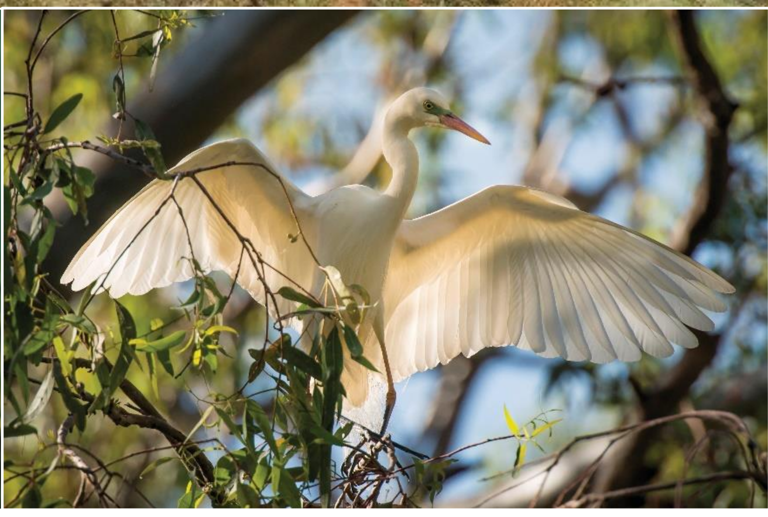
Measuring biodiversity and ecological integrity in NSW

Method for the Biodiversity Indicator Program



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Like biodiversity, developing this method has been complex and has drawn on a wide range of knowledge and expertise. It has also been a highly collaborative project and it would not have been possible without the dedication and willing input of many people. We thank them most sincerely:

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Foreword

In 2016, the NSW Government introduced new legislation to manage land and conserve biodiversity. As part of the *Biodiversity Conservation Act 2016* (the BC Act) and supporting regulation (the Biodiversity Conservation Regulation 2017), the Environment Agency Head is to establish programs for the collection, monitoring and assessment of the status and trends of biodiversity in New South Wales. The programs are to use a method which identifies key biodiversity indicators and sets out how those indicators are to be measured and how the data informing them are to be collected.

I present to you this peer-reviewed method developed under the Biodiversity Indicator Program. It will contribute to assessing the effectiveness of biodiversity management in New South Wales and will be applied to establish the current status of biodiversity for future comparison and reporting, including informing the five-year review of the BC Act. It complements other programs under the BC Act, including *Saving our Species* and the *Private Land Conservation* program, by drawing on data and information from these programs and providing information to support their management and evaluation.

Biodiversity encompasses all the species and ecosystems in New South Wales, in all their variety. Many of these species and some ecosystems are not well known. Office of Environment and Heritage (OEH) has collaborated with Commonwealth Scientific and Industrial Research Organisation (CSIRO) and others to develop this method and suite of indicators. This method is cutting-edge science using field data, environmental modelling and remote sensing to assess biodiversity for the whole of the State for the first time. It is cost-effective, repeatable, minimises bias, is consistent statewide and by bioregion, and can be improved continually as the amount of data collected and scientific knowledge increases and as technology evolves. I also see great opportunities to engage the NSW community through citizen science projects to fill important data gaps.

The products from the program will have multiple uses and the results of the first assessment will be reported in a peer-reviewed NSW biodiversity outlook report. This first report will provide report cards for indicators that are ready now. The method sets out an aspirational program to further develop and refine indicators for future reporting. In the future, the same method will be repeated with new data to help us track our progress in managing biodiversity.

I commend this method to you. It is the first step in a continuing journey to better understand and improve our ability to monitor and manage biodiversity in New South Wales.

Anthony Lean

Chief Executive

Office of Environment and Heritage NSW

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Summary

The purpose of this report is to describe the method and suite of indicators developed for measuring biodiversity and ecological integrity in New South Wales, as required by the *Biodiversity Conservation Act 2016* (BC Act).

The BC Act requires the establishment of programs to collect, monitor and assess information on the status and trends of biodiversity in New South Wales. This report describes the method designed under the Biodiversity Indicator Program which will be applied to establish the current status of biodiversity in New South Wales for future comparison and reporting. It will be repeated to inform the five-year review of the BC Act.

Office of Environment and Heritage (OEH) has collaborated with leading experts at Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Museum and Macquarie University to develop the method that will be used in New South Wales at bioregional and statewide scales. The method, detailed in this report, has been subject to independent peer review. The method identifies key biodiversity indicators as required by the Biodiversity Conservation Regulation 2017 accompanying the BC Act. The indicators have been designed to detect change, specifically the rate of loss of biodiversity, as well as the effectiveness of conservation actions.

