available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecolind

An operational method to assess impacts of land clearing on terrestrial biodiversity

P. Gibbons [a,*], S.V. Briggs [b], D. Ayers [b], J. Seddon [b], S. Doyle [b], P. Cosier [c], C. McElhinny [a], V. Pelly [d], K. Roberts [e,1]

[a] The Fenner School of Environment and Society, The Australian National University, Canberra, ACT 0200, Australia
[b] Department of Environment and Climate Change NSW, GPO Box 284, Canberra, ACT 2601, Australia
[c] Wentworth Group of Concerned Scientists, Level 13 Macquarie House, 167 Macquarie Street, Sydney, NSW 2000, Australia
[d] Department of Environment and Climate Change NSW, Federation House, 24 Moonee Street, Coffs Harbour, NSW 2450, Australia
[e] Department of Environment and Climate Change NSW, PO Box A290, Sydney South NSW 1232, Australia

ARTICLE INFO

Article history:
Received 16 April 2007
Received in revised form
15 January 2008
Accepted 21 January 2008

Keywords:
Land clearing
Regulation
Offsets
Compensatory habitat
No net loss
Metrics

ABSTRACT

We developed a methodology to objectively and transparently assess the impacts on terrestrial biodiversity of proposals to clear native vegetation in New South Wales (NSW), Australia. The methodology was developed to underpin a policy to permit land clearing only where it 'improves or maintains environmental outcomes'. It was developed in the following steps: (1) operational requirements and resource constraints were defined. (2) Biodiversity surrogates and assessment techniques that matched these requirements and constraints were identified. (3) Sites were assessed locally, but also in the broader landscape, regional and national contexts. (4) Explicit rules and metrics were developed to facilitate transparent and consistent assessments. (5) These rules, metrics and the data that underpinned them were codified into a simple computer software tool. The tool did not permit clearing in vegetation communities or landscapes that were already over-cleared or listed as threatened, unless the vegetation was in 'low condition' (unlikely to persist in the long-term). Other native vegetation could be cleared if regional, landscape and site impacts could be offset. In the first year after the assessment methodology was implemented a net area of approximately 187 ha of native vegetation was approved for clearing with offsets. Most approvals (68%) were for proposals to clear native vegetation with a low likelihood of persistence under the existing land use (predominantly scattered trees among cultivation) and offset these impacts by improving the condition and likelihood of persistence of native vegetation in comparable ecosystems. Remaining approvals were for clearing relatively small areas (mean = 0.6 ha) of partially modified native vegetation. Proposals to offset the impacts of clearing substantially intact native vegetation or larger areas of partially modified native vegetation were generally assessed as unlikely to 'improve or maintain environmental outcomes'.

* *Corresponding author at*: The Fenner School of Environment and Society, The Australian National University, Canberra, ACT 2601, Australia. Tel.: +61 2 6125 2562; fax: +61 2 6125 0757.
E-mail addresses: pgibbons@cres.anu.edu.au (P. Gibbons), Sue.Briggs@csiro.au (S.V. Briggs), Danielle.Ayers@csiro.au (D. Ayers), Julian.Seddon@csiro.au (J. Seddon), Stuart.Doyle@csiro.au (S. Doyle), pcosier@wentworthgroup.org (P. Cosier), chris.mcelhinny@anu.edu.au (C. McElhinny), Vanessa.Pelly@environment.nsw.gov.au (V. Pelly), kevin_roberts@rta.nsw.gov.au (K. Roberts).
[1] Present address: Roads and Traffic Authority NSW, P.O. Box K198, Haymarket, NSW 1240, Australia.
1470-160X/$ – see front matter
doi:10.1016/j.ecolind.2008.01.006

1. Introduction

There remains considerable demand to clear or modify native vegetation for agricultural development. The Food and Agriculture Organization of the United Nations (FAO, 2005) estimated that 13 million ha of forest were cleared per year, mainly for conversion to agriculture, and listed 28 countries in which the net loss of forest exceeded 100,000 ha per annum between 2000 and 2005. Even in countries where the net loss of forest cover is lower, there is still substantial conversion of native vegetation to other land cover types. For example, in the United States of America (USA), natural pine forests were cleared or converted to planted forests at an average rate of 246,000 ha per annum between 1989 and 1999 (Wear and Greis, 2002) and woody vegetation in Australia was converted to another vegetation type or land use at an average rate of around 470,000 ha of per annum between 1988 and 2001 (The Australian Greenhouse Office, 2005).

Excessive clearing of native vegetation poses a threat to biodiversity and its attendant ecosystem services (Millennium Ecosystem Assessment, 2005). The impacts of excessive land clearing include: (1) reduced abundance, localized extinctions and declining viability of native biota populations (Cogger et al., 2003); (2) disruptions in ecological processes (e.g. soil formation, soil stability, water quality, insect control, carbon sequestration) that help sustain agricultural production and human health (Millennium Ecosystem Assessment, 2005); and (3) a reduction in the resilience of ecosystems to change (e.g. climate change) (Walker and Salt, 2006). Excessive land clearing is a significant factor in the demise of numerous societies (Diamond, 2005).

Regulation is an important element of governance for controlling land clearing (Kishor, 2004). Morton et al. (2002) identified effective regulation of land clearing as one of the most cost-effective means of biodiversity conservation. However, few operational tools (as distinct from indicators and metrics) for assessing impacts on biodiversity of clearing native vegetation have been published. Examples of methods that are employed as part of operational procedures to assess impacts of land clearing on biodiversity are: Habitat Evaluation Procedures (US Fish and Wildlife Service, 1980) in which impacts are predicted using habitat models (Habitat Suitability Indices) for indicator species (Roloff and Kernohan, 1999); Indices of Biotic Integrity, which are based on species metrics for indicator species (typically invertebrates) for assessing impacts of development on aquatic ecosystems (Andreasen et al., 2001); Habitat Hectares (Parkes et al., 2003) in which change in habitat value is assessed according to the deviation from reference conditions.

The aim of this research was to produce an objective, transparent and operationally feasible method to assess impacts on terrestrial biodiversity of proposals to clear native vegetation for rural land uses. The methodology was developed to support a policy to allow land clearing only if it 'improved or maintained environmental outcomes'. This assessment methodology is used with other decision-support tools that assess impacts of land clearing on threatened species, soils, water quality, salinity and vegetation known as invasive native scrub. These tools are not discussed here.

While this paper is structured in the traditional Materials and methods, Results, Discussion format, it is important to note that many of the important outcomes of this research are contained in the Materials and methods where the assessment methodology is described. In the Results we present outcomes from field trials and the first 12 months of implementation.

2. Materials and methods

2.1. Study area

The assessment methodology was developed for applications to clear native vegetation in rural and semi rural areas in the State of NSW, an area of 80 million ha in eastern Australia. Approximately 60% of the native vegetation in NSW has been cleared, with the most heavily cleared regions being those that are most productive for irrigation, broad-acre cropping and grazing for sheep and cattle (data from Benson, 1999). Recent land clearing in NSW remains high with annual estimates between 60,000 and 100,000 ha (Department of Environment and Conservation, 2003). In 2005 (the year prior to the adoption of the methodology described here) approximately 74,000 ha of native vegetation were cleared in NSW with 22,389 ha of this formally approved for land uses other than plantation forestry (Auditor-General of New South Wales, 2006). Most of this approved clearing was for conversion of native vegetation managed for stock grazing to cropping for grains such as wheat. In 2003 independent scientists recommended to the NSW Government that broad-scale clearing of remnant vegetation should cease, with minor clearing permitted only under a strict, but workable, net environmental gain mechanism (Wentworth Group of Concerned Scientists, 2003). The State subsequently introduced the Native Vegetation Act 2003 to end broad-scale clearing unless it will 'improve or maintain environmental outcomes'. The assessment methodology described here describes the scientific basis for applying the 'improve or maintain' test in practice for impacts on biodiversity generally.

2.2. Operational requirements and resource constraints

The assessment methodology was developed in light of several operational requirements and resource constraints. These included: legislative requirements, the scale at which assessments were to be undertaken, skill-level of assessors, time allocated to assessments and availability of other resources such as existing data (Table 1).

2.3. Guiding ecological principles

We defined guiding ecological principles from the outset to provide a structured pathway for considering options for assessment and stakeholder input. We developed each rule in the tool with respect to these ecological principles so disagreement about any aspect of the tool had to be argued, and any adjustment made, with recourse to ecological principles. This avoided confusing the ecological assessment with socio-economic considerations, which were not within our brief to consider. Socio-economic impacts were addressed by other policy responses.

