patch' or part of the agricultural matrix, where the latter was not recognised as providing any benefits for biodiversity conservation.

The prevailing, target-based approach attempted with ever diminishing effectiveness, to treat the various dimensions of complexity as unrelated, additive issues to be addressed separately, e.g. through increasing the range and number of conservation targets (Ferrier & Drielsma 2010). Development of the BFT followed an alternative paradigm that sought to recognise the entire landscape as an integral whole and to integrate habitat condition, extent and connectivity into a process-based, complementarity-based modelling framework (Ferrier & Drielsma 2010).

Within the BFT, each location, regardless of land tenure or land-use history, can contribute biodiversity benefits in various and individualistic ways. The level of contribution in each case depends on:

1. the habitat features present (based on its floristic composition and vegetation structure) at the site level, and
2. the contribution of that location to functional connectivity within the landscape (Noss 1990).

The state of habitat at the site level and the level of functional connectivity is however very much influenced by past and present management, disturbances such as vegetation clearing and soil erosion, and by pest and weed invasions.

Table 6: Summary of variables chosen for the BFT analysis

Variable	Description	Benefits modelling
Spatial precision	Size of gridcell analysis units	250 m x 250 m (6.25 ha) gridcells
Taxonomic precision of the vegetation surrogate	The number of classes used to describe compositional diversity	125 Keith classes (Keith 2004)
Vegetation communities as categories or as continuous probability surfaces	Form of vegetation community spatial data, i.e. a single 'flat' map with categories or a 'stack' of probability surfaces, one for each class	Continuous probability surfaces
Vegetation condition as classes or as a continuous surface	Form of vegetation condition spatial data, i.e. a set of classes such as high, medium, low; or continuous values	Integer values between 0 and 100
Threats or risks to biodiversity included as a consideration	The expected outcomes for biodiversity can be influenced by threatening processes and management actions that modify them	No threats explicitly incorporated
Spatial scale for connectivity calculations	The fragmentation of each cell is measured as the colonisation potential. Distance is calculated as effective distance, where high condition vegetation provides more permeability to species movement	The radius of influence around each location was defined by mobility parameters ($1/\alpha$) ranging between 2000 and 5000 m
Consideration of compositional overlap between communities	The conservation status of each class is buffered by the status of classes with similar species composition	Included

Table 7: Data inputs used in the BFT

Data input	Description	Source	Usage	Influence
Current vegetation condition	A grid of 6.25 ha cells representing the relative potential to support the original biodiversity of the location	Derived as part of the NVM benefits analyses using best available spatial data and expert elicitation process (see Appendix 3)	Key input for describing the current state of native vegetation	Major determinant of the conservation status of each vegetation class and the status of individual locations
Vegetation class probability surfaces	A stack of 6.25 ha probability grids where each cell value represents the likelihood of finding the vegetation class at that location	Derived as part of the project using classification of generalised dissimilarity model (see Appendix 2)	Defines the compositional diversity of the state. Replaces earlier use of Mitchell Landscapes which were large units without biological basis	Major determinant of benefit estimate for each location
1/α mobility parameters (Hanski 1999)	For the purposes of this analysis, 1/α ranges from 2000 m, for cleared cells, to 5000 m for maximum condition cells	Following on from other applications of the BFT, the range of 1/α values was selected to correspond to the landscape-scale analysis. It incorporates day-to-day movements and dispersal for many listed fauna (Fuller et al. 2011) and species that are sensitive to habitat connectivity at this scale. This scale does not fully account for large-scale movements (e.g. owls, raptors and migrating birds), which are better considered by the Landscape Value methodology (Section 4)	Defines the permeability of various habitat conditions	Large values of 1/α increase the radius of influence of neighbourhood locations on the connectivity score of any cell. The y parameter (see Technical Note 1) modulates the overall influence of spatial configuration