Biodiversity is defined by the BC Act as the ‘variety of living animal and plant life from all sources, and includes diversity within and between species and diversity of ecosystems’. It encompasses all the variability among living organisms from all sources, including genetic, species and ecosystem diversity across terrestrial and land-based aquatic realms and certain coastal and marine species. Biodiversity includes both species and ecosystems that are currently known, as well as those that are yet to be discovered.

The purpose of the BC Act also includes the concept of ecological integrity, that is, maintaining the diversity and quality of ecosystems and enhancing their capacity to adapt to change and provide for the needs of future generations.

Biodiversity is too complex to be measured by one indicator alone, thus a combination of several different indicators is used to characterise its many components and to answer environmental questions. To this end, the indicators have been allocated to two classes: biodiversity and ecological integrity.

The indicators are then categorised into themes and indicator families. This categorisation reflects the scientific framework used to interpret the requirements of the BC Act to encompass different aspects of biodiversity and ecological integrity and different measurement methods. It allows for new or alternative indicators to be identified as knowledge and data grow and monitoring and assessment methods evolve. The implementation of the indicators depends on their level of readiness. For example, there are three categories of indicators for terrestrial species and ecosystems, with results for the first category of indicators (those ready now) to be reported in the first NSW biodiversity outlook report. Indicators for freshwater, coastal and marine species and ecosystems are not ready, but peer-reviewed methods for their selection and quantification are being prepared and will be used to inform the next cycle of reporting. This staged approach reflects the need for further development, continuous improvement and/or a staged delivery process due to time constraints in data or method readiness.

The indicators for terrestrial species and ecosystems are based largely on remote sensing and environmental modelling, complemented by field-based monitoring data and analysis. Each biodiversity indicator has the potential to be expressed through different feature types (plant and animal groups) or ecosystems (i.e. ecological communities). Ecological integrity indicators focus on the condition or quality of ecosystems and how pressures (i.e. threats) and policy responses interact to alter the capacity of landscapes and habitats to support biodiversity and maintain ecological functions. Component indicators provide the information needed to understand feedbacks and cause and effect relationships, toward a predictive measure of the capacity of ecosystems to adapt to change. This method mainly addresses the design of terrestrial biodiversity indicators to assess and monitor change. The equivalent indicators for freshwater, coastal and marine species and ecological communities will be developed and added to this method.

1. Introduction

The NSW Government has streamlined the legislative and policy framework for biodiversity conservation and land management in the State. These changes included the introduction of the *Biodiversity Conservation Act 2016* (the BC Act) (NSW Government 2016) and its subordinate legislation, the Biodiversity Conservation Regulation 2017 (the BC Regulation) (NSW Government 2017), as part of a suite of legislative and policy reforms (i.e. the Land Management and Biodiversity Conservation Reforms).

The BC Act requires the Environment Agency Head to establish 'biodiversity information programs' for the collection, monitoring and assessment of information on biodiversity (section 14.3). Clause 14.2 of the BC Regulation sets out the requirements for these programs. Requirements include the collection, monitoring and assessment of status and trends of biodiversity in New South Wales, and the development of a peer-reviewed method which identifies key biodiversity indicators and sets out how data related to those indicators is to be collected and measured.

Office of Environment and Heritage NSW (OEH) collaborated with Commonwealth Scientific and Industrial Research Organisation (CSIRO), Macquarie University and the Australian Museum to develop the method that will be used for the collection, monitoring and assessment of terrestrial biodiversity in New South Wales at bioregional and statewide scales. The method, developed under the Biodiversity Indicator Program, is detailed in this report and will be applied initially to assess NSW terrestrial biodiversity at the time the BC Act commenced.

This introductory section outlines the context in which the method was designed and developed, including the relevant legislation, the approaches and strategies used, and the scope of this report. A glossary at the end of the report provides definitions of key terms.

1.1 Legislative context

The purpose of the BC Act is 'to maintain a healthy, productive and resilient environment for the greatest well-being of the community, now and into the future, consistent with the principles of ecologically sustainable development and in particular:

(a) to conserve biodiversity at bioregional and State scales, and

(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, and

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

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

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

(f) to assess the extinction risk of species and ecological communities, and identify key threatening processes, through an independent and rigorous scientific process, and

(g) to regulate human interactions with wildlife by applying a risk-based approach, and

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

(i) to support and guide prioritised and strategic investment in biodiversity conservation, and

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

(k) to establish a framework to avoid, minimise and offset the impacts of proposed development and land use change on biodiversity, and

(l) to establish a scientific method for assessing the likely impacts on biodiversity values of proposed development and land use change, for calculating measures to offset those impacts and for assessing improvements in biodiversity values, and

(m) to establish market-based conservation mechanisms through which the biodiversity impacts of development and land use change can be offset at landscape and site scales, and

(n) to support public consultation and participation in biodiversity conservation and decision-making about biodiversity conservation, and

(o) to make expert advice and knowledge available to assist the Minister in the administration of this Act' (NSW Government 2016).

