Biodiversity Conservation Trust

Biodiversity Conservation Trust Ecological Monitoring Module

This document outlines the Ecological Monitoring Module of the BCT's Monitoring, Evaluation, Reporting (MER) Framework.

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Contents

Acknowledgements 4
1 Introduction 5
2 Objectives 6
2.1 Statutory and organisational objectives 6
2.1.1 Biodiversity Conservation Act 2016 6
2.1.2 Biodiversity Conservation Investment Strategy 6
2.1.3 Biodiversity Offsets Scheme (BOS) 7
2.1.4 Amalgamated objectives 7
2.2 Objectives of the ecological monitoring program 7
2.2.1 Ecological questions 8
3 Conceptual Framework 9
3.1 Hierarchical design 10
3.1.1 How much to monitor 10
3.1.2 What to measure 12
3.1.3 Fit-for-purpose monitoring 13
3.2 Outcome targets 15
3.3 Compliance monitoring 17
4 Measuring ecological integrity 17
4.1 Vegetation integrity 17
4.2 Soil function 20
4.3 Threatened species values 21
4.3.1 Koalas 21
4.3.2 Other threatened species and TECs 21
4.4 Other values 22
4.5 Measuring management effectiveness 22
4.5.1 Monitoring total grazing pressure 24
4.5.2 Fire 25
4.5.3 Documenting management effort 25
4.6 Complementary Data Collection 25
4.7 Landholder monitoring 26
4.7.1 Citizen science 27
5 Sampling design 27
5.1 Baselines 27
5.2 Replication, Stratification and controls 28
5.2.1 Control sites 29
5.2.2 Power analysis 31
6 Data management 32

6.1 Field data collection 33
6.2 Centralised data repository 33
7 Evaluation and reporting 33
7.1 Evaluating ecological outcomes 33
7.2 Quantifying return-on-investment 35
7.2.1 Aggregated Ecological Condition Index 35
7.2.2 Complementary data sources – remote sensing and modelling 36
7.2.3 Statistical analyses 37
8 References 38

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1 INTRODUCTION

The success of any natural resource management organisation (and its landholder partners) is highly dependent on the quality of its monitoring and evaluation program. For the BCT, demonstrating return on its significant investment in biodiversity conservation and ensuring its activities are leading to optimal ecological outcomes, are critical. Both will be informed by the ecological monitoring program described here.

Over the past decade there has been much written in the scientific literature about the importance of ecological monitoring and what constitutes best practice (e.g. Lindenmayer and Gibbons 2012). This has included several documented examples of ecological monitoring programs delivering poor or suboptimal outcomes (e.g. Hajkowicz 2009; O'Keefe *et al.* 2015). There is now general consensus among the scientific community on the attributes of an effective ecological monitoring program:

1. based on meaningful ecological questions;
2. refers to conceptual models of ecological processes;
3. involves strong partnerships between scientists, policy-makers and land managers;
4. strong and consistent leadership;
5. supported by secure ongoing funding;
6. regularly uses data to inform decisions and adapt; and
7. maintains rigorous data collection and management protocols (Lindenmayer and Likens 2010).

The BCT has the requisite expertise, governance and support systems in place to ensure that its ecological monitoring program conforms to all of the above.

There are some additional guiding principles informing the approach to ecological monitoring and program design, which have come from lessons learned following the evaluation of similar private land conservation programs in Australia. First, the importance of monitoring ecological outcomes is proportionate to the risk of not monitoring. In this context, risk may be ecological (e.g. improvement in biodiversity values at a Biodiversity Stewardship Agreement (BSA) is insufficient to adequately offset the loss for which associated credits were generated), financial (e.g. biodiversity values at a Conservation Agreement (CA) site secured through BCT investment are degraded or lost) or reputational (e.g. landholder non-compliance and/or degradation or loss of biodiversity values at an agreement site leads to widespread perception of poor governance and erodes the credibility of the BCT).

Second, investment in ecological monitoring should be cost-effective, because any investment in monitoring in excess of what is sufficient to meet the program's objectives (see below) reduces the availability of resources to deliver management programs, thereby reducing biodiversity outcomes. In practice, this means prioritising investment and targeting monitoring based on where the utility of the information gained is greatest (McDonald-Madden *et al.* 2010; Possingham *et al.* 2012). Generally, this relates to critical reporting requirements for the BCT and dependent programs, values/assets associated with significant risk (i.e. see above), management with highly uncertain outcomes (e.g. vertebrate pest management, grassland restoration) or opportunities to address ecological knowledge gaps (e.g. under-surveyed ecosystems, validating novel monitoring techniques, testing ecological models underpinning decision-making).

The scope of this module includes the monitoring and evaluation of all ecological outcomes from the BCT's investment in private land management (i.e. BSAs, CAs, Wildlife Refuge Agreements [WRA] and legacy agreements [e.g. BioBanking, Nature Conservation Trust [NCT], including grant programs at these sites). The module responds to and aligns with the overarching *BCT Monitoring, Evaluation, Reporting (MER) Framework*.

2 OBJECTIVES

The stated Vision and Purpose of the BCT includes, '*....to maximise the biodiversity conservation outcomes achieved with...resources entrusted to the BCT…*' This is guided by the overarching objectives of the *Biodiversity Conservation Act 2016* (BCT Act), the legislation that provides for the establishment of the BCT and delivery of its programs and articulated further in the *Biodiversity Conservation Investment Strategy* (BCIS). It is this broad objective which will set the priorities for the BCT's ecological monitoring program, outlined in this document.

2.1 STATUTORY AND ORGANISATIONAL OBJECTIVES

2.1.1 Biodiversity Conservation Act 2016

The stated purposes (objectives) of the BC Act relevant to this module, are:

a) '*to conserve biodiversity at bioregional and State scales,*

b) *to maintain the diversity and quality of ecosystems and enhance their capacity to adapt to change and provide for the needs of future generations,*

c) *to improve, share and use knowledge, including local and traditional Aboriginal ecological knowledge, about biodiversity conservation,*

d) *to support biodiversity conservation in the context of a changing climate,*

e) *to support collating and sharing data, and monitoring and reporting on the status of biodiversity and the effectiveness of conservation actions,*

f) *to support conservation and threat abatement action to slow the rate of biodiversity loss and conserve threatened species and ecological communities in nature,*

g) *to support and guide prioritised and strategic investment in biodiversity conservation,*

h) *to encourage and enable landholders to enter into voluntary agreements over land for the conservation of biodiversity,* and

i) *to establish a scientific method for assessing…improvements in biodiversity values* [to offset impacts from development and land use change].'

2.1.2 Biodiversity Conservation Investment Strategy

The purpose of the Biodiversity Conservation Investment Strategy (BCIS) is to guide the BCT's investment in private land conservation to maximise outcomes in line with statutory objectives outlined above. It includes the specific objective, '*to optimise biodiversity outcomes at bioregional and state scales,*' through conservation of the least protected ecosystems, improving landscape connectivity and working towards a comprehensive, adequate and representative (CAR) protected area system for NSW. The BCIS also includes an investment principle whereby, '*Investment in private land conservation should seek to maximise conservation benefits*' by targeting the following conservation assets:

- good examples of the least protected ecosystems;
- NSW Landscapes not represented or inadequately protected by the protected area system;
- large areas of remnant native vegetation (core areas);
- biodiversity corridors;
- climate refugia; and
- other high value conservation assets (e.g. threatened species).

2.1.3 Biodiversity Offsets Scheme (BOS)

The BCT Business Plan (2017/18-2020/21) includes a Strategic Goal, to '*deliver a strategic biodiversity offsetting service…consistent with the Biodiversity Offset Scheme rules*.' This includes the administration of Biodiversity Stewardship Agreements, which secure those biodiversity values required to offset losses, assessed through application of the Biodiversity Assessment Method (BAM), having the objective of contributing to achieving no net loss of biodiversity in NSW.

2.1.4 Amalgamated objectives

With reference to the above, the following ecological objectives have been interpreted to inform the BCT ecological monitoring program:

1. to maintain or improve, as required, the ecological integrity of agreement sites;
2. to maximise return on investment, in terms of biodiversity value (comprising dimensions of area, condition, change in condition, representativeness and security);
3. to ensure that improvement in biodiversity values at BSA sites is consistent with the assumptions of the BAM supporting the generation of biodiversity credits, and is contributing to achieving no net loss to biodiversity; and
4. to gain ecological knowledge required to improve management effectiveness and support strategic decision making.

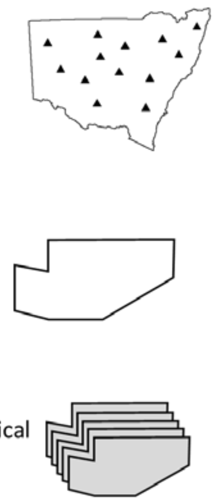
2.2 OBJECTIVES OF THE ECOLOGICAL MONITORING PROGRAM

The specific objectives of the BCT's ecological monitoring program, as distinct from the BCT's ecological objectives, are:

1. to collect and analyse data to inform evaluation and reporting of ecological outcomes against relevant BCT objectives and demonstrate return on investment to the Board, Government, landholders and the wider community;
2. to enable evaluation of management effectiveness and test assumptions about improvement in biodiversity values, the security of those values, and the relationships between different indicators of ecological integrity;
3. to support broader evaluation of the outcomes of the BC Act; and

4. to collate and manage ecological data so that it is accessible, reliable, useful, and can support the BCT's reporting requirements for the Board, the Minister, and the community (e.g. informing the compilation of an aggregated ecological condition index [organisational KPI]).

The articulation of Specific, Measurable, Achievable, Relevant and Time-bound (SMART) objectives is important (Maxwell *et al.* 2015), as they will inform the development of ecological questions and associated indicators, which subsequently inform the selection of appropriate monitoring design and methods (see Figure 1).