Table 7 continues overleaf

Table 7, continued

Data input	Description	Source	Usage	Influence
z species-area parameter	The aberration of the species-area relationship from a linear relationship	A value of 0.27 was derived from statistical analysis of compositional turnover (Ferrier 2002, Ferrier et al. 2002) using a technique described by Harte et al.(1999). This value matches closely values for z used in similar studies around the world	Exponent value within biodiversity index (see Technical Note 2)	Smaller values of z will lead to a slower loss of species in relation to habitat loss when proportion of habitat remaining is high and a more rapid loss when proportion remaining is low
25 year regeneration future vegetation condition	A grid of 6.25 ha cells representing the potential vegetation condition after 25 years of regeneration starting with the current condition	Modelled 25 year condition improvement using transition function (Drielsma & Ferrier 2006)	Used to calculate ‘improve’ benefits by providing an estimate of potential condition improvement for each location	Locations with moderate current condition possess the highest potential for improvement over the timeframe
Vegetation class similarity table	A class by class matrix of compositional similarities	Derived from GDM model (see Appendix 2)	Modulates compositional diversity calculations	The conservation status of each class is buffered by the status of classes with similar species composition

Appendix 6: Calculating the fragmentation level of ecosystem types

Biodiversity viability

The viability of populations, especially fauna, relies on the amount and spatial configuration of habitat. In general terms, the proportion of original species that are expected to persist will increase as a function of the area of habitat remaining. Also, a higher level of viability is expected when the habitat is arranged across the landscape in ways that provide organisms access (connectivity) to adequate resources and provide dispersal opportunities to ensure survival of populations.

In many cases habitat is naturally fragmented, i.e. small patches of a species' preferred habitat are interspersed with other habitat types. Natural fragmentation is ignored in this analysis. In other cases, the original connectivity between locations has been disrupted through the clearing and alteration of native vegetation, leading to reduced viability of populations from the natural state. For example, a site within a naturally small patch (e.g. 2 ha) of rainforest surrounded by a large patch (e.g. 600 ha) of wet sclerophyll forest is considered in this analysis to be contiguous with native vegetation and will therefore fall into the least fragmented class (i.e. the ≥500 ha class in Table 8). If the wet sclerophyll forest has been cleared but the rainforest remains, the same location will be considered fragmented (assigned to the <5 ha class).

An analysis was undertaken of non-natural fragmentation of each ecosystem in NSW as a coarse-scale measure of the viability of the biodiversity contained within or reliant on those habitats.

Methods

A raster-based neighbourhood habitat area assessment of each location (500 m x 500 m gridcells) in the state was undertaken. This assessment does not recognise actual habitat patches but rather the landscape is treated as a continuum. Each location is examined in terms of its connectivity to its surrounding neighbourhood and allocated to a 'virtual' patch-size class. These are aggregated for each ecosystem.

The cut-off values for discriminating between the patch-size classes were calculated by undertaking the assessment of a location at the centre of three 'ideal' patches of 25 ha, 100 ha and 500 ha (the 5 ha cut-off was a special case, see below). The neighbourhood habitat area assessment analytical steps are as follows.

The probability of each vegetation class (Keith 2004) was modelled using a generalised dissimilarity model (Ferrier et al. 2007) of NSW. The GDM was derived using a range of environmental and climatic surfaces, and floristic plot sites from OEH's YETI database (Logan et al. 2009). The classes were aggregated into probabilities of occurrence for each Keith vegetation ecosystem.

The vegetation condition map (described in Appendix 4) was used to calculate the connectivity of each location to its neighbourhood at four spatial scales corresponding to the 25 ha, 100 ha, and 500 ha cut-offs[1]. The <5 ha class was a special case due to the relatively large size of the gridcells (25 ha). If a cell did not qualify for any larger patch class it was assigned to the <5 ha size if there was effectively <5 ha of native vegetation within the cell.

---

[1] The cost–benefit spatial context tool (Drielsma et al. 2007a) was used for the analysis. The technique calculates the Neighbourhood Habitat Area *N* (Hanski 1999) of each focal cell *j* as $N_j = A_i e^{-\alpha d_{ij}}$, where *Ai* is the vegetation condition of neighbourhood cell *i*, *1/α* is a distance decay parameter and d_{ij} is an effective distance between the focal and neighbourhood cell. The required cut-off areas (calibrated against ideal patches of 25, 100 and 500 ha) could be drawn from larger areas, subject to the exponential decay kernel (*1/α* values depending on vegetation condition were 84–126 m, 188–282 m, 376–564 m and 841–1261 m respectively).

The highest patch-size class was recorded for each location, i.e. a map of patch-size class for each gridcell was produced. This map was intersected with each vegetation ecosystem surface and the patch-size composition calculated[2].

Ecosystem patch-size classes

This analysis summarises the fragmentation pattern for each ecosystem in NSW, subject to the limitations of the data and the spatial resolution of the analysis (Table 8).