This method for measuring biodiversity and ecological integrity in New South Wales focuses on:

- conserving biodiversity at bioregional and state scales
- maintaining the diversity and quality of ecosystems and enhancing their capacity to adapt to change and provide for the needs of future generations
- supporting biodiversity conservation in the context of a changing climate
- assessing the extinction risk of species and ecological communities
- supporting conservation and threat abatement actions to slow the rate of biodiversity loss and conserve threatened species and ecological communities in nature
- establishing a scientific method for assessing the likely impacts on biodiversity values of proposed development and land-use change, for calculating measures to offset those impacts and for assessing improvements in biodiversity values
- collating and sharing data and monitoring and reporting on the status of biodiversity and the effectiveness of conservation actions.

The BC Regulation requires the proposed assessment method to be peer-reviewed by at least three scientists who, in the Environment Agency Head's opinion, are appropriately qualified to undertake the review. It also requires occasional publication of a NSW biodiversity outlook report on the results of the programs, including the method used for collection, monitoring and assessment of biodiversity information.

Five years after commencement, a review is to be undertaken of the BC Act in conjunction with a review of the native vegetation land management provisions under the *Local Land Services Act 2013* 'to determine whether the policy objectives of the BC Act remain valid and whether the terms of the BC Act remain appropriate for securing those objectives' (s. 14.11 BC Act). The biodiversity information program is to inform this review by comparing changes in biodiversity status and trends from those established prior to commencement of the BC Act.

1.2 Scope of the biodiversity information program

The BC Act applies to the terrestrial environment in relation to native animals, plants and fungi native to New South Wales, and the habitats that support them, including freshwater ecosystems such as wetlands. In relation to marine and coastal environments, it applies to marine birds, reptiles (turtles and sea snakes) and mammals (whales, dolphins and dugongs). Fish, and marine and coastal plants are managed under either the *Fisheries Management Act 1994* or the *Marine Estate Management Act 2014*.

This report focuses on the design of terrestrial biodiversity indicators. The equivalent indicators for freshwater, coastal and marine species and ecosystems will be developed and added to the method.

Biodiversity, as defined in s. 1.5(1) of the BC Act, 'is the variety of living animal and plant life from all sources, and includes diversity within and between species and diversity of ecosystems'. The definition applies to biodiversity that originated in New South Wales. To encompass this scope of variety, indicators aim to include measures of genetic diversity, species diversity and ecosystem diversity.

The conservation status of species and ecological communities is assessed by the NSW Threatened Species Scientific Committee (henceforth the NSW Scientific Committee) to determine if they are at risk of extinction in New South Wales. Currently, nearly 1000 species of plants and animals (Schedule 1 of the BC Act) and over 100 ecological communities (Schedule 2 of the BC Act) are threatened with extinction at the state level. These lists of threatened species and ecological communities are dominated by terrestrial vascular plants and vertebrates, with fewer listed lower plants and invertebrates, which are generally poorly studied.

Biodiversity also includes those species and ecosystems that are yet to be discovered, catalogued and assessed for their conservation status.

Therefore, to establish a method that encompasses all biodiversity, indicators that address gaps in knowledge related to both biodiversity discovery and conservation concern are needed (see Figure 1). Applying the framework presented in Figure 1, the following complementary indicator sets for biodiversity can be identified:

- measures based on extinction risk standardised to survival in 100 years
- measures of the status of overall biodiversity relative to that which originally existed.