Table 1 – The operational requirements and constraints that underpinned the assessment methodology

Operational requirement or constraint	Explanation
Available time and resources	The period between the introduction of the policy and the development of the assessment procedure was short and resources did not permit collection of new data.
Tests whether clearing proposals 'improve or maintain environmental outcomes'	This was the legislated standard that had to be met before clearing could be approved. Offsets could be used to enable clearing to meet this standard.
Conserves landscapes	Assessments focus on landscapes as a whole rather than impacts on individual plants or animals (although a separate tool was developed to assess impacts on threatened species).
Applicable at the scale of an individual proposal	Proposals are typically 1–500 ha.
Objective/repeatable/auditable	For equity and probity reasons the assessment methodology had to be objective, repeatable and apply consistently across all proposals within the jurisdiction. This latter point is a major limitation because most datasets were not available to a consistent standard across the jurisdiction.
Rapid and supports on-the-ground decision-making	Assessments had to be completed rapidly (generally within a day), at any time of the year and lead to immediate indicative decision-making.
Can be undertaken by individuals without specialized field skills	Site assessors were not expected to possess specialized skills in flora and fauna survey, however, some ecological training (e.g. the response of native vegetation to management), field skills (e.g. familiarity with field sampling techniques, ability to identify exotic and native plants), local knowledge and experience dealing with landholders are assumed.
The assessment is instructive to assessors and landholders	The assessment should be useful for identifying biodiversity issues, directing management priorities that are relevant for landholders and educating assessors and land managers.
Allows us to track what is happening in landscapes	Indicators of biodiversity conservation achievements are required to meet reporting and monitoring requirements.

The key guiding ecological principles were:

(1) Biodiversity is composition, structure and function at a hierarchy of scales

Biodiversity encompasses diversity at different levels of organization or scales (Gaston, 1996). Noss (1990) presented a tractable framework for measuring biodiversity that we adopted, i.e. composition, structure and function assessed at different scales.

(2) Representative examples of all ecosystems should be conserved

Effective biodiversity conservation requires representative examples of all ecosystems to be adequately conserved (Pressey et al., 1993). Sites that make up a clearing proposal therefore need to be assessed in the context of conservation priorities at broader scales.

(3) Priorities should be given to actions that result in long-term viability

If there are limited resources for conservation, priorities should be directed towards sites that are under most threat without management intervention (Pressey et al., 1993). However, if the level of required management intervention is too great relative to the likely conservation gain then a process akin to triage should be applied (Hobbs and Kristjanson, 2003). In certain conditions clearing can therefore be undertaken at sites with little likelihood of persistence provided offsets improve the condition and likelihood of long-term persistence of native vegetation in equivalent ecosystems elsewhere (Gibbons and Lindenmayer, 2007). Conservation or restoration activities should focus on sites with inherent resilience that are likely to respond to management and be viable in the long-term (McDonald, 2000).

2.4. *The assessment methodology*

The assessment process is summarized in Fig. 1. The steps to determine whether clearing could improve or maintain environmental outcomes for biodiversity are outlined below.

Step 1. Map and stratify the proposal area

The proposal to clear native vegetation was first mapped and then stratified into zones of the same vegetation type and broadly similar condition. This was undertaken by assessment officers after field reconnaissance by digitising these boundaries on a laptop computer with a Geographic Information System (GIS) using high-resolution satellite imagery

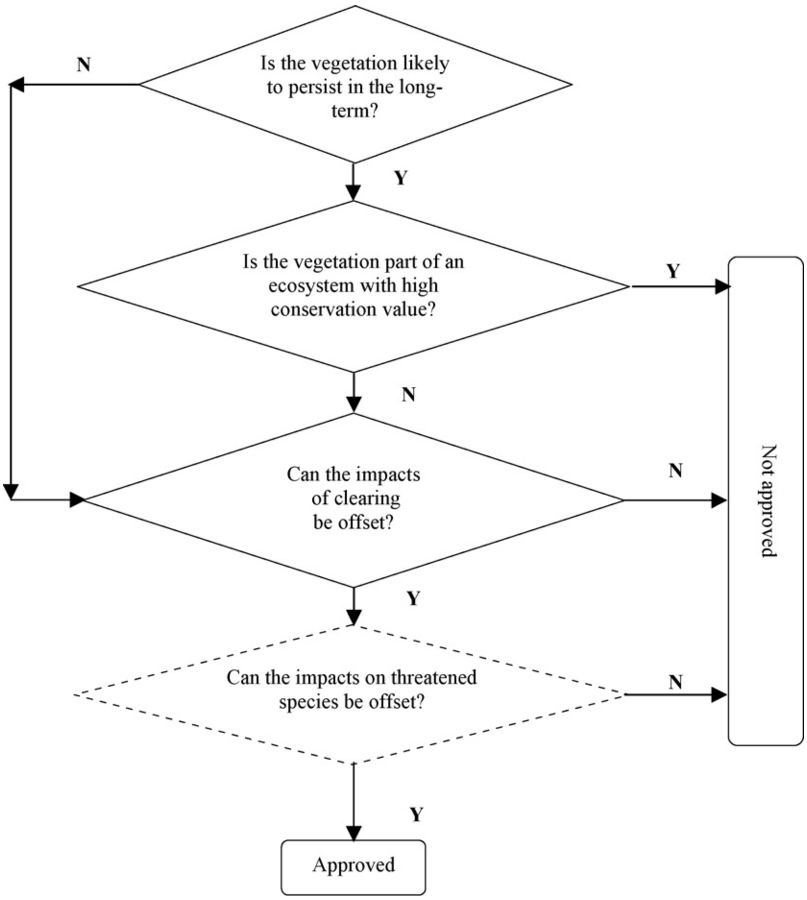

Fig. 1 – A flow diagram summarizing the process for assessing whether proposals to clear native vegetation improve or maintain biodiversity. The diamond with broken lines represents a step undertaken with a separate decision-support tool not described here.

in which most native vegetation could be discerned (typically SPOT 5 with a pixel resolution of 2.5 m $\times$ 2.5 m) as a backdrop.

Step 2. Identify vegetation of high conservation value that cannot be cleared

Native vegetation in an ecosystem with a high conservation value could only be considered for clearing if in 'low condition'. Vegetation in 'low condition' was defined as relictual over-storey (<25% of benchmark crown cover) dispersed among a predominantly ($\geq$50%) exotic groundcover (the groundcover threshold was pre-determined in the NSW Native Vegetation Act 2003 for which this tool was developed). Benchmark cover is the typical range of cover in a vegetation type that is relatively unmodified by Europeans. The lower range of the benchmark for cover was used to assess whether the vegetation was in low condition. Vegetation in low condition could only be approved for clearing if: (a) the impacts could be offset as described in Step 3 (below) and (b) it did not represent habitat for a threatened species which could not be offset (threatened species were assessed in a separate tool).Ecosystems of high conservation value were defined at different scales (national, State, regional) consistent with the first guiding ecological principle described previously.

The surrogate for ecosystems with a high conservation value at national scale was ecological communities listed as threatened under federal legislation (Environmental Protection and Biodiversity Conservation (EPBC) Act). Ecological communities are typically listed as threatened if highly cleared, of limited extent and/or vulnerable to threatening processes at the national scale. These were identified on the ground using descriptions of these communities provided as part of supporting material for the EPBC Act.

We used two surrogates to identify ecosystems that were of high conservation value at State scale. The first surrogate was ecological communities listed under the State's threatened species legislation (Threatened Species Conservation (TSC) Act), which, like the ecological communities listed as threatened at the federal level, were typically highly cleared, of limited extent and/or vulnerable to threatening processes, but at the scale of the State of NSW. These were identified on the ground using descriptions provided as part of supporting material for the TSC Act. The second surrogate for ecosystems was based on a division of the State into relatively homogeneous units known as Mitchell Landscapes, based on abiotic data (geology, soils, terrain) and coarse biotic data (broad vegetation type). The Mitchell Landscapes was the only ecosystem surrogate that was mapped to a consistent standard across the State and identifiable by assessors on the ground. The Mitchell Landscapes were overlain with an updated version of the vegetation layer developed by Pressey et al. (2000), which was the only consistent vegetation layer at the time that included non-woody native vegetation. Remaining native vegetation cover within these ecosystems was significantly correlated ($r = 0.80$, $P < 0.001$) with priorities for conservation across the State identified in a more exhaustive process by Pressey et al. (2000). Mitchell landscapes with >70% cleared of native vegetation cover were considered to be high conservation value and therefore could not be cleared unless the vegetation was unlikely to persist (i.e. was in low condition).

Vegetation communities were selected as the surrogate of ecosystems at the regional scale (regions were defined as 13 major catchments across the State). Vegetation communities are a useful surrogate for the turnover of some fauna communities (Ferrier and Watson, 1997) as well as flora, and can be identified by assessors in the field. Vegetation communities that were highly cleared (>70%) in each region relative to their predicted pre-European distribution were considered high conservation value and therefore not available for further clearing, unless in low condition.