	Objectives	Questions	Indicators*
State-wide	• Maximise total biodiversity value • Maximise BCT return on investment • Contribute to no net loss under the BOS	• What is the aggregate area, condition, connectivity and biodiversity 'value' of ecological assets? • What is the contribution to the viability of high environmental value assets (e.g. threatened species/ecological communities, over-cleared vegetation types)? • What is the contribution to a C.A.R. reserve system? • What amount of risk reduction is conferred by entering into agreements with landholders? • Is aggregate ecological gain from BSA sites consistent with the value of associated biodiversity credits?	• Vegetation integrity at agreement and control sites • State (extent/condition) of high environmental value assets • Total loss of woody vegetation from the landscape • Modelled biodiversity value (e.g. environmental dissimilarity)
Site	• Maintain or improve ecological integrity • Enhance biodiversity values in line with assumptions generating biodiversity credits	• What is the ecological condition of the conservation area, compared to target/BAM gain predicted condition and controls? • What is the state of any specified high environmental value assets, compared to target state? • What is the security value of the landholder agreement?	• Vegetation integrity compared to bioregional control sites • Ecologically relevant, value-specific indicators for particular assets (e.g. species abundance) • Loss of woody vegetation from biophysically similar sites in the bioregion
Methodological	• Improve management effectiveness and decisions	• Is vegetation integrity improving as expected (e.g. as predicted by BAM gain models)? • Are target ecological values responding as expected to targeted management (e.g. weed control, grazing management)? • Are different indicators of ecological integrity in agreement and/or fit for purpose?	• Attributes of vegetation integrity (i.e. composition, structure, function) • Management effort • Ecologically relevant, value-specific indicators for particular assets at agreement and control sites • Complementary biodiversity indicators (e.g. soil function, faunal activity, soundscapes, eDNA)

Figure 1: Ecological objectives, questions and indicators associated with three different scales of BCT management and ecological outcomes.

**Addressing some ecological questions will require the integration and interpretation of multiple indicators and data*

2.2.1 Ecological questions

The monitoring program will address ecological questions at three main scales; state-wide, site (conservation area under agreement within property), and methodological (i.e. types of management activity or objectives, across multiple sites) (Figure 1). Each scale is important for different reasons: State-wide questions allow for program-level evaluation of the BCT's outcomes and inform high-level reporting to the Board, government and wider community. Site level questions enable evaluation of progress against site-specific objectives and can inform adaptive improvement of management actions. Finally, methodological questions facilitate generalised learning and improvement in the evidence base for decisions; for example, contributing the ongoing refinement of models relied on by the offsets program, or reducing uncertainty / improving effectiveness in threat abatement.

Specifying ecological questions also provides support for specific aspects of monitoring design, in particular, the use of replication and controls. For example, if it is important from an evaluation perspective to quantify the value (or change in value) of biodiversity directly attributable to BCT investment – as opposed to background environmental change (e.g. drought) – then controls are crucial (see *Controls* below).

3 CONCEPTUAL FRAMEWORK

The foundational concept of this module is that ‘ecological integrity’ – comprising elements of vegetation integrity and soil function, and assessed via plot-based sampling of the landscape – is an indicator surrogate of the biodiversity values protected and managed via BCT investment at agreement sites. This assumption is generally supported by the scientific literature (e.g. Oliver *et al.* 2014 Hunter *et al.* 2015). To comprehensively assess biodiversity outcomes, however, complementary methods and indicators are required, and different monitoring prescriptions are required depending on the different focal values, ecological questions and scale. The framework guiding the design of monitoring in this module is based on different types of agreement sites having different ecological monitoring requirements. There are several factors influencing the ecological monitoring prescription for a given site, comprising *how much* and *what*, to monitor. Table 1 summarises these factors and provides a basis for determining methods appropriate for each scenario.

Table 1: Conceptual framework for site-specific monitoring prescriptions.

Factor	Explanation	Variable element(s)	Application
How much to monitor			
Risk	Ecological, financial or reputational risk of not monitoring the site	Frequency, intensity and precision	Sites with greater risk (e.g. BSAs) to receive greater monitoring effort/investment relative to those with lower risk (e.g. unfunded agreements)
Uncertainty	Limited understanding of ecological processes causes high uncertainty in the response of biodiversity values to management	Scientific rigour	Investment in a more rigorous / adaptive management approach is appropriate for highly uncertain management interventions (e.g. grassland restoration, resource supplementation)
Rate of change	Particular sites, values and ecological attributes are expected to change at different rates	Frequency	Re-survey interval is determined based on the likelihood of detecting meaningful change in the attribute(s) measured
What to measure			
Objective	What is the predicted or intended ecological outcome of BCT investment?	Monitoring method / indicators	Monitoring prescription is tailored to the site-specific management objective (e.g. maintenance vs improvement)

Additional values	Some agreement sites will contain ecological values for which standard plot-based ecological integrity measures are not an appropriate surrogate	Monitoring method, intensity	Threatened species and/or their habitat, for example, have targeted monitoring protocols (aligned with SoS) in addition to plot-based measures

3.1 HIERARCHICAL DESIGN

3.1.1 How much to monitor

3.1.1.1 Risk

Given the large number (>1000 and growing year-on-year), size (2-2000ha) and distribution of BCT agreements, comprehensively monitoring all variation in all aspects of biodiversity across all agreement sites would be prohibitively expensive (as well as including a level of redundancy). Therefore, as is conventional for most environmental monitoring, the ecological monitoring program design will be based on the use of surrogates and a series of assumptions. These assumptions include:

- ‘vegetation integrity’ and ‘soil function’ (defined below) are adequate surrogates for site biodiversity value;
- establishment of a BCT agreement significantly reduces the likelihood of total loss of biodiversity values from a site, relative to biophysically and geographically similar sites without an agreement (or similar statutory protection);
- for an agreement site in high condition, in the absence of anthropogenic disturbance and with only ‘maintenance’ level management, its biodiversity value will remain stable through time, relative to controls;
- implementation of appropriate management actions will result in an improvement in the target biodiversity values over time (specifically for BSA sites, predicted improvement underpinning the generation of biodiversity credits), relative to controls;

The application of monitoring effort is hierarchical – proportionate to the risk associated with any of the above being faulted. In general, this risk can be categorised by agreement type – BSA sites (including Offset CAs for the purposes of this document) having the greatest risk (i.e. failing to adequately offset biodiversity loss), funded CA sites having relatively lower, but significant risk (i.e. ineffective investment of government resources), and unfunded sites having a low risk (predominantly a reputational risk to the BCT if there was undetected non-compliance or degradation of biodiversity values, including at adjacent sites) (see Figure 2).

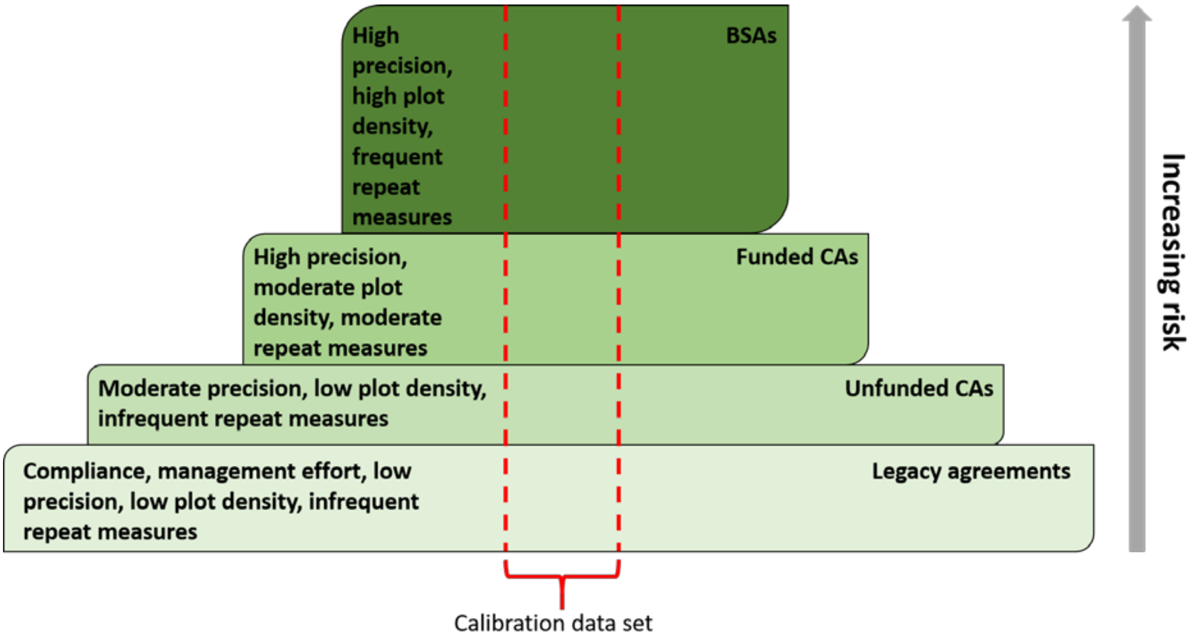


Figure 2: Hierarchy of monitoring effort by agreement type.

The design is nested, such that for sites in each tier moving up the hierarchy, additional monitoring effort is cumulative. For example, compliance and management effort (where relevant) monitoring will occur at all sites, and the subset of sites receiving the highest precision, intensity and frequency of monitoring will produce data equivalent to each lower tier. The benefit of the nested hierarchical design is that it produces a matched data set which enables comparison and calibration of methods across all tiers. Such analyses should support evaluation of state and change of biodiversity values at all agreement sites, by allowing inferences to be made in the interpretation of data from rapid / low precision methods (where demonstrated to be valid). Consequently, evaluation and reporting of outcomes

(if/where rapid, low precision methods are shown to have explanatory power), without a requirement for resource-intensive monitoring minimal investment in a significant proportion of sites (i.e. 100% of sites receive some form of monitoring). The approach will also facilitate adaptive improvement in lower-cost methods to maximise their explanatory power and utility over time.

3.1.1.2 Uncertainty

Ecological uncertainty poses a different form of risk. In under-studied and/or complex systems where there is scant empirical evidence for the effectiveness of management interventions, there is a risk that investment in management will result in poor outcomes. In these scenarios, taking an adaptive management approach is warranted. Adaptive management refers to a process whereby management and monitoring are designed for the purpose of learning something about the system (McCarthy & Possingham 2007). This approach is generally more resource intensive, as it involves a more rigorous monitoring design, including replication and controls. Management scenarios where such a design is recommended may include:

- vertebrate pest control;
- active grassland restoration
- resource supplementation (e.g. nest-boxes); or
- ecological burning.

Given the additional expense, it is important that any application of adaptive management considers the likely value of the information to be gained – in terms of its ability to inform management decisions – relative to the costs incurred (Runge *et al.* 2011).

3.1.1.3 Rate of change

Under a cost-effective program the frequency of monitoring (i.e. inter-survey interval) should be the minimum required to adequately detect ecological change. This will vary dependent on the ecological attribute in question and its likely rate of change. For example, in most mature/climax communities, attributes such as canopy cover (opaque crowns) and density of large trees are likely to change very slowly (i.e. on a decadal scale), therefore monitoring is only required infrequently (e.g. 5-10 year interval). In contrast, relatively rapid change is expected in early successional stages (e.g. during active restoration or following fire), which may necessitate relatively frequent monitoring (e.g. annual, quarterly). At the site scale, sites (or vegetation zones) in low or moderate condition are much more likely to exhibit measurable change over a given period than high condition sites. This adds an extra dimension to the hierarchical design – whereby sites and/or specific ecological attributes will have a monitoring frequency informed by the likelihood of exhibiting observable change within the return interval.