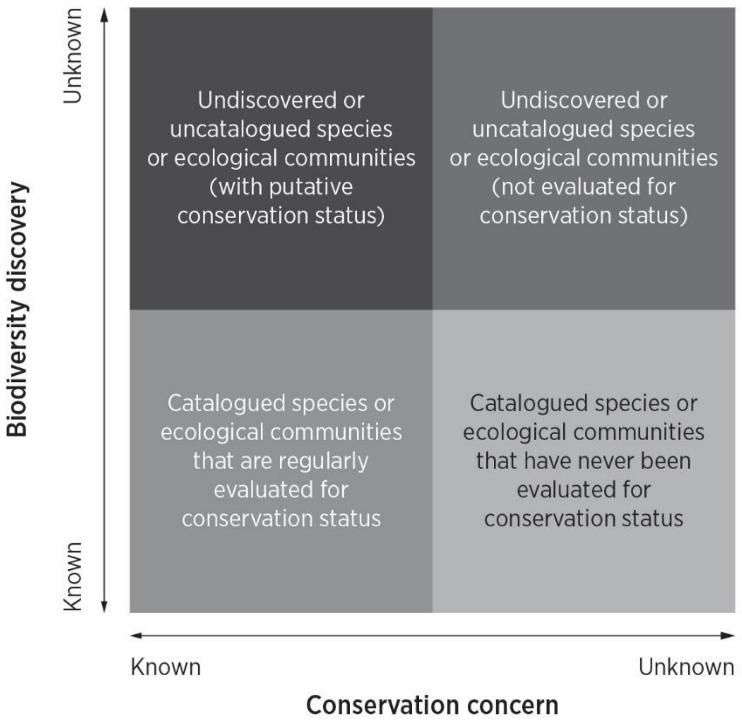

Figure 1 Biodiversity knowledge framework for this method

The purpose of the BC Act also includes 'ecological integrity', defined by the International Union for Conservation of Nature and the World Wildlife Fund (IUCN and WWF, respectively, see Mansourian 2005) to be 'maintaining the diversity and quality of ecosystems, and enhancing their capacity to adapt to change and provide for the needs of future generations' (s. 1.3b BC Act).

Indicators of ecological integrity are also relevant to the method under the BC Act to assess the quality of ecosystems and their capacity to adapt to change (see Figure 2). The status and outlook for biodiversity will depend on the extent, condition and connectivity of ecosystems and the effectiveness of conservation actions to mitigate pressures. In this report, a ‘pressure’ is a threat in the landscape that causes biodiversity loss or threatens the quality of ecosystems, including key threatening processes listed under Schedule 4 of the BC Act as well as other threats not listed on the BC Act.

It will also be important to assess the capacity of ecosystems to adapt or recover from change or disturbance, including climate change, and retain their biological diversity.

Applying the framework presented in Figure 2, the following complementary indicator sets for ecological integrity can be identified:

- Present ecosystem quality (quadrant A), which requires information about site condition and landscape context, including integrating what is known about pressures (including key threatening processes such as clearing of native vegetation, climate change, invasive species and high frequency fires).
- Present ecosystem diversity (quadrant B), which requires additional information about the natural variety of species in the absence of pressures (i.e. estimated from modelling original ecosystem diversity); and then integrated with the measure of present ecosystem quality.
- Capacity to maintain ecosystem quality (quadrant C), which requires additional information about the present and ongoing appropriateness and effectiveness of local-scale management actions in response to pressures causing ecosystem quality decline and preparedness to facilitate ecosystems in adapting to change. This capacity of land management is a form of ‘local system resilience’ (following Cumming 2011).
- Capacity of ecosystems to adapt to change and retain biological diversity and ecological functions (quadrant D). This requires additional information about ‘spatial resilience’ (Cumming 2011), addressing, in particular, the roles that spatial and environmental connectedness of habitat may play in facilitating persistence of biological diversity under climate change and other pressures; informed by our capacity to maintain ecosystem quality given present approaches to land management.

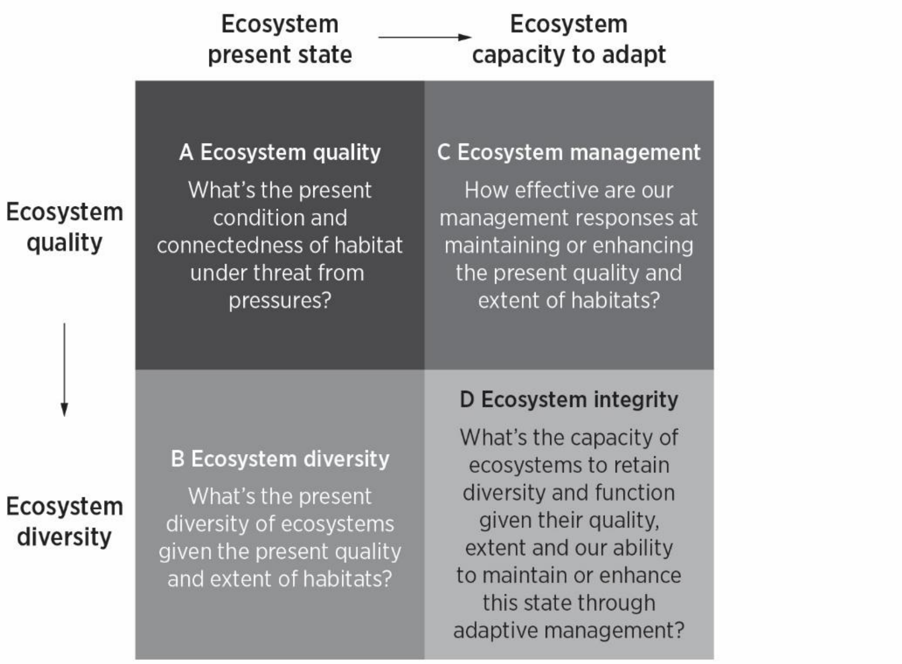

Figure 2 Ecological integrity knowledge framework for this method.
Note: quadrant B is reported under the biodiversity class of indicators.