Step 3. Assess whether losses from proposed clearing are sufficiently offset

Vegetation in an ecosystem that was not of high conservation value or was in 'low condition' could only be cleared if any loss in Regional Value, Landscape Value or Site Value from the proposed clearing could be offset by commensurate gains in each of these measures according to the criteria summarized in Table 2. Regional Value, Landscape Value and Site Value are defined below. No other strictures, such as their proximity to the clearing, were placed on offsets.

The conservation significance of vegetation at the regional scale (Regional Value) was based on the per cent that the vegetation communities at the site had been cleared within the region and a generic relationship between habitat and species loss (i.e. species–area curve) (Rosenzweig, 1995) (Appendix A). Vegetation communities with higher levels of clearing had a higher Regional Value.

Landscape Value was derived from four measures: (1) change in the total cover of native vegetation in the landscape (measured in 10, 100 and 1000 ha circles around the site); (2) change in connectivity; (3) total area of native vegetation adjacent to the proposal; and (4) proximity of the offset site to riparian areas. Methods used to assess each of these measures are provided in Appendix B.

Site Value was assessed using ten surrogates of composition, structure and function that were relatively easy to measure in the field (Appendix C). Standardized field methods were developed to assess each variable (Gibbons et al., 2005) so that the measures were not confounded by sampling effort (e.g. different plot sizes). Site Value was calculated by:

(a) allocating each of the ten variables measured on the site a score from zero to three (0 = poor condition, 1 = moderate condition, 2 = high condition, 3 = very high condition) based on the difference between its measured value on the site and pre-defined reference conditions or benchmarks for each vegetation type;
(b) multiplying each of these scores by a weighting based on the relative ease with which the variable can be restored or regenerated with management (Appendix C);
(c) adding several interaction terms (with their own weightings) that recognize improved function when some variables co-occur (e.g. over-storey and regeneration);
(d) summing all of the weighted scores;
(e) multiplying this final score by area.

Any combination of stock grazing exclusion or strategic stock grazing, planting/direct seeding, weed control, erosion control, feral herbivore control, retention of dead timber and the retention of regrowth (that could be legally cleared) were permitted as management actions. The details of each management action were developed in discussions between the proponent and assessor. Changes in Site Value at the offset site from proposed management actions were predicted by assessors in the field. Guidelines were provided to assist assessors based on the state and transition framework of Westoby et al. (1989), which recognizes that an ecosystem will revert to its previous state after disturbance only under certain conditions. Thus, we identified the range of conditions that must be present before a positive response (i.e. movement towards benchmark) could be recorded for each variable and fixed the amount of increase that could be scored to reflect the uncertainty associated with the response (see Gibbons et al., 2005). For example, managing stock grazing at a site could translate to an increase in native plant species richness only if the site was near a suitable seed source and exotic plant cover was controlled and this increase could only be a maximum of one increment in the score to reflect the slow and uncertain response in this variable. However, we encouraged the development of specific guidelines to predict the response with management for each region and ecosystem type.

When predicting whether gains on an offset site were sufficient to offset the impacts from development we considered whether landholders had managed native vegetation on their property above their

Table 2 – A summary of the criteria to assess whether proposed clearing can be offset

	Regional Value	Landscape Value	Site Value
Clearing site	A	$A - B$	$A - B$
Offset site	D	$D - C$	$D - C$
For clearing to be approved	$D \geq A$	$(D - C) \geq (A - B)$	$(D - C) \geq (A - B)$

For clearing to be approved the balance for each of the Regional Value, Landscape Value and Site Value scores must be equal to, or greater than, zero. A = current value of site proposed for clearing; B = predicted value of site after proposed clearing; C = current value of site proposed for offsets; D = predicted value of site proposed for offsets.

duty of care, defined as the minimum standard in the legislation for which the assessment was developed (Native Vegetation Act 2003). Increases in condition on a site were calculated as the difference between the minimum condition at which the landholder was required to manage their native vegetation, as defined in legislation (i.e. duty of care), and the predicted increase from management (Fig. 2).

Step 4. Summarize assessment outcomes and conditions

The final step in the assessment process was to summarize the assessment outcomes. This involved determining whether losses in each of Regional Value, Landscape Value and Site Value from clearing were offset by sufficient gains in each of these. This was in the form of a simple balance sheet for each proposal. For proposals that were approved a template containing details of the proponent, a map of the proposal and details of agreed management actions for each zone was generated.

2.5. *Codifying the rules into computer software*

These rules, metrics and data that underpinned them, were codified in a tool (BioMetric) (Gibbons et al., 2005) developed in Microsoft Excel^{TM}. Excel was chosen because it was a standard piece of software on assessors' computers, it could be disseminated and installed with ease, and there was a high rate of familiarity with this software among assessors. The tool contained most datasets that an assessor required to complete an assessment. A copy of this tool is available from the authors. Data and results from each assessment, including all raw field measurements, were downloaded into a relational database for auditing, monitoring and compliance purposes.

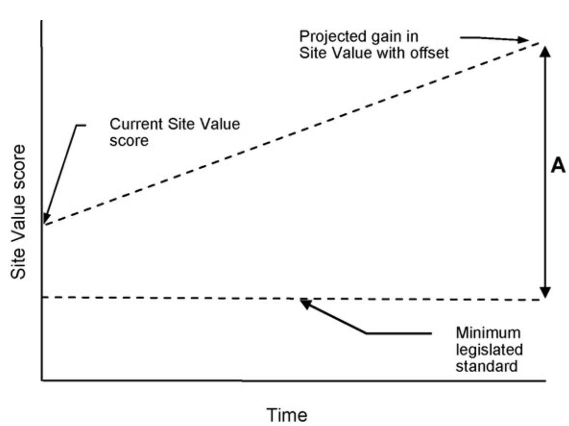

Fig. 2 – Site Value on offset sites (*A*) is calculated as the difference between the minimum level at which each variable is legally maintained (duty of care), and the projected gain in each variable with the proposed offset.

2.6. *Field trials*

Proposals to clear native vegetation were assessed in field trials undertaken at 77 sites with 69 different landholders across 12 of the 13 major catchments in NSW using 41 different assessment teams in 2004. The purpose of field trials was to test an earlier version of the tool among assessment staff, present the outcomes to stakeholders and make any necessary changes to the tool before the legislation was enabled. However, for the purposes of this paper we entered data from field trials into the final version of the tool to illustrate the types of clearing that were, and were not, permitted by the tool. Outcomes from assessments for impacts on threatened species, water quality and soils were conducted separately and are not reported here. Proposals had to pass each of these assessments to be approved, so approvals for assessments undertaken using the assessment methodology described here did not necessarily mean the proposal was approved for clearing.

We identified which variables had greatest bearing on the field trial outcomes by fitting generalized additive models (GAMs) to the following parts of the assessment methodology: (a) whether the vegetation was of high conservation value and therefore could not be cleared; (b) the change in Landscape Value with each proposal; and (c) the change in Site Value with each proposal. The Regional Value metric was not assessed as it contained only two independent variables. The outcome or score for each part of the assessment methodology were the response variables and the measured variables for each part of the assessment methodology were the independent explanatory variables. The sensitivity of each part of the assessment methodology to changes in each measured variable were assessed with the change in deviance to each model when the variable was dropped—a higher change in deviance indicating the metric was more sensitive to a variable.

2.7. *Implementation*

The assessment methodology described here became Regulation in late 2005. Approved clearing proposals undertaken using the tool were downloaded from a public register on 29 November 2006 (http://www.nativevegetation.nsw.gov.au/pams/PublicRegisterSearch.jsp), approximately one year after the tool was made operational. The number and areas of vegetation approved for clearing were summarized into categories representing scattered trees (i.e. sites that were already partially cleared) and sites without a previous history of substantial clearing.

Table 3 – A summary of the Regional Value, Landscape Value and Site Value losses and gains across all proposals in which clearing was permitted in the field trials

	Regional Value	Landscape Value	Site Value
Clearing sites	−638	−377	−24,286
Offset sites	753	653	84,272
Balance	116 (+18%)	277 (+73%)	59,986 (+247%)

3. Results

3.1. Field trials

The gross areas of native vegetation proposed for clearing in the 77 trials ranged from 0.14 to 1254 ha with a mean of 123 ha. These areas were calculated from polygons bounding the outermost remnants of native vegetation in the proposals, so can be a misleading indicator of the net area of native vegetation proposed for clearing. Approximately half of all proposals (49%) were entirely in native vegetation in ‘low condition’ (e.g. trees scattered among improved pasture or cultivation), so the net areas of native vegetation proposed for clearing were often substantially lower than the gross areas indicated above.