3.1.2 What to measure

3.1.2.1 Objective

It is important for any monitoring regime to be informed by an ecological objective. The ecological objectives broadly guiding this module are outlined in Figure 1, however, these require translation into site-specific objectives to inform selection of appropriate methods and indicators at the site scale (Burgman *et al.* 2012). In practice, this will mean the application of alternative monitoring prescriptions for agreement sites or vegetation zones, dependent on the desired ecological outcome (see Table 2). For example:

- for a high condition site where the primary objectives are averted loss and maintenance of condition, monitoring should focus on quantifying risk-reduction (e.g. desktop analysis; see 7.2.2.1) and apply relatively low precision plot-based methods (sufficient to detect decline outside of acceptable margins);
- where there is a specific objective to improve biodiversity values (e.g. 'enhance' or restore' zone or where biodiversity credits have been generated based on predicted gain), monitoring should have high precision and frequency, sufficient to detect the expected change and evaluate progress against the relevant objective.

3.1.2.2 Additional values

In addition to the suite of biodiversity values at an agreement site that are assumed to be represented by the standard indicators of ecological integrity (see below), there are other important biodiversity values for which plot-based measures of ecological integrity are not an appropriate surrogate (or require additional direct measures for comprehensive assessment). These include (but are not limited to):

- koala habitat;
- other threatened species and/or their habitat;
- wetlands; and
- response to management activities (e.g. strategic grazing, pest animal and weed control, revegetation, habitat enhancement).

Agreement sites (within relevant zones) should be subject to targeted monitoring of specific indicators required to adequately assess state and change in these values, in addition to the standard plot-based measures (Table 2).

3.1.3 Fit-for-purpose monitoring

The most important consideration when designing a monitoring prescription for a given agreement site is whether it is fit-for-purpose. The prescriptions outline above and in Table 2 should be interpreted as recommendations in the context of highly variable environmental conditions and management scenarios between agreement sites, all of which cannot be represented here. Wherever these prescriptions are deemed inappropriate by relevant persons with detailed ecological knowledge of a site, modifications are valid, so long as the monitoring is consistent with the principles articulated in Table 1: i.e. the design considers risk, uncertainty, specific biodiversity values under management, the expected change in those values and the objectives of management.

This also applies to cost-effectiveness – i.e. the monitoring regime for a given agreement site should be designed such that it answers the required ecological questions in the most cost-effective way, which may require trade-offs. For example, different management or vegetation zones within a conservation area may require different or misaligned monitoring frequencies based on the recommendations in Table 2, which if strictly adhered to, would require frequent site visits to monitor particular zones. Under such circumstances it would be appropriate to reduce the monitoring frequency of some zones in order to streamline monitoring across the property and minimise site visits overall. These decisions should also be made in the context of travel time to and from the site, as well as associated disturbance of landholders (e.g. a site visit to monitor a single zone may be justified if the associated travel is minimal and the landholder is amenable).

Table 2: Summary of monitoring regime recommendations relevant to different types of agreement sites and management types, based on different attributes, following the hierarchical approach. See the Ecological Monitoring Operational Manual for more detail.

			Plot-based monitoring		
Agreement type	**Management/objective type**	**Frequency**	**Intensity**	**Precision**	**Additional measures**
BSA	High condition (Required management actions only)	5 years	High	Moderate	Desktop risk analysis (see 7.2.2.1)
	Low-moderate condition (Required management actions only)	5 years	High	High	Desktop risk analysis
	Low-moderate condition (Active restoration actions)	2-5 years	High	High	Desktop risk analysis
	Generating species credits or Threatened Ecological Communities (TECs)	Species-dependent (generally annual)	High	High	Direct population or surrogate measure (as per SoS* monitoring plan)
Funded CA	High condition (maintain actions only)	5 years	Low	Moderate	Desktop risk analysis
	Low-moderate condition (Enhance/restore actions)	2-5 years	High	High	Desktop risk analysis
	Koala habitat	5 years	High	Moderate	Koala monitoring module (see 4.3.1)
	Other threatened species, TEC, or special values	Species-dependent (generally annual)	High (TECs)	High (TECs)	Direct population or surrogate measure (as per SoS* monitoring plan)
BSA (active restoration) and funded CA (enhance / restore) (also see Table 5)	High threat weed control	2 years (initial); then 5 years	High	High	Infestation boundary map
	Native herbivore management	2-3 years	High	High	Biomass exclosures (see 4.5.1)
	Ecological burning	5 years	High	High	More frequent monitoring of recruitment/ground-layer attributes as appropriate
	Introduced herbivore control	2 years (initial); then 5 years	High	High	Remote camera herbivore monitoring or disturbance impacts
	Introduced predator control	Annual (initial); then 5 years	n/a	n/a	Remote camera predator monitoring**
	Habitat enhancement	Annual (initial); then 5 years	n/a	n/a	Resource-specific occupancy monitoring
	Supplementary planting	Annual – 2 years (initial); then 5 years	High	High	Stem survival and disturbance impacts monitoring
Voluntary (unfunded) agreements	No funded management	10 years	Low	Low	Desktop risk analysis
	Grant-funded management	5 years	Low	Moderate	Management-specific methods as above
Legacy*** agreements	All legacy sites	10 years	1/agreement	Low	None
Control sites	All control sites	5 years	As feasible	High	Management-specific methods as above, where relevant[c]

**Saving our Species program ** Under specific conditions only (see Table 5) ***Includes BioBanking agreements established under the Threatened Species Conservation Act, CAs and Wildlife Refuges (WRs) established under the National Parks and Wildlife Act, Nature Conservation Trust agreements and Registered Property Agreements;*

3.2 OUTCOME TARGETS

Monitoring of ecological indicators is necessary to document state and change in biodiversity values under management, however, properly evaluating outcomes requires some form of target or reference (i.e. understanding if the program has been successful is only possible if 'success' is clearly defined). Targets also provide triggers for review and amendment of management where desired ecological outcomes are not being achieved, as per a passive adaptive management approach.

Target outcomes should be defined with reference to either a control, a conceptual model, a known benchmark state, or a combination of these. Targets do not necessarily need to be quantitative or highly precise, but should be quantifiable in terms of the monitored indicator (to enable comparison with observed values), be described with a level of precision equivalent to the sensitivity of the monitoring, and reflect achievement of the management objective relevant to investment and timeframe (Bakker *et al.* 2000). In practice, most of the targets relevant to BCT agreement sites should be based on either BAM gain models (Fig. 3a; required for all BSA sites), comparison with relevant control sites (see 5.2.1) or a valid conceptual model (Fig. 3b), with the purpose of ensuring outcomes are within acceptable limits of variation (e.g. 'control limits;' Burgman *et al*. 2012) (see Table 3). At a minimum, targets should identify whether the objective of management is maintenance or improvement (e.g. 'maintain *vegetation integrity within 10% of controls'* versus '*increase vegetation integrity at a rate significantly higher than controls'*).

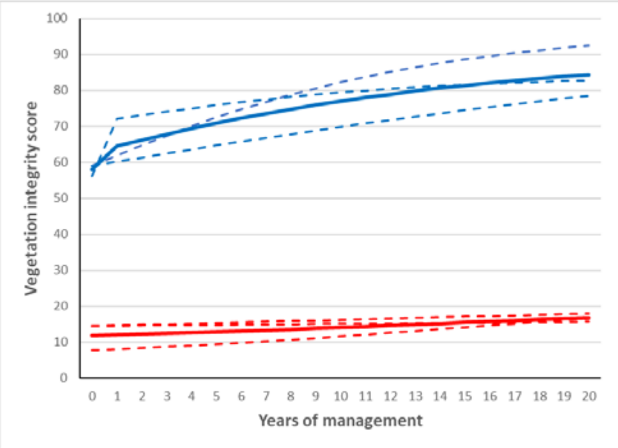
Table 3: Example targets for different management scenarios

Management scenario	Example target(s)
High condition site with maintenance management.	Vegetation integrity score does not decline below 5% of baseline value (or is less than controls).
Assisted regeneration following stock exclusion	Groundcover, soil function and recruitment attributes increase significantly more than controls or as per BAM predictions* for the vegetation community.
Moderate condition site being managed for improvement towards benchmark	Improvement in vegetation integrity is within 10% of the relevant BAM gain predictions* for the vegetation community after 5 years or is significantly greater than controls.
Maintenance of high condition koala habitat	Stem density of feed tree species in all size classes and recruitment, does not decline below 90% of baseline at any point in time.
Targeted management of a threatened plant population currently suppressed by weed infestation	Minimum 10% increase in the number of flowering adults and 20% increase in recruits, within 5 years, or within 10% of BAM-predicted gains for the species.
Habitat supplemented with nest-boxes targeting a threatened arboreal mammal	Minimum of 20% occupancy (breeding) of nest-boxes across the site by the target species, within 5 years.

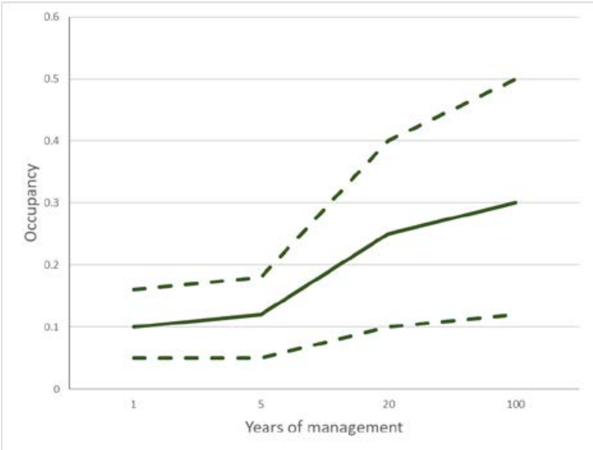
**The Biodiversity Assessment Method (BAM) includes modelling that projects improvement in vegetation integrity for different regional vegetation classes over 20 years, to inform calculation of biodiversity credits at BSA sites (see Figure 3a).*

Targets should be developed for an agreement site or specific to vegetation or management zones, as appropriate, and should be based on what is realistic given the investment in management, baseline condition of the site and prevailing climatic conditions. Information to support target-setting, however, is available from various sources, including the BAM and benchmarks and gain calculations therein (OEH 2017), and *Saving our Species* monitoring plans (and see Mayfield *et al.* 2019) (see Figure 3).