1.2.1 The concept of indicators

An environmental indicator is a specific, measurable characteristic used to show trends or changes in the environment. It can be physical, biological or chemical; or can be an indicator of environmental pressures, conditions or anthropogenic management responses (Niemeijer 2002). Environmental indicators ‘provide an important source of information for policy makers and help to guide decision-making as well as monitoring and evaluation’ (Niemeijer & de Groot 2008). Biodiversity is too complex to be measured by one indicator alone, thus a combination of several different indicators is used to characterise its many components and allow for innovation in technologies. Indicators are developed using direct and indirect measurement methods and are designed to also enable prediction.

1.3 Approach to developing the method

The method for the Biodiversity Indicator Program (detailed in this report) requires a suite of indicators, of specific relevance to the BC Act, to establish a measure of the status of biodiversity and ecological integrity in New South Wales at statewide and bioregional scales. The indicators should be repeatable to facilitate ongoing monitoring and reporting on status and trends, and drive the collection of data on essential variables. The general approach used to develop the method for the biodiversity information program is outlined in Figure 3, informed by the framework of essential variables. Essential variables are described in greater detail in section 1.5.4.

This approach was driven by:

- the policy and legislative needs of the BC Act and BC Regulation
- a scientific understanding of biodiversity and ecosystems and the underlying drivers of biodiversity change (i.e. ecological requirements)
- the need for indicators to be pragmatic, cost-efficient, achievable and realistic in reporting on cumulative outcomes across whole bioregions
- use of existing capacity to apply predictive models that integrate data for reporting across scales and can provide an outlook based on current policy settings.