3.1.1. Types of clearing approved

Of the 77 proposals to clear native vegetation, 36% were likely to be approved by the tool. The majority (71%) of approvals were in vegetation in ‘low condition’ (predominantly scattered trees among cultivation), 18% of approvals were for partial clearing of native vegetation (e.g. thinning of the mid-storey layer, reduction of native increaser species) and the remaining 11% of approvals were for clearing small areas of relatively intact native vegetation. The mean area approved for the last type of clearing was 2.0 ha and the mean Site Value score (per ha) for these proposals was 50 out of 100.

A summary of the overall losses on the clearing sites and gains on the offset sites in Regional Value, Landscape Value and Site Value scores across proposals likely to be approved for clearing is in Table 3. Gains in Regional Value scores were because some offsets were in vegetation types with per cent cleared levels higher than the vegetation types proposed for clearing. Most gains in Landscape Value scores from offsets were from (in order of effect on the score) the location of offsets in riparian areas, the location of offsets adjacent to existing remnants and gains in the connectivity score. The mean current Site Value score (per ha) for offset sites was 35 out of 100. Most gains in Site Value scores with management on offset sites were due to increased scores for native plant species richness, over-storey cover and tree regeneration. There were only minor gains in scores for cover of native forbs and volume of coarse woody debris, and a loss in the overall score for numbers of hollow-bearing trees. All proposed offsets were located on the same property as the proposed clearing.

3.1.2. Types of clearing rejected

Of all proposals to clear native vegetation, 64% were rejected by the tool. Twenty per cent of rejections were because the vegetation was in a Mitchell Landscape that was >70% cleared, a vegetation type >70% cleared and/or was a threatened ecological community. The remaining 80% of rejections were because the proposed offset did not achieve gains in one or more of the Regional Value, Landscape Value and Site Value scores. Of these rejections, 67% could not proceed because impacts of the proposal on Landscape Value could not be offset, 33% could not proceed because impacts on Site Value could not be offset and 15% could not proceed because the offset had a lower Regional Value score than the vegetation proposed for clearing.

3.1.3. Sensitivity analysis

Data from 127 vegetation zones were used to test the part of the assessment methodology that indicates whether vegetation is of high conservation significance and therefore could not be cleared under the tool. None of the potential explanatory variables were highly correlated ($r \leq 0.46$). The model for this part of the tool was most sensitive (as measured by the change in deviance when the variable was dropped from the full model) to the variable indicating whether the vegetation was in low condition and the variable representing the per cent of the vegetation type that was cleared within the region, and least sensitive to the per cent that the landscape was cleared.

Data from 70 sites were used to assess the change in Landscape Value with each proposal. The change in per cent cover at the 0.2 km radius was reasonably highly correlated ($r = 0.68$) with per cent cover of vegetation within 0.55 km of the site, however, we kept both variables in the model. The Landscape Value metric was most sensitive to the variable representing the adjacency of the offset to existing remnants and least sensitive to the variables representing the change in vegetation cover within 0.2 and 1.75 km cover of the sites.

Data from 56 sites were used to assess the change in Site Value with each proposal. There were high correlations between: over-storey cover and length of fallen logs ($r = 0.89$); over-storey cover and the number of trees with cavities ($r = 0.89$); and the number of trees with cavities and length of fallen logs ($r = 0.86$). Of the correlated pairs of variables we elected to remove the variables over-storey cover and length of fallen logs from subsequent analyses. The Site Value metric was most sensitive to the area of the offset site. This metric was least sensitive to the cover of shrubs in the ground layer (below 1 m height) and the cover of ‘other’ plant species in the ground layer (i.e. non-woody plant species other than grasses below 1 m in height).

3.2. Implementation

Forty clearing proposals were approved using the tool in the first 12 months after it became operational. Results were similar to the field trials. Most approvals (68%) were for clearing scattered trees in land managed principally for cultivation. These approvals allowed clearing of 3004 scattered trees (1455 of which were in one clearing proposal). This equates to clearing approximately 107 ha of woodland based on an average density of 28 trees (>40 cm DBH) per ha in uncleared woodland (Gibbons et al., unpublished data). The remaining 32% of approvals were for clearing a total of 46 ha of native vegetation not in 'low condition'. The latter approvals were for proposals averaging 0.6 ha (range 0.1–3.1 ha), although one additional approval for clearing 33.3 ha was granted after using minor variation—part of the Native Vegetation Regulation 2005 which was gazetted after the completion of the tool to permit changes to the assessment methodology provided the 'improve or maintain' objective could still be met (New South Wales Government, 2005). A total area of 3645 ha was established as offsets for all clearing (the area of offset was also determined in a separate threatened species tool). Thinning of native vegetation to benchmark stem densities, management of invasive native scrub (which can include some clearing), clearing to establish plantations and clearing exempt from assessment (e.g. unprotected regrowth, clearing for utility easements) were permitted in NSW over this period using other assessment methods not described here.

4. Discussion

4.1. *The rationale for using the selected biodiversity assessment techniques*

We employed several different biodiversity surrogates and assessment techniques to assess the impacts of land clearing on biodiversity. As no single surrogate for biodiversity is comprehensive we spread risk (Lindenmayer et al., 2002) by using different surrogates for biodiversity across multiple scales. Surrogates for biodiversity and the techniques used to measure these were selected after considering the range of surrogates available and the range of feasible assessment techniques given the operational and resource constraints listed in Table 1.

Species metrics are commonly used for rapid assessment at fine scales, especially in aquatic systems (Karr, 1991), but were not suitable for our purpose except for vascular plants. This was because: assessors lacked time and skills to undertake a species inventory at each site (one day was typically allocated to field work for each proposal); effective species inventory is seasonally dependent for many taxa (assessments of clearing proposals occur at any time of the year); and existing species data were patchy across the State. An approach based on indicator species was not used for similar reasons, and also because of the preliminary work required to identify appropriate indicator species and uncertainty about the validity of indicator species as surrogates for other biota (Lindenmayer et al., 2002). For site assessment we used species metrics for plants only, with the remaining part of the assessment at the scale of the site based on predominantly structural attributes of vegetation that are surrogates for fauna (reviewed by McElhinny et al., 2006) and ecosystem function (Oliver, 2003).

Structural and compositional attributes of vegetation measured on each site were compared with a benchmark representing the range of variability for that attribute in comparable natural ecosystems (vegetation types) exhibiting relatively little evidence of modification since post-European settlement. This approach is consistent with several other rapid biodiversity assessment techniques (e.g. Karr, 1991; Landres et al., 1999; Parkes et al., 2003; Parsons et al., 2004; McElhinny et al., 2005). Benchmarks represent the range of alternative stable states (sensu Westoby et al., 1989) in ecosystems undergoing natural disturbances, but do not represent conditions after recent major perturbations (e.g. major fire or flood). The use of benchmarks for assessment is based on the premise that communities of biota are adapted to and function better within environments with relatively little contemporary anthropogenic modification (Landres et al., 1999), that an ecosystem is more resilient within its natural range of variation (Holling and Meffe, 1996) and that condition within an ecosystem has to be assessed in relative terms for that ecosystem rather than in absolute terms (which would lead to ecosystems that are naturally more structurally diverse always being assessed as in higher condition that ecosystems that are naturally less structurally diverse).

To provide landscape context for sites we used simple landscape measures based on the extent and configuration of vegetation estimated from visual inspection of high-resolution satellite imagery or aerial photography. These measures were guided by the species–area relationship (Rosenzweig, 1995) and the patch-corridor-matrix model (Forman, 1995). Developing models for individual species, functional groups, communities or populations (Ferrier et al., 2002a,b) to inform this part of the assessment was impractical because of the number of species under consideration, our limited understanding of habitat requirements for many of these, the enormity of the task given the area subject to the legislation (80 million ha) and because of a paucity of consistent, spatially explicit habitat data for fine-scale assessments. For example, the finest scale spatial data on vegetation available across the study area did not capture woody vegetation below approximately 20% crown cover, or narrow, linear remnants and non-woody vegetation which provide important habitat in large parts of NSW (Gibbons and Boak, 2002) and represented much of the vegetation proposed for clearing. Impacts of clearing proposals on individual threatened species were assessed in a separate assessment tool (not discussed here) in recognition that generic relationships of the type we used do not account for the habitat requirements of all species.