Ultimately, the ability to set meaningful targets will be influenced by the availability of data or knowledge on the target biodiversity values. Targets – as with all aspects of monitoring – should be adaptive, and be updated to reflect learning, and where uncertainty is high, target precision should be set accordingly low. In particular, evaluation against conceptual models (e.g. BAM gain predictions) should proceed with caution where environmental conditions are outside of ‘typical’ (e.g. drought) or where published benchmarks or reference states are inappropriate (e.g. due to low confidence or high attribute variability within regional vegetation classes). In these scenarios the use of appropriate – i.e. biophysically matched – controls for evaluation becomes more important. See the Ecological Monitoring Operations Manual for more detail and guidance on target-setting.



a) BAM predicted gain in vegetation integrity under (required) management for an example regional vegetation class (Western Slopes Grassy Woodland in the South Western Slopes bioregion, with ‘moderate’ starting conditions [all attributes median value]) (solid blue line) and associated structure, composition and function components (broken blue lines), and with ‘poor’ starting conditions (all attributes 25% of benchmark) (solid red line) and associated structure, composition and function components (broken red lines) (OEH 2017).



*b) Predicted increase in occupancy of the long-nosed potoroo (*Potorous tridactylus*) with comprehensive management of threats (e.g. foxes), based on structured expert elicitation (Mayfield et al. 2019).*

Figure 3: Potential data sets for informing target-setting.

3.3 COMPLIANCE MONITORING

The BCT places a strong emphasis on maintaining compliance with all agreements. Management actions are prescribed based on best available evidence and are underwritten by assumptions that their proper application will lead to positive ecological outcomes. The BCT compliance policy indicates that compliance site visits will occur annually for all BSAs and at a frequency proportionate to non-compliance risk for other agreements (generally annually for funded CAs). This compliance monitoring includes an assessment of whether scheduled management actions have been implemented as required, whether specific performance measures have been met (BSAs), and whether landholders have properly documented management effort.

To maximise efficiency, ecological monitoring should be coordinated with on-site compliance monitoring wherever practicable. In particular, annual compliance visits should be used to make qualitative assessments of changes to biodiversity values and inform any revisions to the monitoring regime accordingly. For example, increased frequency of monitoring may be required if there has been fire within the conservation area or an emergent weed infestation.

4 MEASURING ECOLOGICAL INTEGRITY

For the purposes of the *Biodiversity Conservation Act*, biodiversity is the variety of living animal and plant life from all sources and includes diversity within and between species and diversity of ecosystems. In addition, biodiversity values include:

a) vegetation integrity—being the degree to which the composition, structure and function of vegetation at a site and the surrounding landscape has been altered from a near natural state; and
b) habitat suitability—being the degree to which the habitat needs of threatened species are present at a site,

For the purposes of the ecological monitoring program, ecological integrity will comprise *a*, *b* (where relevant), and soil function.

4.1 VEGETATION INTEGRITY

The measurement of vegetation integrity (VI) under this module will be broadly consistent with the established and validated method applied by the BAM (OEH 2017). This is appropriate for several reasons:

- the BAM is used to assess biodiversity values for the establishment of BSAs and a related method – Rapid VI (derived from the BAM, applies a coarser estimation method producing categorical data for attributes rather than continuous) – is used by the BCT to assess site values as part of its Conservation Management Program (CMP);

- NSW Government continues to invest in the collection and management of data relating to benchmark values for ecological attributes and vegetation types referenced by the BAM; and
- the method is consistent with BioNet systematic flora survey method, so can contribute to (and be informed by) the >60,000 plot data set in NSW.

The method has been amended slightly for the purposes of this module, primarily to increase precision and repeatability. The BAM is designed for snapshot assessment purposes rather than for the collection of longitudinal data and detection of ecological change, therefore some elements (e.g. estimates of species cover) are likely to be highly susceptible to inter-operator variability and unreliable indicators of ecological change. The amendments (specifically the high precision methods; detailed below) were designed such that the enhanced data produced remains consistent with the requirements for calculation of a BAM VI score and contributing to the state-wide floristic survey data set, while reducing inter-operator error and maximising likelihood of detecting ecological change.

In line with the broader hierarchical approach of this module, the plot-based vegetation integrity assessment method has a tiered design, based on varying levels of precision. Following the BAM, the method is partitioned into the measurement of three elements – structure, composition and function. The method is summarised in Table 4 and Figure 4. See the Ecological Monitoring Operational Manual for more detail.

Table 4: High, moderate and low precision vegetation integrity assessment methods.

	HIGH	MODERATE	LOW
Composition	Abundance by species (native + exotic) in 20x20m plot	As per BAM	As per Rapid VI
Structure	• Foliage cover by species (native + exotic) in 20x20m plot (as per BAM) • Foliage cover by growth form at 100 (5x20m transects) intercept points within 20x20m plot, for ground layer and midstorey • Overstorey cover assessment at ten 1x1m plots	As per BAM	As per Rapid VI
Function	• Species name, DBH and number of hollows for all tree stems >5cm DBH in 20x50m plot (10x50m plot if >50 stems; 5x50m plot if >100 stems) • Species name, stem count and recruit type* for all tree species in size classes <1cm and 1-5cm max stem diameter • Total length of fallen logs >10cm diameter (measured) • Soil surface condition assessment in ten 1x1m quadrats** • Species x volume of dung within ten 1x1m quadrats	• Count of tree stems >5cm per size class in 20x50m plot (as per BAM) • Presence/absence of tree stems <5cm DBH (as per BAM) • Total length of fallen logs >10cm diameter (as per BAM) • Litter cover in five 1x1m quadrats (as per BAM) • Species x volume of dung within five 1x1m quadrats	• Presence/absence of each tree stem size class >5cm DBH, plus <5cm max stem diameter • Visual estimate of total length of fallen logs and litter cover

**Lignotuber or seedling. **See Soil function below.*

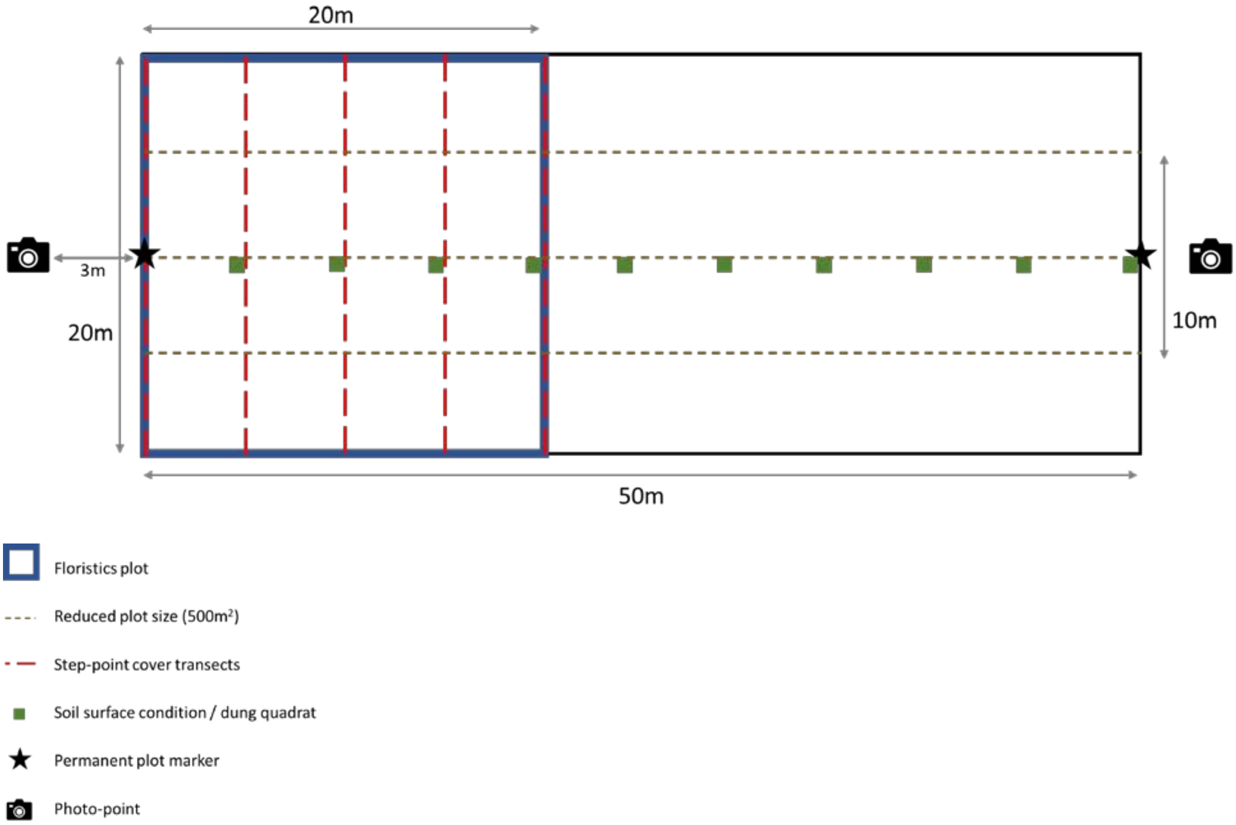


Figure 5: Plot layout for vegetation (and soil) integrity assessment method.

4.2 SOIL FUNCTION

Functionality of the soil, incorporating elements of stability, infiltration and nutrient cycling, is a fundamental driver of ecosystem function and ecological integrity in general (e.g. Culman *et al.* 2010). Since the development and validation of rapid techniques to assess soil function, they have been incorporated into many landscape-scale monitoring programs (e.g. Izquierdo *et al.* 2005; Raiesi 2017). This module applies components of Landscape Function Analysis (LFA) (Tongway 1995; Tongway and Hindley 2004; Tongway and Ludwig 2011) to the ecological integrity assessment, which includes rapid assessment of 11 soil surface condition variables. These variables will be scored for samples of 'functional' (e.g. covered / litter present) and non-functional (e.g. bare) patches within the 20x50m vegetation integrity assessment plot (Figure 5), for all instances where the high precision method is being applied (Tables 2 and 4). Positioning of quadrats is dependent on stratification across. As the method includes an assessment of litter cover/depth, cryptogram cover and bare ground, this negates the requirement to additionally assess litter cover via the BAM technique (while remaining consistent with the NSW Systematic Flora Survey Method and enabling calculation of a BAM VI score). Where time and resources permit, a 0-5cm soil core sample should be collected at each quadrat for analysis (i.e. C, N, P, pH, EC), which can contribute to the Soil and Land Information System (SALIS). See the Ecological Monitoring Operational Manual for more detail.