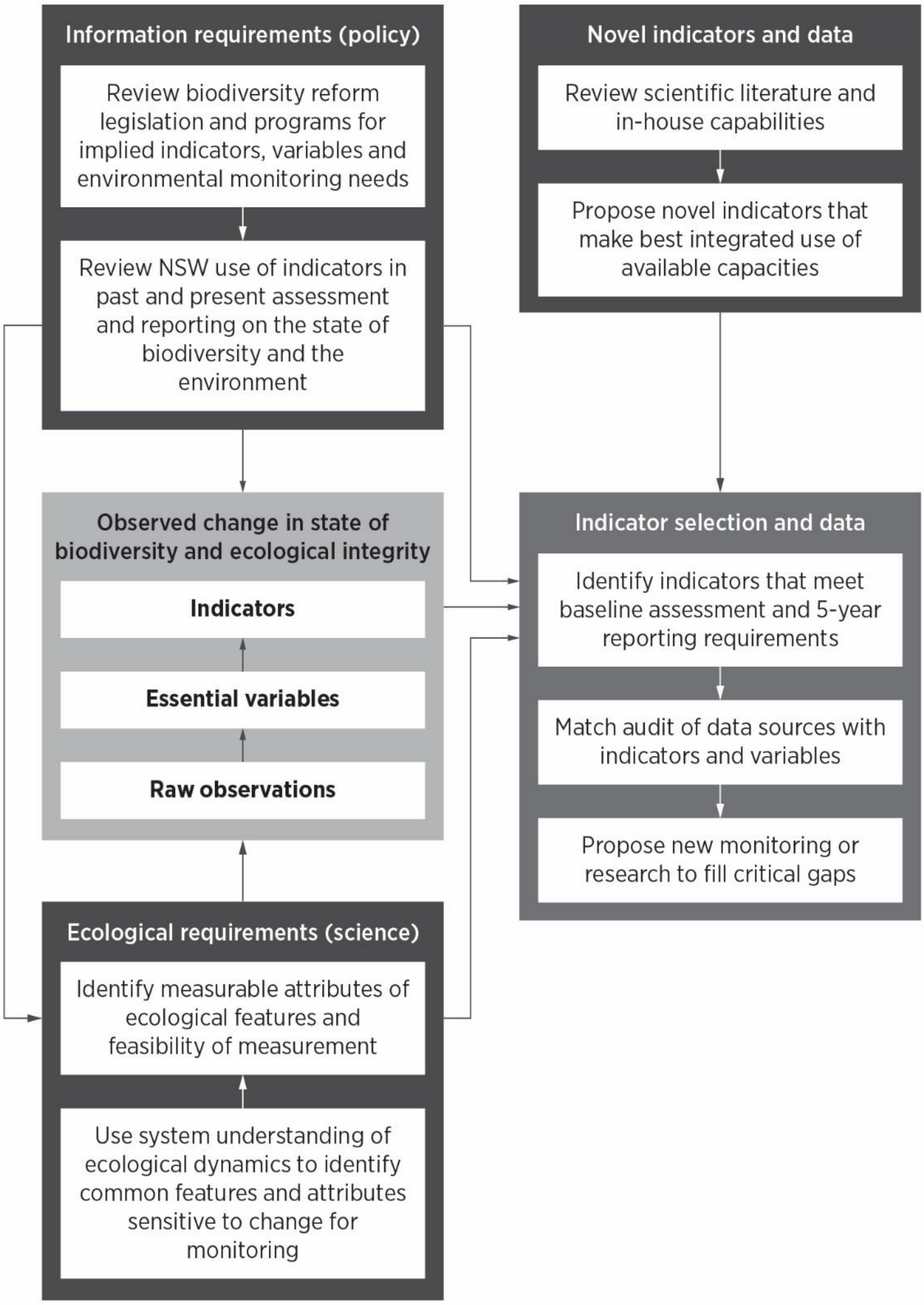

Figure 3 General approach to reviewing the data and determining indicator requirements of the biodiversity information program

This approach considered indicators that build on methods that have already been tested and can be applied using available data, as well as those requiring research and/or development. In cases where existing indicators were unsuitable or non-existent, new indicators were designed. A review of accessible data sources that could be used to support indicator development was also undertaken, such as the species distribution records accessed through NSW BioNet (the repository for biodiversity data products managed by OEH) and remote-sensed spatial data products. Both existing approaches and novel integrated uses of data and models were considered in developing the suite of biodiversity and ecological integrity indicators.

Five years is a relatively short period within which to detect change to biodiversity for the first review of the BC Act. Therefore, the approach taken in designing indicators integrates a wide variety of data, including on-ground surveys, with remote sensing, modelling and prediction. The indicators also represent impacts of pressures on biodiversity and whether conservation management responses are directly or indirectly influencing a change in biodiversity status over five years.

1.3.1 Additional frameworks guiding indicator selection and development

Applying the frameworks outlined in Figures 1 and 2, a combination of complementary indicators has been selected to provide information on different aspects of biodiversity and ecological integrity and their management in New South Wales. These indicators are based on a response–pressure–state–benefit (RPSB) framework (Sparks et al. 2011, see Figure 4), which is a simplified form of the driver–pressure–state–impact–response (DPSIR) framework (e.g. see Burkhard & Müller 2008), commonly used in state of the environment reporting.

This framework allows an understanding of causal linkages between biodiversity loss, pressures and responses and the data needed to support that understanding:

- Response indicators measure the implementation of policies or actions that aim to prevent or reduce biodiversity loss, such as conservation actions including offsets.
- Pressure indicators measure the extent and intensity of the threats to or causes of biodiversity loss, such as certain land uses.
- State indicators measure the current condition and status of biodiversity or ecological integrity, such as the status of threatened species or condition of suitable habitats.
- Benefit indicators quantify nature's contribution to people. These are not currently included in the indicator suite but the benefit of biodiversity to NSW society is well articulated in the BC Act, that is, a 'healthy, productive and resilient environment for the greatest well-being of the community, now and into the future, consistent with the principles of ecologically sustainable development'.

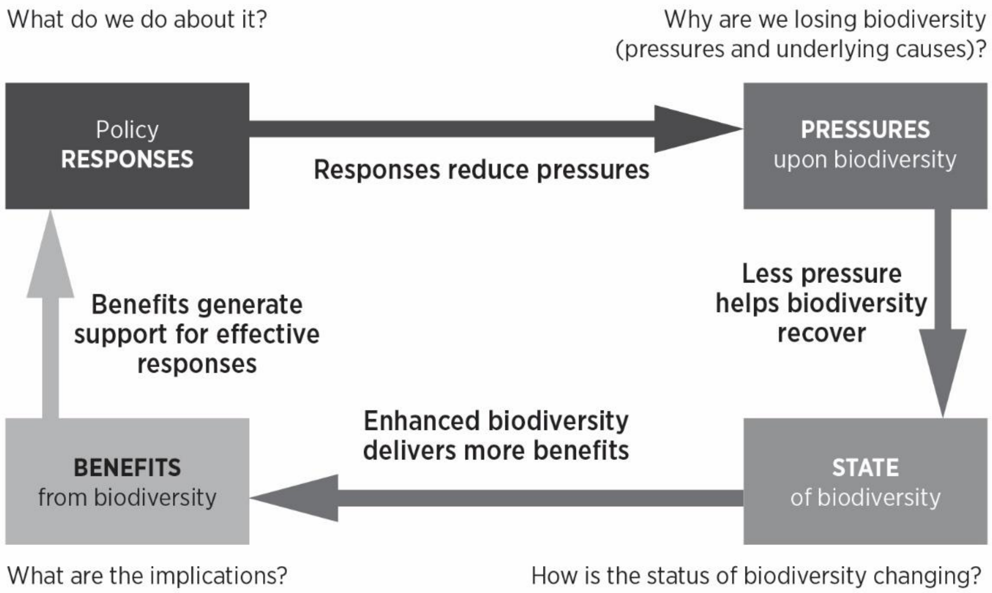

Figure 4 The response–pressure–state–benefit (RPSB) framework used to identify and classify indicators for biodiversity monitoring and evaluation. Adapted from Sparks et al. (2011)