We considered using systematic conservation planning techniques (sensu Margules and Pressey, 2000) to assess the marginal effect of individual proposals for conservation outcomes at broader scales. However, these techniques were difficult to apply because few data for the measured attributes were available at broad scales or to a consistent standard at broad scales. Further, spatial data that were available to a consistent standard across the study area were typically mapped at scales that were too coarse to use in a spatially explicit way for individual clearing proposals (that could be <1 ha). Another practical constraint is that complementarity (sensu Margules and Pressey, 2000) is a dynamic measure that changes with each decision on clearing, so a feedback loop is required to update datasets periodically. Instead we placed sites in the broader geographic context by using existing analyses of conservation priorities undertaken at broad scales (e.g. Pressey et al., 2000) that were based on surrogates that could be identified, or for which there was a correlated surrogate that could be identified, at the scale of individual proposals. Systematic conservation planning techniques are a promising approach for assessments of biodiversity at fine scales if these operational issues can be overcome.

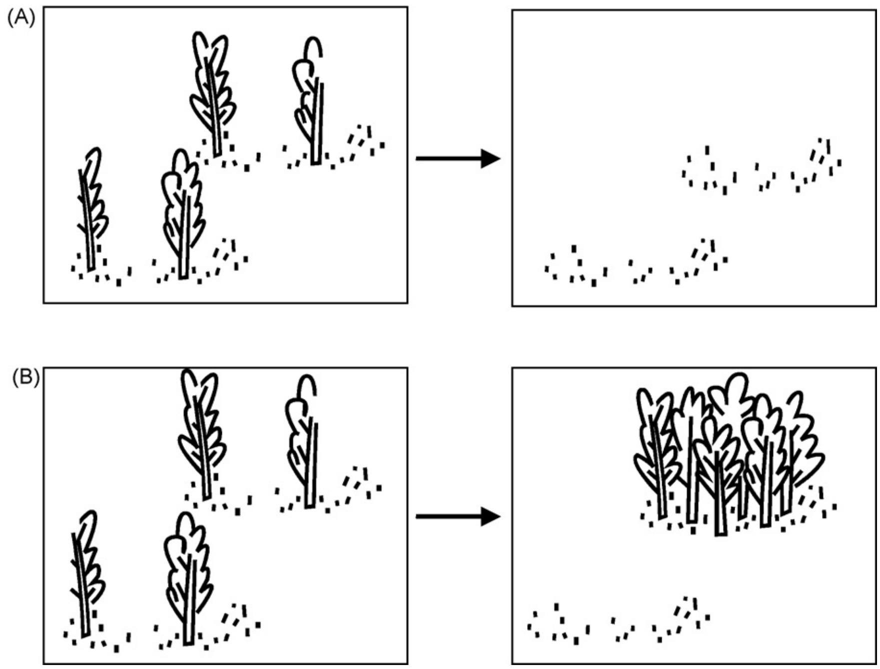

Fig. 3 – Possible change to vegetation in low condition over time with and without clearing and offsets. The site on the left (e.g. scattered trees among cultivation) is not viable. It is on a trajectory of degradation and ultimate loss under current land use even if clearing were not permitted (A). If this site were partially cleared with an offset that restored the long-term viability of vegetation on the same site (B) or equivalent vegetation on another site then the outcome could be a net gain over the long-term (provided the short-term loss in habitat is not irreversible).

4.2. *Offsets*

Our brief was to develop a tool to assess whether a proposal to clear native vegetation 'improves or maintains' environmental outcomes for terrestrial biodiversity, which is analogous with the principle of 'no net loss'. In practice, this meant that most proposed clearing (64% of applications) could not proceed. Relatively intact native vegetation could not generally be cleared which is consistent with the findings of Hilderbrand et al. (2005) that natural ecosystems cannot generally be replicated. Further, we argued successfully that it was not prudent to allow ecosystems of high conservation significance (unless they were unlikely to persist under current land use) to be managed with clearing and offsets. This is because offsets provide gains that are not strictly equivalent to losses (Hilderbrand et al., 2005; Gibbons and Lindenmayer, 2007) which could potentially place already rare ecosystems in a more perilous position.

Most vegetation in which clearing with offsets was permitted was vegetation that was in 'low condition' or unlikely to persist in the long-term with existing land use. The rationale for including this step in the assessment methodology was to identify vegetation that was unlikely to persist under current land use and therefore for which clearing and offsets could potentially lead to a better conservation outcome in the long-term than the prohibition of clearing (Fig. 3). Field trials indicated clearing of relatively intact native vegetation was permitted it was for small areas (mean = 2.0 ha) of vegetation that were substantially modified (mean Site Value score per ha = 50/100) or vegetation assessed as unlikely to persist under current land use (i.e. low condition), within landscapes or ecosystems that were <70% cleared, did not represent irreplaceable habitat for threatened species and was accompanied by offsets.

Impacts from clearing were offset with management actions (e.g. stock exclusion, weed control, planting) to improve the condition, or increase the likelihood of persistence, of comparable native vegetation. The Site Value metric encouraged offsets to be established in vegetation that was already in moderate condition (mean Site Value score per ha = 35/100) rather than vegetation in poor or excellent condition (Fig. 4). This outcome reflects the guiding ecological principle that restoration actions should build upon, and are more likely to be successful in, existing native vegetation (McIntyre et al., 2002), rather than attempting to restore ecological communities from non-native vegetation. Offset requirements increased on sites in high current condition (Fig. 4) because there is decreasing scope to achieve gains on these sites and in a regulatory environment that does not permit clearing of intact vegetation these sites are not at great risk. Offsets on sites that have no scope for further improvement, or added protection, from clearing will result in a net loss commensurate the impacts of clearing (Gibbons and Lindenmayer, 2007) which is consistent with the principle that priorities should be directed towards sites that are under most threat without management intervention (Pressey et al., 1993).

Although offsets were required to achieve gains that were greater than or equal to losses from clearing for each of the Regional Value, Landscape Value and Site Value scores, we did not strictly adhere to the principle of equivalency or 'like-for-like' in accounting for these gains. Each of these metrics is

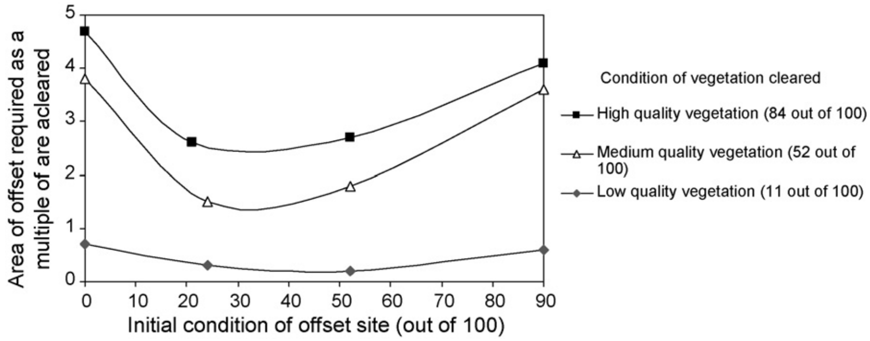

Fig. 4 – The area of offset required as a multiple of the area cleared (*y*-axis) according to the initial condition of the offset site (*x*-axis) and the condition of the vegetation cleared (separate lines). Assumes maximum improvement to offset sites with management.

derived from multiple variables and thus different combinations of attributes could provide the same score. Clearing that could be offset was permitted before the offsets were mature. This led to the short- and medium-term loss of some features (e.g. hollow-bearing trees). Offsets have to remain in place for a period commensurate with the duration of the impacts from clearing (typically in perpetuity) and were legally binding with changes in ownership and tenure. Adequate monitoring and compliance over the long-term—an identified problem with offsets (Race and Fonseca, 1996)—is therefore critical for the success of this approach.

4.3. *Duty of care*

Increases in condition on a prospective offset site were calculated as the difference between the minimum condition at which the landholder was required to manage their native vegetation, as defined in legislation (i.e. duty of care), and the predicted increase from management (Fig. 2). For example, landholders were permitted, within the legislation, to harvest coarse woody debris for personal use as firewood. If the volume of coarse woody debris at a site was within the benchmark then the landholder could not improve their score unless they harvested the coarse woody debris prior to the assessment. This would create a perverse incentive to degrade prospective offset sites prior to assessment. By calculating the improvement on an offset site as the difference between the minimum legislative standard (e.g. zero coarse woody debris volume) and the projected improvement with management we removed the perverse incentive to degrade vegetation prior to an assessment that was managed above the duty of care and rewarded, rather than penalized, past management above the duty of care. The corollary of this is that gains in Site Value can theoretically be calculated without an improvement to the site and therefore "no net loss" is calculated relative to this legislated duty of care rather than existing condition. However, the degree of gain in Site Value that can be achieved in this way alone is modest in practice because only a few Site Value variables can be degraded legally and the maximum increase in scores with management are one increment for most Site Value variables to reflect uncertainty associated with the efficacy of many management actions.