4.3 THREATENED SPECIES VALUES

For every BSA or funded CA site, as part of assessing the site and establishing an agreement, there will be explicit documentation of any high value threatened assets, including threatened species populations, areas of important habitat, or areas of threatened ecological community (for CAs these values are generally identified *a priori* based on the target values of a given tender, rather than via a comprehensive site survey). For BSAs, this may include populations or habitat generating species credits. In all cases, these assets require targeted monitoring in addition to what is required to assess ecological integrity for the rest of the agreement site.

4.3.1 Koalas

For all agreement sites where koala habitat has been identified as a critical asset (e.g. as a result of a CMP tender focused on koala habitat), targeted monitoring focusing on the assessment of habitat quality/suitability will occur. The method will complement (not duplicate) the standard vegetation integrity assessment method, and include:

- quantification of density, recruitment, regeneration and health of preferred koala feed trees (PKFTs) within a 500x20m belt transect
- additional photo-points

The method also aligns with those endorsed under the NSW Koala Strategy.

Recommended methods for koala occupancy monitoring include the use of faecal pellet surveys, spotlighting, call playback, wildlife detection dogs, and thermal imaging drones (e.g. Phillips & Callaghan 2011; Wilmott *et al.* 2018; Law *et al.* 2019). Given the additional costs associated with these methods, and the fact that most agreement sites containing koala habitat are very small relative to koala home ranges (therefore site occupancy is not a meaningful indicator of site value), occupancy monitoring is unlikely to be a viable option as a standard technique for all agreement sites. However, a pilot study trialling one or more of these methods, and calibrating the data with habitat assessment, for a subset of (larger) agreement sites, is proposed for the initial stages of the program.

For BSA sites where koala species credits have been generated, occupancy monitoring is mandatory under this module.

See the Ecological Monitoring Operational Manual for more detail.

4.3.2 Other threatened species and TECs

For any other threatened species population, important habitat, or patch of threatened ecological community identified on an agreement site, targeted monitoring should align with the approach (method, indicators, targets) described in the relevant SoS monitoring plan. If a monitoring plan has yet to be developed for the required species or community, regional staff should consult with the SoS Project Coordinator (and other experts as relevant) when designing a targeted monitoring prescription for the site. Broadly, the approach should align with the SoS Monitoring, Evaluation and Reporting Guidelines for Conservation Projects (OEH 2016). Monitoring effort (i.e. precision, frequency and intensity) should be consistent with the hierarchical approach outlined above – i.e. should generally be highest for BSA sites generating species credits and funded CAs where the species or TEC in question has been a key value justifying the establishment of the agreement (e.g. as part of a targeted tender round). For relevant BSAs (i.e. those generating species credits, occupancy (or valid surrogate) monitoring is mandatory under this module, and long-term targets with respect to population size, habitat condition, extent and/or appropriate surrogate, should be consistent with predicted gains associated with the number of species credits generated at the site.

4.4 OTHER VALUES

For some agreement sites there will be other types of biodiversity values for which vegetation or soil integrity are not appropriate surrogates. These may include:

- wetlands;
- riparian zones; and
- karst systems.

These values are likely to require targeted monitoring in addition to the plot-based methods described above. As more of these types of values are identified on agreement sites over time more prescriptive methods can be defined. In the interim, however, the approach to monitoring such values should be informed by published resources outlining best practice (e.g. *Monitoring Outcomes from Murry Local Land Services Riparian Interventions: Plan and Year 1 Pilot* [for riparian zones] and Saintilan and Imgraben 2012 [for wetlands]) and align with the monitoring principles articulated in this module.

4.5 MEASURING MANAGEMENT EFFECTIVENESS

For any BCT investment in management interventions beyond standard maintenance activities (e.g. active restoration), there is an expectation of a greater associated response – i.e. reduction the extent/severity of threatening processes and/or improvement in target biodiversity values. As outlined above, investment (frequency, intensity and precision) in monitoring this response should be proportional to the outcome uncertainty for the system or management action(s) in question. Table 5 summarises the prescribed approach to monitoring the effectiveness of the most commonly applied management activities.

Table 5: Monitoring and data collection for common management action types.

Management activity	Management effort quantification	Outcome/effectiveness monitoring approach
Weed control	• Person hours • Treated area (ha) • Treatment date/s • Treatment method • Expenditure ($)	Monitoring should focus on mapping the infestation boundary (or % exotic foliage cover areas), initially annually (if feasible, 3-yearly otherwise) to calculate infestation area/density. Once the infestation has been reduced to the point of requiring only maintenance control, monitoring frequency can reduce to 5-yearly.
Regeneration / revegetation	• Site area (ha) • Site preparation • Number of stems planted (tubestock) • Area seeded (ha) (direct seeding) • Planting/seeding date/s • Expenditure (labour, seed/tubestock ($)	Uncertainty in the outcome of revegetation projects generally decreases over time as propagated plants become established. Survival and condition of all stems should be monitored every 1-2 years initially, until established, then every 5 years. After year 10, this method should be replaced with the standard plot assessment of vegetation and soil integrity. For natural regeneration, high precision and intensity plot-based methods should be monitored within the treatment zone every 2-3 years for the first initially (dependent on baseline monitoring results), then 5-yearly.
Ecological burning	• Area burnt (ha) • Burn intensity (categorical) • Season (month) • Relevant conditions (e.g. weather, fuel loads) • Expenditure ($)	Post-fire changes in vegetation integrity (particularly ground layer) are likely to be relatively rapid, therefore monitoring should be initially frequent, using the high precision and intensity plot methods (focusing on ground layer and functional indicators if time is constrained).
Habitat enhancement	• Target area (ha) • Supplementation quantity (e.g. no. nest-boxes, total log length [woody debris]) and type • Date • Expenditure ($)	Habitat enhancement generally has uncertain outcomes; therefore, monitoring should be relatively rigorous (particularly where species credits are being generated on BSA sites). Monitoring the outcome of any habitat enhancement should focus on occupancy and/or resource usage by the relevant target species (or functional group). For example, for nest-box supplementation – nest-box occupancy rate by target (and non-target) species should be measured. Where artificial debris is being added to the landscape, relevant herpetofauna should be surveyed using appropriate methods (e.g. pitfall traps, artificial habitat) within the treatment zone.
Introduced herbivore control	• Control method • Number/density and replenishment frequency of baits/traps • Person-days • Expenditure ($)	Ideally, an independent indicator of pest activity (e.g. via remote cameras) should be monitored in addition to pest impacts (e.g. direct assessment of disturbance; browsing, pugging etc.), as well as target biodiversity response (captured via vegetation integrity measures outlined above). However, pest activity measures are likely to be highly variable at the scale of most agreement sites, and unlikely to be informative if management is being coordinated at the landscape scale (best practice). Under this scenario, monitoring of disturbance impacts should be the priority.
Introduced predator control	• Control method • Number/density and replenishment frequency of baits/traps • Person-days • Expenditure ($)	Given the significant uncertainty associated with the management and monitoring of predators – particularly at the site scale, targeted monitoring of predator activity (e.g. via remote cameras) is recommend only under a narrow set of conditions. Specifically, where a prey species has been identified as a high value asset on the site (e.g. generating species credits, focus of a targeted tender), sufficient detectability can be achieved with camera density and distribution, and there is an expected change in predator density at the site scale.

When evaluating management effectiveness – particularly when an adaptive management design is not cost-effective or feasible – it is important that targets are set for threat abatement (or intermediate) outcomes (based on a valid conceptual model), in addition to outcomes related to the desired state of biodiversity (i.e. ecological integrity). This provides more useful and timely information to inform management decisions, as threats often respond more quickly than target biodiversity values. Also, if direct monitoring of a threat in response to management indicates a significant reduction in extent/severity, but associated monitoring of the response in ecological integrity shows no improvement (over sufficient time), this suggests that the conceptual model of the system guiding management is flawed or incomplete (e.g. response dynamics are different to expected or another threat/driver has been overlooked [potentially an uncontrollable environmental factor]), and the management plan requires revision.

As a caveat to the above, in some scenarios – particularly vertebrate pest management – the scale of the site and/or detectability of the target pest species will inhibit the application of an adequate monitoring design (Meek *et al.* 2015). In these scenarios it may be more appropriate to focus on monitoring the target biodiversity only (e.g. prey species, disturbance impacts). For vertebrate predators (i.e. foxes, cats), it is strongly recommended that a decision to undertake this management activity is informed by an assessment of its cost-effectiveness (based on scale of application, target biodiversity response and known efficacy of the control method), noting that fox control is a required management action for most BSA sites. Where predator management is being implemented (at any agreement site), targeted monitoring of predator activity or density (e.g. via remote cameras) is recommended only if/where a specified prey species population has been identified as a high value asset for protection at that site (and is being monitored concurrently).

4.5.1 Monitoring total grazing pressure

Any zone within an agreement site that is subject to any frequency of stock grazing should be managed in accordance with the Livestock Grazing Guidelines. This includes landholder monitoring of groundcover to ensure that stock grazing only occurs while the *healthy condition* threshold for the vegetation type is maintained. In addition to this, monitoring of ecological integrity as above (see Table 2) should apply within the relevant zones, with specific priority given to the measurement of dung volume and species, as well as high precision ground layer and functional attributes (i.e. recruitment) in the first five years.

At a subset of sites – particularly if/where the above measures indicate significant unmanaged (i.e. overabundant native and/or introduced herbivore) grazing pressure – grazing exclosure cages should be erected within the strategically grazed zone (ideally four per zone). The cages should be left in place between monitoring visits to assess difference in biomass accumulation in the absence of grazing (using a rising plate meter or cover and sward height measures, as appropriate). Similar exclosure cages should be erected at a subset of vegetation integrity control sites within regional vegetation classes (and condition states) most frequently subject to grazing at agreement sites. These data can be used both in aggregate – to create predictive models of grazing pressure based on data available for all sites (i.e. groundcover attributes, dung volume, rainfall, stocking rates), and to address site-specific questions – i.e. where there are concerns about compliance with grazing guidelines, biomass and dung volume/species data can be compared to make inferences about the relative pressure attributable to unmanaged grazing.