OEH's Environmental Monitoring Assessment and Reporting (eMAR) Framework (OEH unpub.) was also used to guide the choice of indicators. In this framework, essential variables (EVs, see section 1.5.4) are a unifying concept (as shown in Figure 3) and can help to reconcile disparate sets of data. Based on the eMAR framework, indicators are grouped into functional themes, underpinned by raw data collection and their consolidation into EVs.

1.4 Considerations and strategy for designing indicators

In identifying and developing biodiversity and ecological integrity indicators, a number of criteria, requirements and methods guide the final design process.

Key requirements for the suite of biodiversity and ecological integrity indicators were considered separately along with the interaction between these requirements. These considerations are outlined below.

Biodiversity indicators need to:

- be inclusive of all levels of biological organisation, that is, diversity within and between species and diversity of ecosystems (within the meaning of the BC Act)
- represent all plants, animals and fungi native to New South Wales, including those yet to be discovered and catalogued, and the variety of habitats that support them (e.g. plant community types)
- evaluate the rate of loss of living variation and extinction risk of all species, not just species and ecological communities currently listed as threatened
- be sensitive to change in the rate of loss of living variation and the amount of extant (existing) biodiversity, over five years.

Ecological integrity indicators need to:

- measure the quality of ecosystems across whole landscapes, bioregions and the State in a way that informs and, in turn, is informed by management of pressures
- encapsulate the complexity of ecological and evolutionary processes that underpin the adaptive capacity of ecosystems, such as population viability, demographic processes, gene flow, primary and secondary productivity, water and nutrient cycling and the need for mobility (e.g. to forage, disperse or migrate)
- integrate with information about the complementarity and diversity of ecosystems that represents the variety of habitats supporting biodiversity (i.e. all plants and animals native to New South Wales including migrants from surrounding areas under climate pressure)
- integrate the activity of people in managing ecosystems, in the context of continuing pressures
- account for the potential overriding influence of climate change.

To meet these requirements, different approaches to measuring the status of biodiversity and ecological integrity are needed. The four approaches are:

1. Direct measures of biodiversity status, such as direct field measurements and long-term monitoring across a representative sample of locations.
2. Indirect measures of biodiversity status inferred from models of biodiversity distribution using species occurrence data and effective habitat area from remote sensing and observation of habitat extent and condition.

3. Direct measures of ecological integrity, such as remote sensing and observation of habitat extent, condition and pressures. Also, direct measures of where mitigations such as conservation actions are being undertaken and their effectiveness, from which effective habitat area can be inferred (and so infer measures of biodiversity status).
4. Indirect measures of ecological integrity, such as forecasting the capacity of ecosystems to adapt to change, based on current conditions and future predicted climate change, considering management objectives and models of ecosystem integrity (from which the retention of biological diversity and ecological functions can be inferred).

Indicators based on direct measures of status and trends (or changes) have the potential to provide concrete evidence of cause and effect. Direct monitoring can be a specific, sensitive and powerful method of change detection. Locations need to be situated strategically and designed to control for sampling artefacts and 'noise' variation over time. However, few long-term monitoring locations have been so designed to achieve such specificity and coverage.

Indicators based on indirect measures using models and scenarios complement those based solely on direct field observation of biodiversity. Both types of measure are needed. Direct observations are needed to assess biodiversity loss because they provide the information needed to predict consequences for biodiversity of observed habitat loss/gain at any point in time. Often, direct observations require longer than five years to measure change confidently and the change may only apply to that specific location. Those trends can, however, be generalised over many locations using remote sensing and models.

The four methods for measuring the status of biodiversity and ecological integrity, listed above, have complementary strengths and weaknesses. Therefore, a balanced and pragmatic blend of all four has been used in the design of indicators in a strategy based on multiple lines of evidence. New or alternative indicators will be identified and refined as knowledge and data grow and monitoring and assessment methods evolve.

Overall, the benefits of this blended strategy include:

- use of a balanced set of direct and indirect observations incorporated into indicators, with capacity to adopt more direct approaches as time series and technologies evolve
- comprehensive assessment of factors that affect biodiversity, including responses and pressures (integrating drivers and impacts)
- integration of existing and ongoing biodiversity monitoring studies into existing and new indicator designs
- capacity for forecasting or outlook reporting using scenarios and predictive models
- ability to assess significant changes at a range of geographic scales, from local to bioregional and statewide.