4.4. *Priorities for improvement*

Most available datasets were inconsistent across the State. To maintain consistency—and therefore equity—between assessments we therefore had to use datasets developed at a broad scale, rather than finest scale dataset available for a particular area. Consistent data are important for assessments of this type. The scale of spatial data was an issue as it was typically too coarse to overlay with individual proposals. The ability to match field observations with units used in coarser datasets was therefore important, but proved problematic in some areas, particularly with respect to the identification of vegetation communities on the ground. Datasets for applications such as this must be used with understanding of limitations of using mapped spatial data at site scales.

While assessors were not required to possess specialized field skills, a reasonable level of expertise was required to undertake effective assessments using the methodology described here. Our observations indicated that some assessors lacked an appreciation of the rigor required to sample effectively and collect consistent field data. Assessors required, as a minimum, sufficient knowledge to identify vegetation communities and exotic plants, and the effectiveness of offsets relied on the ability of assessors to provide advice on appropriate management actions for the prospective offset site. Thus, the assessment methodology described here requires some investment in capacity among assessment staff.

The field trial outcomes were most sensitive to: whether the vegetation was in 'low condition', the per cent of the vegetation type that was cleared within the region, the variable representing the adjacency of the offset to existing native vegetation and the area of the offset site. The area of the offset site had a large effect relative to all other variables in the Site Value metric (making many of these other variables effectively redundant) which suggests that the Site Value score should not accrue linearly with area. These results suggest that: these are the variables that should receive special attention when training assessors, assessors should measure these variables with particular care; data underpinning these variables should receive priority for review; and these variables should receive greatest scrutiny in reviews of the assessment methodology.

5. Conclusions

Effective regulation is an important element of governance to control land clearing (Kishor, 2004). A transparent, quantitative and codified approach for regulating clearing as presented here: (a) provides a consistent scientific basis for assessing individual proposals to clear native vegetation; (b) protects assessment staff from pressures by vested interests; (c) allows all stakeholders to examine, question and propose improvements to the methodology; (d) generates data that can be used for auditing, monitoring and adaptive management; and (e) highlights gaps in existing data and knowledge. This assessment methodology precipitated gap-filling in key datasets, considerable targeted research and broad stakeholder engagement in the assessment process.

The Regulation in which this assessment methodology has been included is a statutory instrument that can be modified as improvements in the assessment methodology are developed (New South Wales Government, 2005). By codifying each rule in the tool explicitly and with recourse to ecological principles meant that the tool cannot be modified without identifying, and arguing on ecological grounds, the specific section of the tool (and the methodology) at fault. When arbitrary rules or figures are used in assessments of this type then the assessment methodology can be modified in a way that is neither transparent nor based on ecological considerations. Some level of flexibility is required in assessment methodologies and tools to accommodate unusual situations, but the flexibility needs to be constrained to ensure that ‘improve or maintain’ outcomes are met. The minor variation provisions of the Native Vegetation Regulation (New South Wales Government, 2005) allow some rule-based flexibility in the assessment methodology providing the clearing improves or maintains environmental outcomes.

The assessment methodology presented here does not represent the only approach that could be used for assessing impacts on terrestrial biodiversity of clearing native vegetation. Each jurisdiction has unique operational requirements and resources, different ecological systems, there are different views on the most appropriate ways to assess biodiversity and research will continuously shed light on avenues for improvement. However, the steps we took to develop this assessment methodology apply universally, i.e.: (1) define operational requirements, resource constraints and ecological principles from the outset, (2) identify biodiversity surrogates and assessment techniques that match these, (3) develop explicit rules for when clearing can, and cannot, occur (with specified flexibility); (4) codify these rules into a tool that is consistent, transparent and auditable; and (5) revise the tool adaptively based on field trials and on operational and policy needs and experience.

Acknowledgements

Thanks to many colleagues in the NSW Government who made contributions to BioMetric, the many staff in Catchment Management Authorities who tested the tool and provided critical feedback and the many stakeholders who provided suggestions that improved earlier versions of the tool. This feedback and the results of research funded by the NSW Government through its Environmental Trust (Better Knowledge Better Bush Project) continue to provide input for periodic reviews of BioMetric and the assessment methodology. We acknowledge the original thinking by David Parkes and colleagues from the Department of Sustainability and Environment, and Peter Smith and colleagues from the Department of Natural Resources upon which much of our work is based. Special thanks to Denis Saunders and John Williams who provided ongoing support, encouragement and feedback. Funding from the National Action Plan for Salinity and Water Quality contributed to this work, and the project was assisted by the NSW Government through its Environmental Trust (Better Knowledge Better Bush Project). This paper does not necessarily represent the official policy of the NSW Department of Environment and Climate Change, the NSW Government or any other agency or organization.

Appendix A. Regional Value

Regional Value is calculated using the formula:

$$\sum_{i=1}^{n}\left(\left(1-\left(\frac{\%\text{remaining}}{100}\right)^{0.25}\right)\times\left(\frac{\text{Zone Area}}{\text{Total Area}}\right)\times 100\right)_i$$

where i is a unique Zone in the proposal; %remaining is the per cent of the vegetation type in the ith Zone that is remaining relative to its predicted pre-European distribution; Zone Area is the area of the ith Zone (in hectares) and Total Area is the sum of the area of all Zones $(1-n)$ in the proposal (in hectares).

This formula was developed to accommodate the situation where a proposal contains more than one vegetation type, and it reflects the non-linear relationship between the amount of habitat and biodiversity value (e.g. clearing an ecological community that is 90% remaining relative to its original distribution will have less impact on species than clearing an equivalent area of an ecological community that is 10% remaining relative to its original distribution). The exponent 0.25 is based on a generic species–area relationship used in fragmented landscapes (Brooks et al., 2002).

Appendix B. Landscape Value

The change in Landscape Value from clearing was calculated as the difference between the current Landscape Value of the site and the Landscape Value of the same site with clearing using the formula

$$\text{Landscape Value}_{\text{Clearing site}} = \left(\sum_{v=a}^{e}(s_v w_v)\right)_{\text{Current}} - \left(\sum_{v=a}^{d}(s_v w_v)\right)_{\text{With proposed clearing}}$$

Table 4 – The variables used to assess Landscape Value, the levels at which different scores are allocated and the relative weighting given to each variable in the overall Landscape Value score

Variable	0 points	1 point	2 points	3 points	Weighting
(a) % Cover of native vegetation within a 1.75 km radius of the site (1000 ha)	0–10%	11–30%	31–70%	>70%	9.99
(b) % Cover of native vegetation within a 0.55 km radius of the site (100 ha)	0–10%	11–30%	31–70%	>70%	6.66
(c) % Cover of native vegetation within a 0.2 km radius of the site (10 ha)	0–10%	11–30%	31–70%	>70%	3.33
(d) Connectivity value	Nil	Low	Moderate	High	6.66
(e) Total adjacent remnant area	Small	Medium	Large	Very large	6.66
(f) % Within riparian area	0–25%	26–50%	51–75%	>75%	6.66

The change in Landscape Value on the offset site was calculated using the formula

$$\text{Landscape Value}_{\text{Offset site}} = \left(\sum_{v=a}^{f}(s_v w_v)\right)_{\text{With proposed clearng and offsets}} - \left(\sum_{v=a}^{d}(s_v w_v)\right)_{\text{With proposed clearing}}$$

where s_v is the score for vth variable (a–f) and w_v is the weighting for the vth variable (a–f) as defined in Table 4. In the absence of any compelling reason for doing otherwise these variables were weighted evenly except the measures of vegetation cover at 1.75 and 0.2 km which were weighted higher and lower, respectively, because of the area over which they covered and the relatively larger amount of landscape change required to affect the former. The variables that make up Landscape Value are described in Table 4.

Total native vegetation cover was assessed within radii of 1.75 km (1000 ha), 0.55 km (100 ha) and 0.2 km (10 ha) around the site. Different radii reflect that different biota range over, and are affected by, activities at different scales. This is a similar approach as applied in other assessment methods (Oliver and Parkes, 2003; Parkes et al., 2003). The maximum radius we employed was the maximum radius at which change in vegetation cover is detectable with the imagery available and the area of vegetation typically proposed for clearing in a single site (approximately 500 ha). Scores of 0–3 were given to vegetation cover values of 0–10, 11–30, 31–70 and >70%, respectively, so the assessments could be assessed visually from air photos or high-resolution satellite imagery. These percentages represent approximate levels at which fragmentation effects escalate for different biota (Andren, 1994; Bennett and Ford, 1997; Reid, 2000; Smith et al., 2000; Radford et al., 2005).