This analysis was undertaken using raster data at a resolution of 25 ha. In this analysis, each cell is treated as homogeneous within its borders. On closer examination a landscape can be highly heterogeneous, having areas of varying condition including some patchiness not apparent at the coarser resolution. As with all spatial assessments of this sort, analysis at alternative resolutions will produce different results. The resolution used here, however, is considered appropriate for a region the size of NSW.

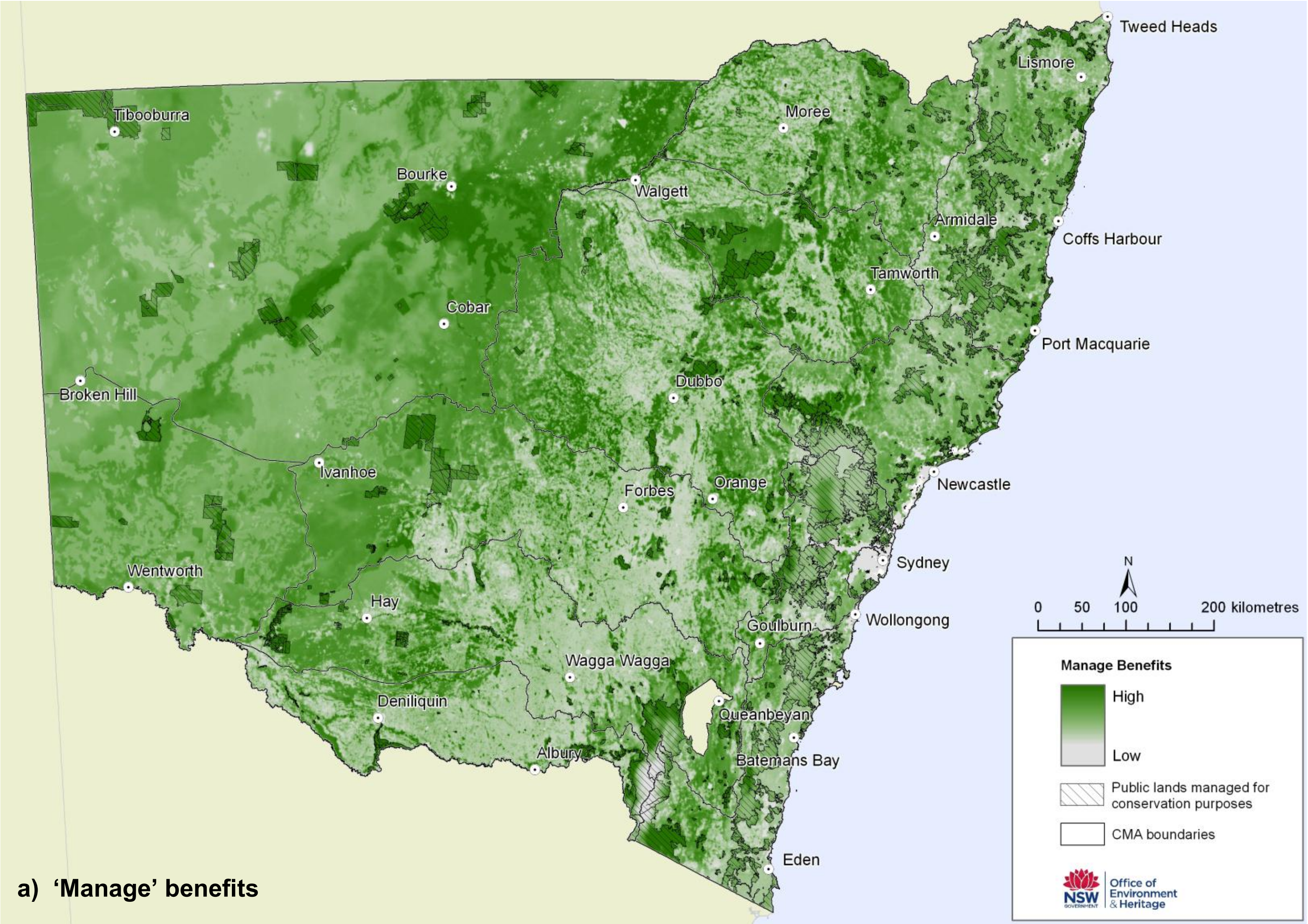
The results are not a measure of clearing rates for the ecosystems. A ecosystem can be relatively uncleared and yet still be fragmented if it generally occurs in small patches set within a largely cleared matrix (of other ecosystems).