4.5.2 Fire

There are three main scenarios under which an agreement site may be subject to fire – ecological burning, hazard reduction burning or wildfire. The approach to management of these sources of fire by landholders and BCT staff and minimising associated degradation of biodiversity values, is documented elsewhere. With respect to monitoring ecological response following fire, the recommended approach is similar for all three scenarios. Post-fire baseline monitoring should occur as soon as possible, using high precision plot methods focusing on the burnt area, with an emphasis on the measurement of ground layer and functional attributes (e.g. recruitment). These measures should be repeated more frequently during the initial phase of post-fire recovery (e.g. annually), for as long as practicable. In some circumstances, where a particular biodiversity asset has been the focus of an ecological burn (e.g. stimulating reproduction in an orchid population), or a fire-sensitive species or community has been unintentionally burnt, this monitoring should include specific measures appropriate to the asset (e.g. more detailed measures of a target species' recruitment).

4.5.3 Documenting management effort

The collection and management of comprehensive, accurate and comparable data on management effort, paired with ecological outcome data, is crucial to any rigorous analysis of management effectiveness. This information will generally be documented by landholders, therefore it is important that landholders have the information, tools and support they need to facilitate good data management. This includes clear and consistent guidance on appropriate units and frequency of measurement for each management type (see Table 5), as well as clear and usable reporting tools (e.g. annual report templates, field data collection systems [see 6.1]).

4.6 COMPLEMENTARY DATA COLLECTION

While this module focuses on vegetation and soil integrity as primary surrogates for biodiversity value, there are many other elements of biodiversity which can be measured more directly, as well as alternative indicators and surrogates which may be useful for assessing different aspects of biodiversity. Given its scale, this ecological monitoring program provides an opportunity to answer specific ecological questions regarding the response of particular taxa or functional groups to management, as well as growing the evidence base for a number of innovative biodiversity indicators, while complementing the collection of core data as outlined above. Such research questions/projects may include:

- Understanding the effects of private land conservation on avian diversity, and the relationship between site-based vegetation integrity and the integrity of avian populations at the landscape scale (e.g. Howard *et al.* 1998; Mac Nally *et al.* 2002; Cunningham *et al.* 2008).
- Linking landscape herpetofauna diversity to ecological integrity (e.g. Cunningham *et al.* 2007) and the management of functional ecosystem attributes such as coarse woody debris (e.g. Driscoll *et al.* 2000).
- Trialling the measurement of soundscapes – an increasingly utilised method for cost-effectively assessing state and change in ecological integrity whereby non-targeted acoustic recordings are interpreted as a surrogate (e.g. Tucker *et al.* 2014; Burivalova *et al.* 2018; Ng *et al.* 2018).
- Trialling the use of environmental DNA – another novel technique for assaying biodiversity in the landscape involves the detection of residual DNA from across multiple taxonomic groups – as a monitoring tool. With recent improvements in sequencing technology and reductions in cost, such methods are likely to have greater detectability and reliability, and may represent cost-effective alternatives to sampling vertebrate diversity (Bohmann *et al.* 2014).

Alongside the BCT Research Strategy, the ecological monitoring program will facilitate partnerships with external organisations (e.g. universities, NGOs) that may be well placed to deliver mutually beneficial research. In many cases, such partnerships may deliver outcomes (i.e. data) at no net cost to the BCT, given the potential benefits to partners such as access to monitoring sites and access to covariate data (e.g. vegetation integrity plots) for analysis and indicator calibration.

4.7 LANDHOLDER MONITORING

Monitoring activity conducted by landholders serves two primary purposes: First, it engages the landholder with the biodiversity values on their property and provides first-hand insight into how their efforts and stewardship are contributing to improving those values. Second, it will provide some important data that would otherwise be inaccessible by the BCT. With regard to the latter, the most important data required to be collected by landholders, in terms of informing evaluation, is that relating to management implementation effort/input (see 4.5.2).

With respect to monitoring ecological outcomes, landholders will be required to conduct photo-point monitoring using standard techniques and locations (i.e. permanent plots; see Figure 5) in interim years between BCT monitoring. BCT staff will provide relevant training to landholders on the standard method (see the Ecological Monitoring Operational Manual for details).

4.7.1 Citizen science

In the first 2-3 years of implementation of the ecological monitoring program, the BCT will develop and trial a citizen science module with the following objectives:

- engages landholders with, and raises their awareness of the biodiversity values present on their property;
- involves data collection methods and tools that are simple and intuitive to use;
- facilitates interpretation by landholders of their own data and how it contributes to the larger BCT data set; and
- is supported by a system that requires minimal administration and maintenance by the BCT.

Once the module has been demonstrated as fit for purpose, it will be scaled up and integrated into the broader ecological monitoring program.

5 SAMPLING DESIGN

5.1 BASELINES

Baselines are essential for measuring long-term ecological change (Magurran *et al.* 2010). Documenting biodiversity values at the point of establishing an agreement provides the BCT with a reference against which change (or stability) in those values over time can be evaluated. The goal will be to collect baseline data from every new agreement site as soon as possible after signing the agreement (ideally within 12 months for BSAs and funded CAs and 2 years for unfunded agreements). These data should be collected during the first site visit (post-signing) and can inform preparation of the Site Values Report (CAs only), which should contain summary, not detailed, information.

In addition to new agreements established under the BC Act, the BCT administers over 800 legacy agreements (i.e. BioBanking agreements established under the Threatened Species Conservation Act, CAs and Wildlife Refuges (WRs) established under the National Parks and Wildlife Act, Nature Conservation Trust agreements and Registered Property Agreements). Although baseline data for these agreements have not been collected and stored as per the protocols outlined in this module, there are still benefits to documenting a baseline now. These baselines will (with some variation) represent time zero reference points for the agreements' custodianship by the BCT and application of its programs (e.g. grants), and therefore will be valuable (in concert with appropriate controls) for assessing improvement in ecological values attributable to BCT partnerships with landholders. In addition, this snapshot data set for all agreements will contribute to a comprehensive 'stocktake' of the BCT's ecological assets, which will greatly enhance the organisation's reporting capacity.

Given the above, where time and resources are limiting, priorities for baseline monitoring should follow the hierarchy illustrated in Figure 2. It is highly unlikely that baselines can be established for all legacy agreements in the short term – an appropriate goal may be collecting baseline data for these sites within 5-10 years, as resources allow.

5.2 REPLICATION, STRATIFICATION AND CONTROLS

The ability to answer key ecological questions with respect to state and change in biodiversity values at the agreement site at bioregional and state scales, will be dependent on (in addition to the precision of measurement; addressed above); *a)* the number and distribution of plots on agreement sites, *b)* the number and distribution of control plots, and *c)* observed variation in the ecological indicators (e.g. vegetation integrity attributes) across space and time.

The number of plots monitored per agreement site must balance power to detect change and representativeness of sampling effort against capacity (i.e. available time and resources). It will also vary dependent on agreement type (i.e. following the established hierarchy; Figure 2), management objective (see Table 2) and within-site environmental variation. Following the stratification convention applied by the BAM (OEH 2017) and BCT site assessments, monitoring plots will be stratified by vegetation community (PCT for BSA sites; Keith [2004] Class for all other agreement types) and condition state (categorical; poor, moderate, high) – i.e. *vegetation zones* (Figure 6). The BAM provides guidance on recommended plot densities per vegetation zone for assessments, however, densities appropriate for monitoring are likely to be lower, given that data can be aggregated among sites to answer program-level questions.

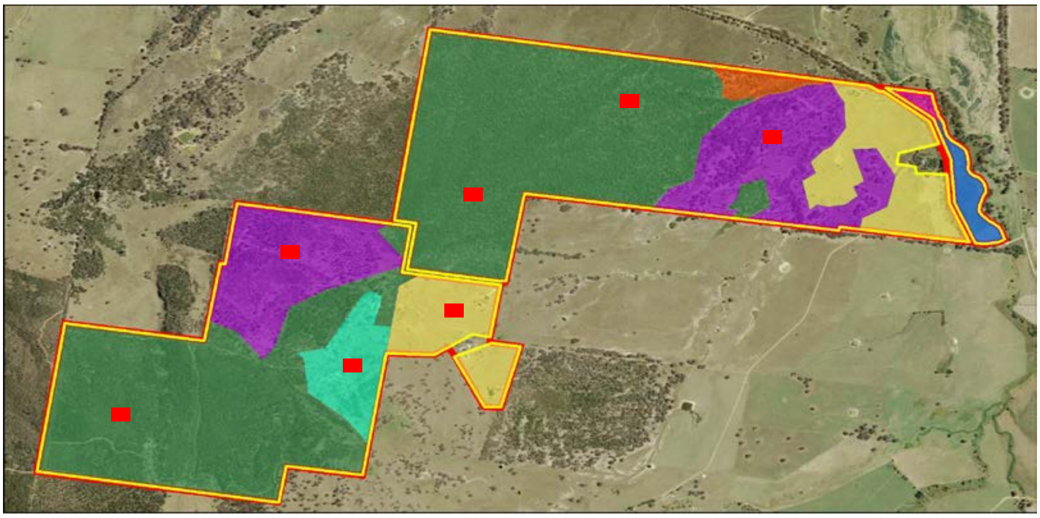
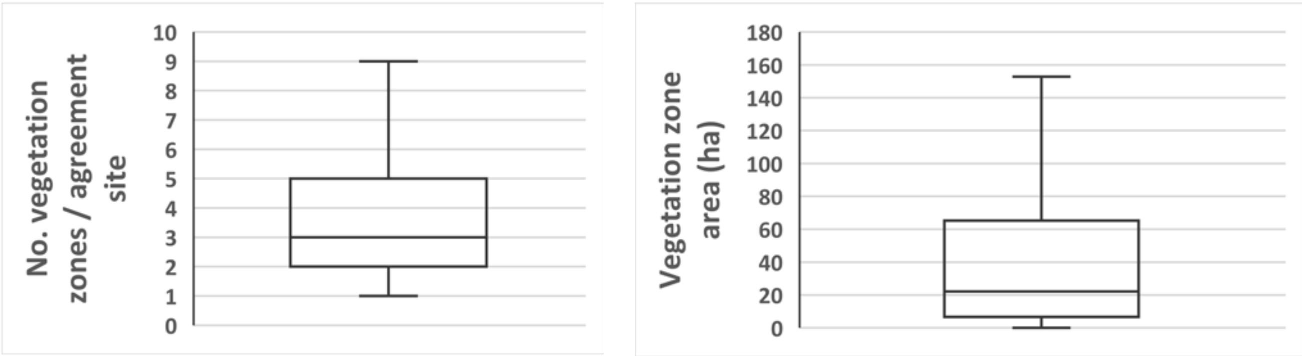


Figure 6: Example agreement site (yellow boundary), depicting six different vegetation zones (coloured shading) and location of stratified monitoring plots (red rectangles).