The criteria for different connectivity values and their scores are summarized in Table 5. Native vegetation in better condition and with greater width provides greater connectivity value (Bennett, 1999), although the evidence is equivocal about the value of linear corridors (Turner, 2005). We defined widths of 30 and 100 m as points where linkages were assessed to provide greater value provided they connected to adjacent native vegetation. Kinross (2000) found that planted corridors in Central West NSW needed to be >25–30 m wide to generally support small, insectivorous birds and in one study in Victoria the Greater Glider (*Petauroides volans*) was only recorded in corridors distal to core habitat if >32 m wide (Downes et al., 1997). Spooner and Lunt (2004) reported an abrupt increase in conservation ranking (vegetation condition) in roadside corridors >30 m wide within southern NSW.

Total adjacent remnant area is the area of contiguous native vegetation connected to the site. Larger remnants generally support greater numbers of species than smaller remnants (Rosenzweig, 1995). Definitions for remnant size varied according to the extent that the landscape had been cleared following the approach of DLWC (1999) (see Gibbons et al., 2005).

Clearing was not permitted in riparian areas for water quality reasons, which was assessed in a separate decision-support tool. However, riparian areas generally have high values for biodiversity (Kavanagh and Bamkin, 1994; Soderquist and MacNally, 2000; Martin et al., 2006), so offsets in riparian areas were given higher scores (Table 4). This was achieved by adding an extra riparian component to the Landscape Value score for offset sites.

Table 5 – Definitions and scores for different levels of connectivity value

Connectivity value	Definition
High (3 points)	Native vegetation not in low condition >100 m wide that forms a link with other native vegetation not in low condition
Moderate (2 points)	Native vegetation not in low condition >30–100 m wide that forms a link with other vegetation not in low condition
Low (1 point)	Native vegetation in low condition >100 m wide or native vegetation not in low condition ≥5–30 m wide that forms a link with other native vegetation not in low condition
Nil (0 point)	None of the above

Appendix C. Site Value

The change in Site Value with either clearing, or management actions at an offset site, was calculated as the difference between the current Site Value and Site Value with the proposal. The Site Value metric was

$$\sum_{z=1}^{n}\left(\left(\frac{\left(\sum_{v=a}^{j}(s_v w_v)\right) + a((s_a s_g) + (s_b s_i) + (s_h s_j) + (s_c s_k)) \times 100}{c}\right) \times (\text{Zone Area})\right)_z$$

Table 6 – The methods used to allocate scores to the variables (*a–j*) in the Site Value metric

Variable	0 points	1 point	2 points	3 points	% Weighting
a, Native plant species richness	=0	>0 AND <(0.5B_a)	≥(0.5B_a) AND <B_a	≥B_a	20
b, Native over-storey per cent cover	≤(0.1B_{bmin}) OR >(2B_{bmax})	>(0.1B_{bmin}) AND <(0.5B_{bmin}) OR >(1.5B_{bmax}) AND ≤(2B_{bmax})	≥(0.5B_{bmin}) AND <B_{bmin} OR >B_{bmax} AND ≤(1.5B_{bmax})	≥B_{bmin} AND ≤B_{bmax}	5
c, Native mid-storey per cent cover	≤(0.1B_{cmin}) OR >(2B_{cmax})	>(0.1B_{cmin}) AND <(0.5B_{cmin}) OR >(1.5B_{cmax}) AND ≤(2B_{cmax})	≥(0.5B_{cmin}) AND <B_{cmin} OR >B_{cmax} AND ≤(1.5B_{cmax})	≥B_{cmin} AND ≤B_{cmax}	5
d, Native ground per cent cover (grasses)	≤(0.1B_{dmin}) OR >(2B_{dmax})	>(0.1B_{dmin}) AND <(0.5B_{dmin}) OR >(1.5B_{dmax}) AND ≤(2B_{dmax})	≥(0.5B_{dmin}) AND <B_{dmin} OR >B_{dmax} AND ≤(1.5B_{dmax})	≥B_{dmin} AND ≤B_{dmax}	5
e, Native ground per cent cover (shrubs)	≤(0.1B_{emin}) OR >(2B_{emax})	>(0.1B_{emin}) AND <(0.5B_{emin}) OR >(1.5B_{emax}) AND ≤(2B_{emax})	≥(0.5B_{emin}) AND <B_{emin} OR >B_{emax} AND ≤(1.5B_{emax})	≥B_{emin} AND ≤B_{emax}	5
f, Native ground per cent cover (other)	≤(0.1B_{fmin}) OR >(2B_{fmax})	>(0.1B_{fmin}) AND <(0.5B_{fmin}) OR >(1.5B_{fmax}) AND ≤ (2B_{fmax})	≥(0.5B_{fmin}) AND <B_{fmin} OR >B_{fmax} AND ≤(1.5B_{fmax})	≥B_{fmin} AND ≤B_{fmax}	10
g, Exotic plant per cent cover	≥90	>50 AND <90	>20 AND ≤50	≤20%	5
h, Number of trees with hollows	=0 (unless B_h includes 0)	>0 AND <(0.5B_h)	≥(0.5B_h) AND <B_h	≥B_h	30
i, Proportion of over-storey species occurring as regeneration	=0	>0 AND <0.5	≥0.5 AND <1	1	10
j, Total length of fallen logs	≤(0.1B_j)	>(0.1B_j) AND <(0.5B_j)	≥(0.5B_j) AND <B_j	≥B_j	5

B_x is the benchmark value for the variable x, B_{xmin} refers to the lower benchmark value for variable x and B_{xmax} refers to the upper benchmark value for variable x.

where *z* is the *n*th vegetation zone, s_v is the score for *v*th variable (*a–j*) as defined in Table 6, w_v is the weighting for the *v*th variable (*a–j*) as defined in Table 6, *a* is a constant weighting given to the interaction terms (we used 5), $k = (s_d + s_e + s_f)/3$, i.e. is the average score for these variables on a site, *c* is the maximum score that can be obtained given the variables that occur in the benchmark for the vegetation type (so a vegetation type does not get a higher score simply because it naturally contains more of the measured variables), Zone Area is the total area of the *n*th vegetation zone in hectares.

The first part of the Site Value metric (scaled from 0 to 100) was multiplied by area to the power of one. While the likelihood of occurrence or abundance of most species increases with area in a non-linear relationship, we use an exponent of one for area because this measure is a surrogate for biota and for ecosystem processes at this scale. Stephens et al. (2002) suggested that general ecosystem services increase at a near linear relationship with the area of habitat. A proposal to clear native vegetation was assessed as improving or maintaining environmental outcomes for biodiversity at this scale if gains to Site Value at the offset site were greater than, or equal to, losses at the clearing site. Changes to vegetation as a result of a proposal to clear or to offset the impacts of clearing on a site were predicted separately for each of the ten variables in the Site Value metric. Changes (negative and positive) to each variable brought about by proposals were predicted on the scale of the score (i.e. 0–3) rather than on the original scale that the variable was measured (e.g. per cent cover) so that the impacts of management could be predicted consistently between assessments and assessors since there are few quantitative data on the response by each variable to different management actions. Most management actions with positive effects on vegetation condition could increase the score for an individual variable by one increment (i.e. from 0 to 1, 1 to 2 or 2 to 3). This was to reflect the time it takes to restore native ecosystems, and uncertainty regarding the efficacy of many management actions. Movement of the score by two increments was permitted only for selected variables and management actions that have a low risk of failure. Further details are provided in Gibbons et al. (2005). One variable (viz. hollows suitable for vertebrate fauna) could not be increased by management because hollows begin to develop in eucalypts from approximately 120–250 years of age (Gibbons and Lindenmayer, 2002), which is too long to reliably predict that a management action will be effective.

REFERENCES

Andreasen, J.K., O'Neill, R.V., Noss, R., Slosser, N.C., 2001. Considerations for the development of a terrestrial index of ecological integrity. Ecological Indicators 1, 21–35.

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

Auditor-General of New South Wales, 2006. Regulating the clearing of native vegetation. Follow-up of 2002 Performance Audit. The Audit Office of New South Wales, Sydney.

Bennett, A.F., 1999. Linkages in the landscape. In: The Role of Corridors and Connectivity in Wildlife Conservation, IUCN, Gland, Switzerland.

Bennett, A.F., Ford, L.A., 1997. Land use, habitat change and the conservation of birds in fragmented rural environments: a landscape perspective from the northern plains, Victoria, Australia. Pacific Conservation Biology 3, 244–261.

Benson, J., 1999. The native vegetation of New South Wales. Background Paper Number 1. Native Vegetation Advisory Council of New South Wales, Sydney.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., Hilton-Taylor, C., 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16, 909–923.

Cogger, H., Ford, H., Johnson, C., Holman, J., Butler, D., 2003. Impacts of Land Clearing on Australian Wildlife in Queensland. WWF Australia, Brisbane.

Department of Environment and Conservation, 2003. New South Wales State of the Environment 2003. Department of Environment and Conservation, Sydney.