Table 8: Percentage of remaining ecosystem in each patch-size class

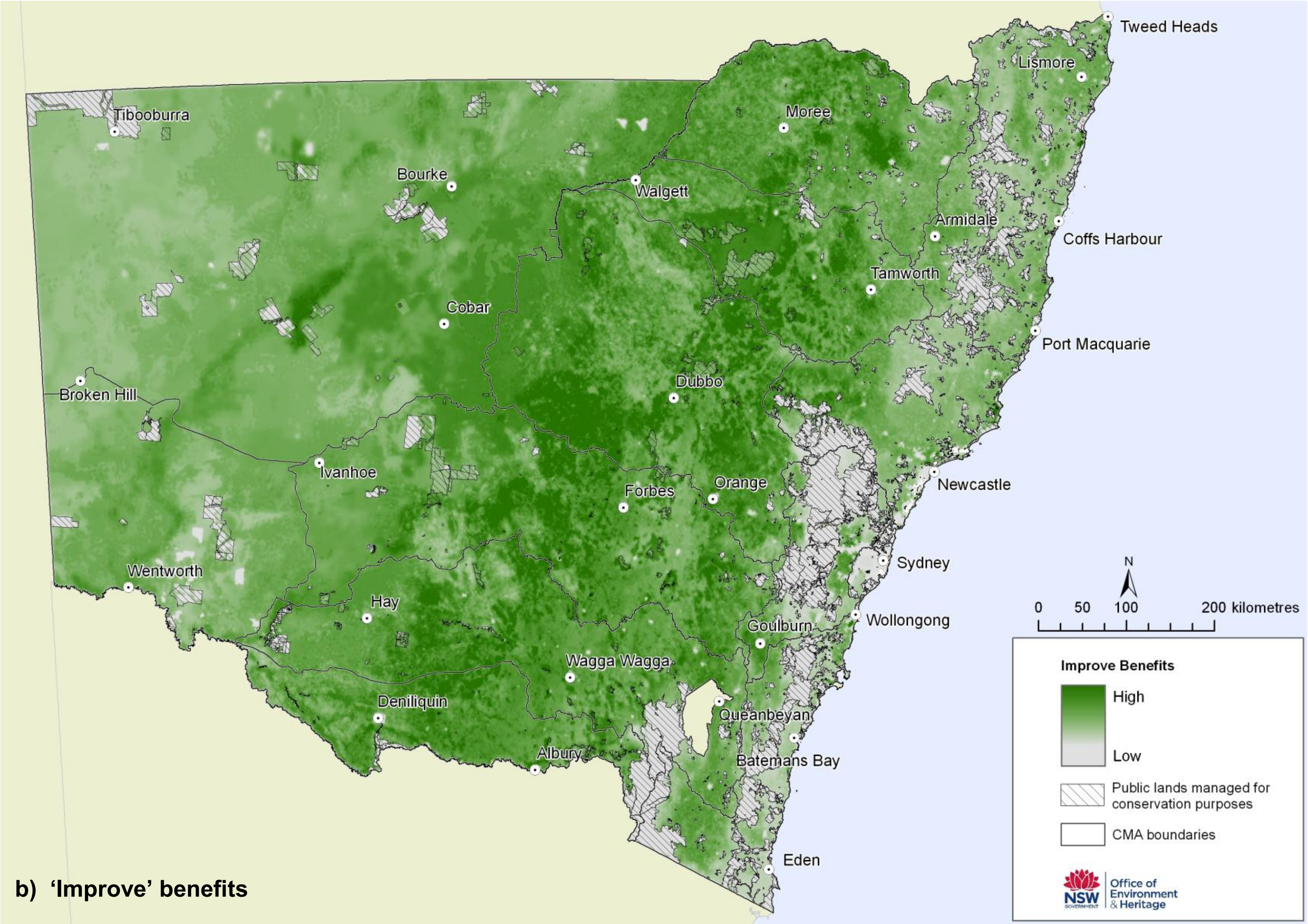
Ecosystem	Patch size class (ha)				
	<5 ha	5–<25 ha	25–<100 ha	100–<500 ha	>=500 ha
Semi-arid woodlands (Grassy subformation)	19	32	9	7	32
Forested wetlands	36	12	10	7	35
Alpine complex	4	1	1	1	93
Heathlands	22	6	6	5	60
Dry sclerophyll forests (Shrub/grass subformation)	40	10	9	5	36
Grasslands	31	18	9	6	36
Grassy woodlands	60	11	10	5	15
Wet sclerophyll forests (Grassy subformation)	21	7	5	4	62
Rainforests	19	7	6	4	65