For a sample (*n*=133) of properties assessed under various BCT programs in 2018 and 2019, the median number of different vegetation zones per agreement site was three and the median size of each zone was 22 hectares (Figure 7). The predicted number of monitoring plots required for an agreement site of ‘typical’ (median) size and variation, applying a stratification similar (lower density) to that recommended for BAM assessment, is 6. This is likely to represent approximately two days’ effort for a team of two ecologists for baseline monitoring.



a *b*

Figure 7: Distribution (boxplots; outliers removed) of the number (a) and size (b) of vegetation zones for a sample (n=133) of properties assessed under six different BCT programs in different regions.

5.2.1 Control sites

Quantifying change in biodiversity values (i.e. ecological integrity) at agreement sites over time is relatively simple, given application of the methods outlined above. Understanding the different drivers of that change (e.g. management versus climatic variation), however, requires the use of controls (Underwood 1997). Figure 8 illustrates how monitoring outcomes at treatment and control sites enables interpretation of the different causes of observed variation resource condition (e.g. ecological integrity).

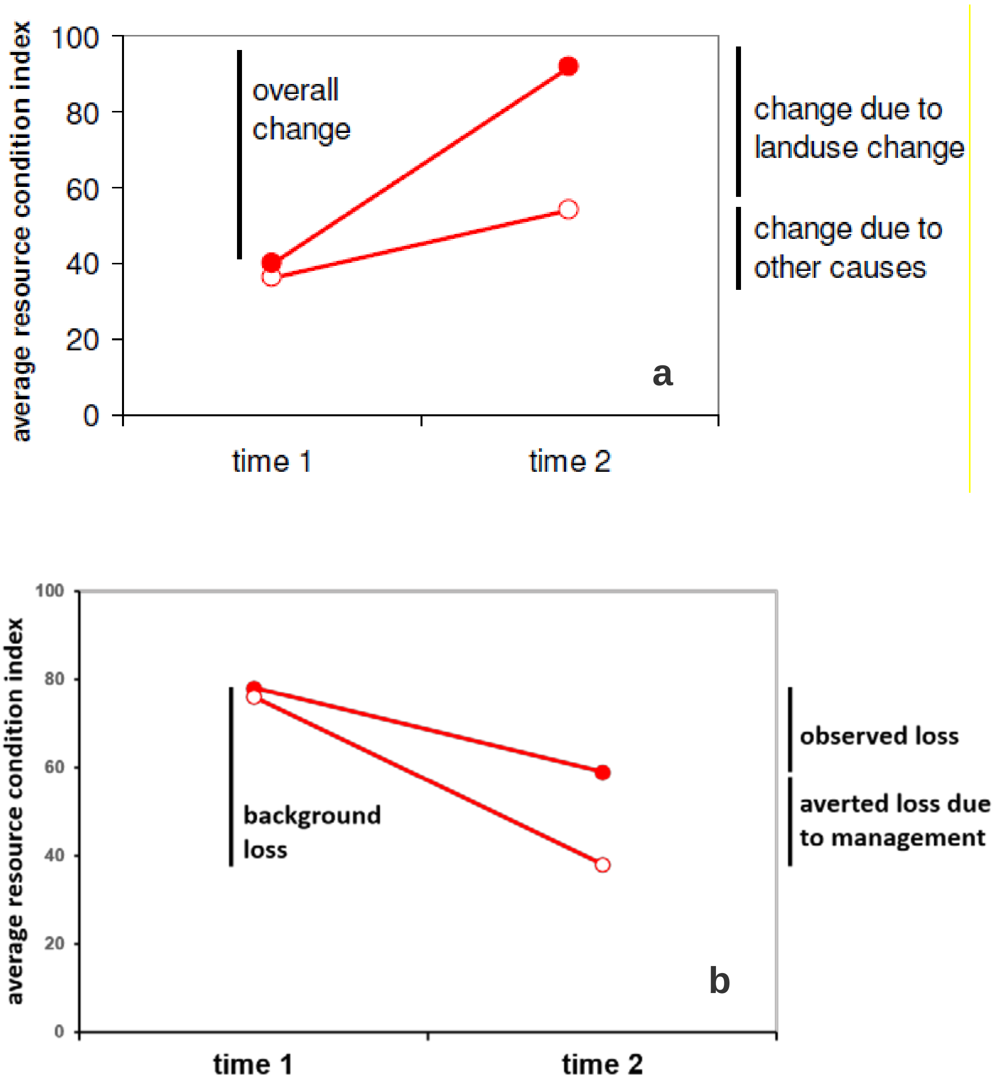


Figure 8: Hypothetical changes in observed resource condition over time for a treatment site (solid circles) and a control site (hollow circles), under a scenario of observed improvement under management (a) and an alternative scenario of observed decline under management (e.g. drought conditions) (b). Reproduced with permission from: O'Keefe et al. (2015).

In the context of the objectives and ecological questions guiding this module, controlling for the effects of climatic (or other uncontrollable environmental) variation on ecological integrity is particularly important in some scenarios. For example, if an agreement site in high condition is subject to prolonged suboptimal climatic conditions (e.g. drought), resulting in a reduction in observed vegetation integrity over time, in the absence of controls, the outcome of BCT investment would be evaluated as a net decline in value. However, monitoring of an appropriate local control site would enable separation of the climatic effects and may demonstrate relative improvement (less severe decline relative to the control) attributable to BCT management (see Figure 8b).

The ecological monitoring program will include monitoring of ecological integrity, following the plot-based methods outlined above, at a sample of control sites within each bioregion. Each bioregional sample of sites/plots should meet the following criteria:

- includes sufficient number of plots in relevant vegetation classes (i.e. those sampled at agreement sites in the bioregion) to detect required changes in ecological integrity;
- includes sites that – to an extent that is feasible – represent a 'business as usual' land management scenario (i.e. are not being actively managed for the purpose of improving biodiversity values); and
- includes sites that are – to an extent that is feasible – biophysically matched (e.g. topography, productivity).

Control sites will be sourced within each bioregion wherever access can be secured and where access arrangements are likely to be maintained in the future. Theoretically, sites could be found on any tenure, however, public land is likely to be more accessible, therefore partnerships will be established with relevant land managers to negotiate access to:

- NSW National Parks and Wildlife estate;
- Travelling Stock Reserves; and
- Forestry Corporation NSW estate, as a priority.

This design requires fewer control sites (and therefore less investment) than one involving a matched control for every agreement site, on the same property but outside of the conservation area. Although such a paired design would enable controlling for between-site variation (i.e. particular management practises of different landholders) and is often considered best practice, the proposed design meets the requirements of this module, in terms of answering key ecological questions at the bioregional and state scales, while being cost-effective.

5.2.2 Power analysis

Estimating the number of plots on agreement and control sites required to detect sufficient change in ecological integrity to answer the key ecological questions, requires a power analysis (Sokal and Rohlf 2012; Legg and Nagy 2006). Power analyses require a measure of the variance in data to be sampled. Although these data have yet to be collected under this module, a representative data set, including measures of structural, compositional and functional attributes of vegetation integrity collected via a consistent method, is available in the Systematic Flora Surveys module of NSW BioNet. A subset of these data (*n*=36,335) was prepared for the development of vegetation condition benchmarks to inform the BAM (Somerville *et al.* 2019; data available here).

To produce a rough estimate (order of magnitude accurate) of the number of required plots at the state-wide scale, a power analysis was conducted using these plot data, with change in total native species richness (*Time 0* to *Time 1*) for all growth forms (tree, shrub, grass/grass-like, forb, fern and 'other') as the response variable in a simple single factor model. All data from regional vegetation classes with <50 plots were removed for analysis, leaving 27,605 data points. The analysis estimates that 235 (34 per BCT region, on average) plots are likely to be required to have a 90% probability (power) of detecting a 30% change in total species richness ($\delta = 0.3$) at the state-wide scale (Figure 9).

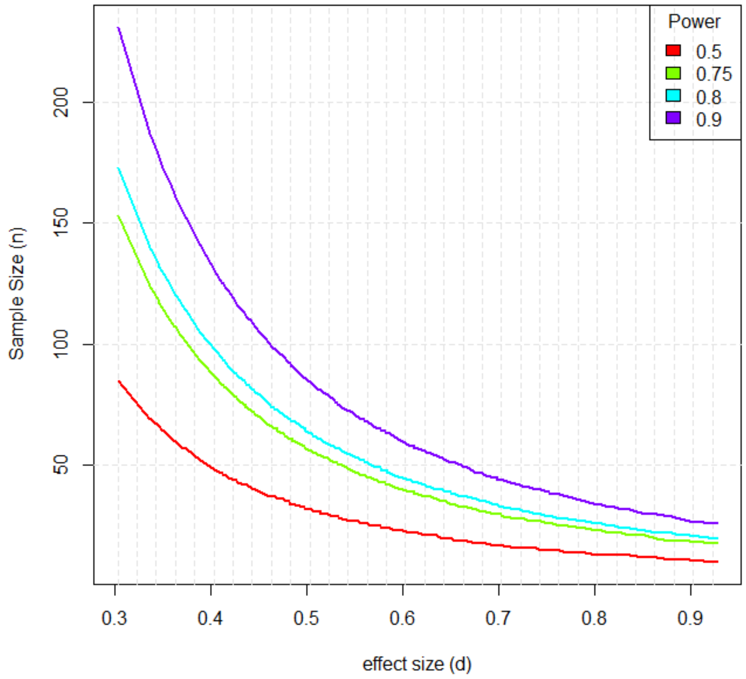


Figure 9: Sample size of plots required versus associated detectable effect size, for four levels of statistical power (probably of detection), to detect change in total species richness at the state-wide scale (p=0.05).

This analysis ignores the independent variation associated with bioregion, vegetation class and property. A more accurate assessment of the number of control plots required per bioregion and per vegetation type requires a more complex model that accounts for these effects (see Ecological Monitoring Operations Manual for more detail).

6 DATA MANAGEMENT

Given the scale of the BCT ecological monitoring program and the importance of the data collected, for informing reporting and decision-making, it is crucial that the management of ecological data is rigorous. All processes related to data collection, storage and analysis should aim to ensure that the data are:

- secure (collection and storage systems are designed to prevent data loss or corruption);
- accessible (data should be available to whomever and whenever required for BCT corporate purposes);
- useful (data are maintained in a format that readily facilitates interpretation, analysis and reporting as required); and
- reliable (data have collected in a consistent and rigorous way and have been quality assured prior to storage and analysis).