Diamond, J., 2005. Collapse. How Societies Choose to Fail or Succeed. Penguin, New York.

DLWC, 1999. Staff Guidelines for the Assessment of Clearing Applications Under the Native Vegetation Conservation Act 1997. New South Wales Department of Land and Water Conservation, Sydney.

Downes, S.J., Handasyde, K., Elgar, M., 1997. The use of corridors by native mammals in fragmented Australian eucalypt forests. Conservation Biology 11, 718–726.

FAO, 2005. Global Forest Resources Assessment 2005. Food and Agriculture Organization of the United Nations, Rome.

Ferrier, S., Drielsma, M., Manion, G., Watson, G., 2002a. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales II. Community-level modelling. Biodiversity and Conservation 11, 2309–2338.

Ferrier, S., Watson, G., 1997. An Evaluation of the Effectiveness of Environmental Surrogates and Modelling Techniques in Predicting the Distribution of Biological Diversity. Environment Australia, Canberra.

Ferrier, S., Watson, G., Pearce, J., Drielsma, M., 2002b. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales I. Species-level modelling. Biodiversity and Conservation 11, 2275–2307.

Forman, R.T.T., 1995. Land Mosaics—The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, UK.

Gaston, K.J., 1996. What is biodiversity? In: Gaston, K.J. (Ed.), Biodiversity. A Biology of Numbers and Difference. Blackwell Science, Oxford, pp. 1–12.

Gibbons, P., Ayers, D., Seddon, J., Doyle, S., Briggs, S., 2005. BioMetric Version 1.8. A Terrestrial Biodiversity Assessment Tool for the NSW Property Vegetation Plan Developer. Operational Manual. Department of Environment and Conservation (NSW), unpublished.

Gibbons, P., Boak, M., 2002. The value of paddock trees for regional conservation in an agricultural landscape. Ecological Management and Restoration 3, 205–210.

Gibbons, P., Lindenmayer, D.B., 2002. Tree Hollows and Wildlife Conservation in Australia. CSIRO Publications, Collingwood.

Gibbons, P., Lindenmayer, D.B., 2007. Offsets for land clearing: no net loss or the tail wagging the dog? Ecological Management and Restoration 8, 26–31.

Hilderbrand, R.H., Watts, A.C., Randle, A.M., 2005. The myths of restoration ecology. Ecology and Society 10.

Hobbs, R.J., Kristjanson, L.J., 2003. Triage: how do we prioritize health care for landscapes? Ecological Management and Restoration 4, S39–S45.

Holling, C.S., Meffe, G.K., 1996. Command and control and the pathology of natural resource management. Conservation Biology 10, 327–328.

Karr, J.R., 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1, 66–84.

Kavanagh, R.P., Bamkin, K.L., 1994. Distribution of nocturnal forest birds and mammals in relation to the logging mosaic in south-eastern New South Wales, Australia. Biological Conservation 19, 41–53.

Kinross, C., 2000. Birds in shelterbelts. Ph.D. Thesis. Charles Sturt University, Bathurst.

Kishor, N., 2004. Does improved governance contribute to sustainable forest management? Journal of Sustainable Forestry 19, 55–79.

Landres, P.B., Morgan, P., Swanson, F.J., 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9, 1179–1188.

Lindenmayer, D.B., Smith, P.L., Possingham, H.P., Fischer, J., Oliver, I., McCarthy, M.A., 2002. The focal-species approach and landscape restoration: a critique. Conservation Biology 16, 338–345.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 415, 243–253.

Martin, T.G., McIntyre, S., Catterall, C.P., Possingham, H.P., 2006. Is landscape context important for riparian conservation? Birds in grassy woodland. Biological Conservation 127, 201–214.

McDonald, T., 2000. Strategies for the ecological restoration of woodland plant communities: harnessing natural resilience. In: Hobbs, R.J., Yates, C.J. (Eds.), Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration. Surrey Beatty & Sons, Chipping Norton, pp. 286–297.

McElhinny, C., Gibbons, P., Brack, C., Bauhaus, J., 2006. Fauna-habitat relationships: a basis for identifying key stand structural attributes in Australian eucalypt forests and woodlands. Pacific Conservation Biology 12, 89–110.

McElhinny, C., Gibbons, P., Brack, C., Bauhus, J., 2005. Forest and woodland stand structural complexity: its definition and measurement. Forest Ecology and Management 218, 1–24.

McIntyre, S., McIvor, J.G., Heard, K.M., 2002. Managing and Conserving Grassy Woodlands. CSIRO Publishing, Collingwood.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

Morton, S., Bourne, G., Crisofani, P., Cullen, P., Possingham, H., Young, M., 2002. Sustaining our natural systems and biodiversity. An Independent Report to the Prime Minister's Science and Engineering Innovation Council. Environment Australia and CSIRO, Canberra.

New South Wales Government, 2005. Native Vegetation Regulation 2005: Environmental Outcomes Assessment Methodology. NSW Department of Natural Resources, Sydney.

Noss, R.F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4, 355–364.

Oliver, I., 2003. An expert panel approach to the assessment of vegetation condition within the context of biodiversity conservation. Stage 1: the identification of condition indicators. Ecological Indicators 2, 223–237.

Oliver, I., Parkes, D., 2003. A Prototype Toolkit for Scoring the Biodiversity Benefits (and Disbenefits) of Landuse Change. Version 5. Department of Land and Water Conservation, Sydney.

Parkes, D., Newell, G., Cheal, D., 2003. Assessing the quality of native vegetation: the 'habitat hectares' approach. Ecological Management and Restoration S29–S38.

Parsons, M., Thoms, M.C., Norris, R.H., 2004. Development of a standardised approach to river habitat assessment in Australia. Environmental Monitoring and Assessment 98, 109–130.
Pressey, R.L., Hagar, T.C., Ryan, K.M., Schwarz, J., Wall, S., Ferrier, S., Creaser, P.M., 2000. Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. Biological Conservation 96, 55–82.
Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., Williams, P.H., 1993. Beyond opportunism: key principles for systematic reserve selection. Trends in Ecology and Evolution 8, 124–128.
Race, M.S., Fonseca, M.S., 1996. Fixing compensatory mitigation: what will it take? Ecological Applications 6, 94–101.
Radford, J.Q., Bennett, A.F., Cheers, G.J., 2005. Landscape-level thresholds of habitat cover for woodland-dependent birds. Biological Conservation 124, 317–337.
Reid, J.R.W., 2000. Threatened and declining birds in the New South Wales Sheep-wheat Belt: II. Landscape relationships—modelling bird atlas data against vegetation cover. Consultancy Report to NSW National Parks and Wildlife Service. CSIRO Sustainable Ecosystems, Canberra.
Roloff, G.J., Kernohan, B.J., 1999. Evaluating reliability of habitat suitability index models. Wildlife Society Bulletin 27, 973–985.
Rosenzweig, M.L., 1995. Species Diversity in Space and Time. Cambridge University Press, Melbourne, Australia.
Smith, P.L., Wilson, B., Nadolny, C.D.L., 2000. The Ecological Role of the Native Vegetation of New South Wales. Native Vegetation Advisory Council of NSW, Sydney.
Soderquist, T.R., MacNally, R., 2000. The conservation value of mesic gullies in dry forest landscapes: mammal populations in the box-ironbark ecosystem of southern Australia. Biological Conservation 93, 281–291.
Spooner, P.G., Lunt, I.D., 2004. The influence of land-use history on roadside conservation values in an Australian agricultural landscape. Australian Journal of Botany 52, 445–458.
Stephens, T., Brown, D., Thornley, N., 2002. Measuring Conservation Achievement: Concepts and their Application Over the Twizel Area. Science for Conservation 2000. New Zealand Department of Conservation, Wellington.
The Australian Greenhouse Office, 2005. Greenhouse Gas Emissions From Land Use Change in Australia: Results of the National Carbon Accounting System 1988–2003. Department of the Environment and Heritage, Canberra.
Turner, M.G., 2005. Landscape ecology: what is the state of the science? Annual Review of Ecology Evolution and Systematics 36, 319–344.
US Fish and Wildlife Service, 1980. Habitat Evaluation Procedures. Department of the Interior, Washington, DC.
Walker, B., Salt, D., 2006. Resilience Thinking. Sustaining Ecosystems and People in a Changing World. Island Press, Washington, DC.
Wear, D.N., Greis, J.G., 2002. Southern forest resource assessment. Gen. Tech. Rep. SRS-54. US Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.
Wentworth Group of Concerned Scientists, 2003. A New Model for Landscape Conservation in New South Wales. WWF Australia, Sydney.
Westoby, M., Walker, B., Noy-Meir, I., 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management 42, 266–274.