[2] The formula used for aggregating the formation by patch-size class was: $B_f^c = s\sum p(f)_j$, where *B* is the area within the *c* patch-size class, *s* is the cell size and *p(f)j* is the probability of formation *f* occurring at cell *j*, i.e. the total area for each formation and patch-size class combination was calculated. These are presented as percentages of the total area for each ecosystem in Table 8.

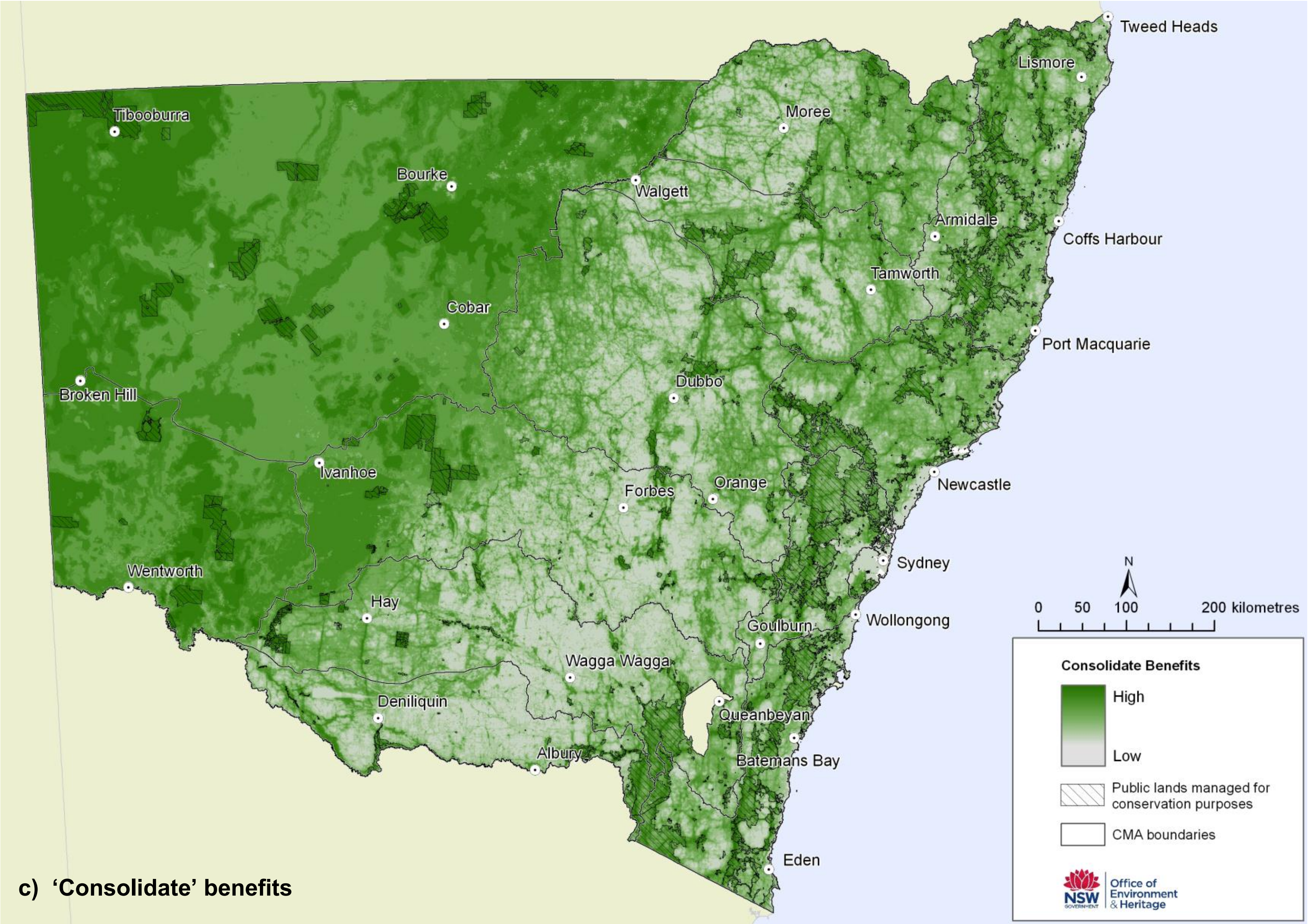
Appendix 7: Native vegetation management benefits layers