6.1 FIELD DATA COLLECTION

Ideally, all field data collected as part this ecological monitoring program should be entered in digital format at point of collection (i.e. via hand-held device), using a BCT corporate system. This may not be possible in all cases, given the role of third parties (e.g. accredited assessors) in ecological monitoring at BSA sites, the potential involvement of partners in monitoring additional biodiversity indicators, and the specific data only suitable for collection by landholders (e.g. management effort). On occasions where data are collected by a third party, data capture should use a BCT system wherever possible (with a structured data entry format to minimise variability), or if not, data should be uploaded to a BCT repository as soon as feasible following collection.

6.2 CENTRALISED DATA REPOSITORY

All ecological and landholder management data should be stored in an adequately secure and backed-up corporate repository. It is important that new data are regularly quality-assured. Wherever feasible, (non-sensitive) data should be made publicly accessible, in line with the NSW Open Data Policy, via upload to repositories such as BioNet or the NSW Government's Sharing and Enabling Environmental Data (SEED) portal. Following analyses for reporting purposes, the relevant supporting data should be stored in a format that readily enables review by anyone seeking more detail underpinning higher-level outcome summaries.

7 EVALUATION AND REPORTING

7.1 EVALUATING ECOLOGICAL OUTCOMES

Evaluating the ecological outcomes of the BCT's programs over time will be guided by the stated ecological objectives. Table 7 illustrates how, at the state-wide/program scale and at regular intervals, evaluation of outcomes against each objective can be framed, and which data are required.

Table 7: Framework for high-level outcome evaluation

Ecological objective	Outcome evaluation statement(s)	Data required
Maintain or improve, as required, the	*% of agreement sites are currently meeting or are on track to meet ecological outcome targets*	• Vegetation and soil integrity, other indicators, per site

ecological integrity of agreement sites		• Target value/range of relevant indicator for current year
Maximise return on investment, in terms of biodiversity value*	• *Total conservation area under agreement = XX hectares* • *Average condition of biodiversity under agreement = XX* • *Total improvement in biodiversity condition attributable to BCT investment = XX* • *Total number and area of under-represented landscapes (and % contribution to CAR targets) under agreement = XX hectares / XX%* • *Total averted loss of biodiversity value attributable BCT agreements = XX* • *Total aggregate value of all the above** • *Number of high biodiversity value assets under agreement and total contribution to the viability of threatened species and ecological communities in NSW*	• Spatial coverage of all agreement sites and conservation areas • Current and baseline ecological integrity values for all agreement sites/zones • Current and baseline ecological integrity values for all control sites • Landscape (background) risk of loss of biodiversity • Landscape contribution to state-wide biodiversity and threatened species values (modelled)
Ensure that improvement in biodiversity values at BSA sites is consistent with the assumptions supporting the generation of biodiversity credits, and is contributing to achieving no net loss to biodiversity	• *Improvement in biodiversity values is consistent with the generation of associated biodiversity credits at XX% of BSA sites* • *Overall gain in vegetation integrity x area is XX% of expected, based on the total number of biodiversity credits generated* • *Overall and per species gains in threatened species values is XX% of expected, based on the total number of biodiversity credits generated*	• Current and baseline ecological integrity values for all BSA sites/zones • BAM vegetation condition benchmarks and predicted gain models • Current and baseline values for site/species-specific indicators of value for species credit species • BAM gain predictions for species credit species
Gain ecological knowledge required to improve management effectiveness and support strategic decision making	• *XX data points have been contributed to the NSW Systematic Flora Surveys data set* • *Data from XX vegetation integrity plots have informed calibration of the BAM vegetation condition gain predictions for XX PCTs* • *XX novel monitoring methods / biodiversity indicators have trialled and demonstrated efficacy* • *Calibration of rapid ecological integrity assessment methods has improved efficiency of the ecological monitoring program by XX%* • *Monitoring data have informed XX adaptive changes to BCT ecological management guidelines* • *XX mutually beneficial partnerships have been established with external organisations*	• Floristic data from all 20x20m plots • Current and baseline vegetation integrity values for all agreement sites/zones • Partner data sets measuring additional biodiversity indicators • Ecological integrity values for all precision levels at all relevant plots

**See below.*

It is important to note that multiple factors at both the site and landscape scales, which are beyond the influence of landholder management or BCT investment (e.g. climate change and related extreme climatic events, emergent pest/weed invasions, disease), can affect ecological outcomes at agreement sites. Therefore, evaluation of these outcomes and progress against objectives should be interpreted in this context. This underscores the importance of controls (see 5.2.1) to evaluation and interpretation of outcomes.

7.2 QUANTIFYING RETURN-ON-INVESTMENT

7.2.1 Aggregated Ecological Condition Index

The BCT Business Plan, under Strategic Goal 3, refers to the development of an *Aggregated Ecological Condition Index.* This index is required to bring together the various elements of ecological 'value' that align with the BCT's ecological objectives, such that when calculated for the BCT's assets (i.e. agreement sites), represents the total benefit accrued, or the organisation's return on investment. For the index to be an accurate representation, it must incorporate dimensions of area, condition, improvement in condition, representativeness and security, as these are the values in which the BCT is investing. Combing all of these values into a single index is challenging, partly because there is a requirement to quantify relative weightings that are meaningful – i.e. how much is accruing one unit of area valued by the BCT compared to one unit of condition, compared to one unit of marginal improvement in condition over time, compared to one unit of risk reduction (i.e. averted loss).

Given that the BCT has already developed a similar index as part of its Conservation Assessment Metric for assessing the biodiversity value of sites under the CMP – the *Biodiversity Value Score* (BVS), it is recommended that the Aggregated Ecological Condition Index is developed to be consistent with the BVS. It is important, however, that any such index be interpreted and reported with caution – combining independently varying measures risks masking variation and losing important information. While the index may be valuable for headline reporting of summary outcomes, it should always be complemented with information regarding each component of ecological outcome separately.

This module has been designed to collect data that will inform the construction of an Aggregated Ecological Condition Index, irrespective of design, as long as it incorporates the elements discussed above.

7.2.2 Complementary data sources – remote sensing and modelling

7.2.2.1 Quantifying risk

A fundamental component of the BCT's return-on-investment is the marginal reduction in risk of loss of biodiversity conferred by entering an agreement (i.e. averted loss). This includes both gradual loss of quality as well as total loss – the former being quantified using control sites (see 5.2.1), while the latter is not (if control sites are located on predominantly public land, total loss is generally unlikely, therefore the sample is not representative of the background rate). Quantifying this component of risk is an important part of quantifying total return-on-investment. The BCT currently uses *Land and Soil Capability* as part of its Conservation Assessment Metric, as a predictor of risk of land clearing, however, a more direct measure is preferable. Also, properly quantifying the value of this risk-reduction attributable to BCT investment requires a counterfactual scenario for comparison (Adams *et al.* 2019) – i.e. what would have been the likely outcome for an agreement site under the alternative scenario where there was no agreement in place?

Currently available satellite imagery and derived products – e.g. Sentinel satellite imagery and the State-wide Landcover and Tree Study (SLATS) woody change data set – allow for direct and regular assessment of the extent of loss of woody native vegetation across the landscape, at high resolution (10m). Using these data, the number and total area of properties with different attributes (e.g. vegetation class, land use, topography, zoning), subject to total native vegetation loss over a given time period, can be accurately quantified. This rate of loss can then be used as the counterfactual scenario, or surrogate for risk of loss at an agreement site with matching attributes, in the bioregion. Given that the NSW Government is required to analyse and report on these data annually under *the Local Land Services Act* 2013, the additional analyses for BCT purposes are likely to be low cost.

For regions or ecological communities where background change in the extent of woody vegetation is not the most appropriate counterfactual (e.g. areas subject to forestry, grasslands, arid systems), other proxies may be used. For example, in productive forest landscapes, where background loss of habitat quality (e.g. removal of very old trees, hollows) is unlikely to be detect via satellite imagery, administrative data such as applications and provision of private native forestry licences, may be more useful. In circumstances where no such data are available, the quantification of averted loss will rely solely on comparison with control sites (increasing their importance in those areas).

7.2.2.2 Quantifying landscape value

Under the NSW Government's Biodiversity Indicator Program, landscape-scale indicators of biodiversity value have been developed covering all of NSW. These indicators include, *State of all known species (2.1)* and *State of biodiversity including undiscovered species (2.2)*. The indicators use generalised dissimilarity modelling (GDM) to calculate a value representing the current state of biodiversity at any point in space (OEH & CSIRO 2018). These data sets provide a measure of the relative value of any given site in NSW and in aggregate, for all of NSW. By simulating the loss of all sites under BCT agreement (and weighted by the risk of loss; see above) from the indicator data set, a counterfactual can be generated, which enables quantification of the total biodiversity value under stewardship of the BCT (as estimated by these indicators).

7.2.2.3 Quantifying contribution to threatened species security

Several projects being delivered through the Science and Research component of the *Saving our Species* program (SoS) are aiming to increase the precision with which management and habitat protection priorities for securing threatened species can be defined spatially. This includes an application of the *Rapid Estimation of Metapopulation Persistence* (REMP) method (Drielsma and Ferrier 2009), which scores locations in the landscape based on their capacity to support viable populations of widespread or mobile threatened species. The ideal endpoint of these projects will be the development of spatial surfaces for each species which quantify the relative contribution of any given site to the species' overall viability. These products could be highly valuable to the BCT in terms of evaluating the contribution of agreement sites – individually and in aggregate – to the security of threatened species and ecological communities.

7.2.3 Statistical analyses

The most appropriate statistical analysis tool to be applied to the state-wide data set, for addressing program-wide ecological questions, for example, 'was there a significant difference between agreement and control sites in terms of change in ecological integrity', is likely to be Generalised Linear Mixed Models (Bolker *et al.* 2008). This is because the data set is unlikely to be balanced (i.e. sample sizes in different stratified groups will vary), and will be structured based on factors that are predicted to influence outcomes, and are therefore stratified as part of the design (i.e. *fixed effects*) and factors that are not stratified but may have an unpredictable influence (*random effects*).

The main GLMM design is likely to include *ecological integrity* (or various attributes) as the response variable, and the following factors:

Fixed effects:

- *Treatment* (agreement/control)
- *Bioregion*
- *Vegetation class*
- *Vegetation condition* (categorical)

Random effects

- *Property* (requires multiple plots per control site)
- *Tenure* (control sites only)

Covariates

- Rainfall previous 12 months

This is a suggested design only. Any analyses should be based on a proper assessment of the data at the time, and should ensure that any assumptions of the proposed statistical method are not violated.

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