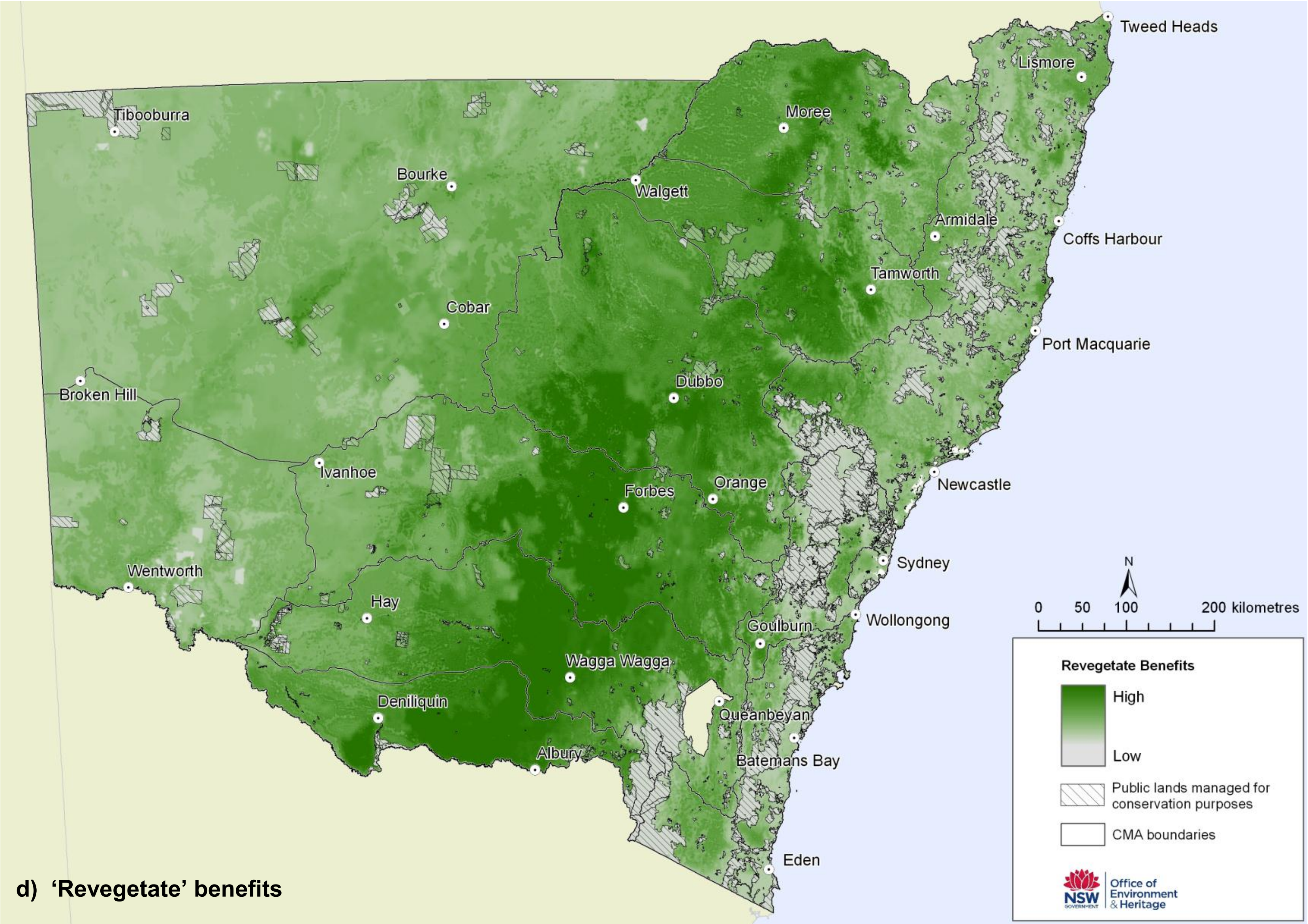
a) 'Manage' benefits



b) 'Improve' benefits



c) 'Consolidate' benefits



d) 'Revegetate' benefits