As part of our multiple lines of evidence-based strategy, we have used a combination of different methods and data to develop the indicators, including:

- specific assessment criteria recommended by the IUCN Red List of Threatened Species™, which provides information on the global extinction risk of plants, animals and fungi (Mace et al. 2008) and is the adopted standard worldwide (IUCN 2017); and the companion standard for ecological communities, the IUCN Red List of Ecosystems™, the adoption of which is growing worldwide (Keith et al. 2015)
- remote sensing (satellite imagery) of land-cover change and habitat condition, calibrated or informed by on-ground observations
- mathematical modelling, including spatial predictive modelling applications, such as the generalised dissimilarity modelling (GDM) approach (see section 1.5.1) which uses on-ground observations of species occurrences and environmental mapping of soils and climate

- direct monitoring of biodiversity or habitat condition status, pressures or responses (via on-ground surveys)
- long-term biodiversity and ecological integrity datasets (i.e. from sites monitored for more than 10 years).

Our strategy and approach mean that the method is cost-effective, repeatable, minimises bias, is consistent statewide and by bioregion, and can be improved continually as the amount of data collected and scientific knowledge increases and as technology evolves.

1.5 Important biodiversity-related concepts

This report contains references to complex biodiversity-related concepts and terms. Several warrant a more detailed explanation as they are central to the report.

1.5.1 Generalised dissimilarity modelling (GDM)

Generalised dissimilarity modelling (GDM) is a statistical technique for analysing and predicting patterns of change in species composition between sites across whole regions (Ferrier et al. 2007).

GDM employs best-available data from systematic surveys of species co-occurrences for a biological group, typically related by taxonomy, such as plants, mammals, reptiles, insects. These data are used to fit a non-linear statistical model relating the similarity in species composition between pairs of locations to mapped environmental predictors (climate, terrain, soil etc.). The compositional similarity in species between sites, or the proportion of species shared, varies from 1 (all species are shared) to 0 (all species are different). Models fitted using GDM effectively weight and scale the environmental variables, so that predicted distances within model outputs match compositional differences in species between sites as closely as possible.

1.5.2 Representative species sets

A representative species set is a sample of species from a biological group selected to represent the range of habitats occupied by the entire group (Faith 2015; Mimura et al. 2017). This approach provides a different line of evidence for measuring overall biodiversity by using known species' ranges as a complement to GDM. Representative sets of species are typically restricted to a nominated taxonomic group, such as plants. A representative sample of all species from a biological group means that a given index calculated on that subset is a good indicator of the index value that would have been obtained if calculated for all species (including those yet to be discovered). This approach overcomes the bias which may be introduced into indicators that use only those species that happen to be available in some databases (e.g. McRae et al. 2017).

The species are chosen so that their habitats represent, collectively, the full range of naturally occurring habitats for the entire group (determined from their diversity-environment association) across a region or statewide. The range of habitats to sample is obtained by comparing with a GDM for the group. A set of locations that evenly spans that modelled variation, equivalent to the number of species to be sampled, is defined. The species which occupies a habitat most like each location is selected to represent it. Together, the selected species form the representative set.

1.5.3 Biodiversity surrogates

A biodiversity surrogate is a component of biodiversity that can be measured more easily than others and acts as a substitute. It may be a species, group of species or ecosystem(s). Surrogates are used when the number of species or ecosystems of interest is too large, or even unknown, to allow each to be assessed individually or comprehensively (Wiens et al. 2008). The use of surrogates is an accepted approach in biodiversity conservation to overcome knowledge gaps (Beier et al. 2015; Engelbrecht et al. 2016; Faith et al. 2004; Faith & Walker 1996a, b).

Surrogate measures of biodiversity may be derived using different approaches. For example, selection of a set of species to be a representative sample of an entire group, or use of a predictive model of biodiversity, such as GDM, to represent the group. Both these approaches are used in the biodiversity indicators that apply indirect assessment methods. The different approaches represent different lines of evidence and reveal some types of uncertainty associated with choice of surrogate method. The effectiveness of a biodiversity surrogate for one biological group, such as plants, to act as a substitute for other biological groups, such as birds, mammals or butterflies, can be systematically assessed.

1.5.4 Essential variables (EVs)

Essential variables (EVs) are the minimum information needed to quantify significant environmental change at a range of geographic scales, from local and regional to nationally and globally (Bojinski et al. 2014; Pereira et al. 2013). They have a sound theoretical basis, are scientifically rigorous and support an internationally agreed approach to environmental monitoring. They enable us to make comparisons between environmental conditions at different locations and times, and can be integrated into indicators to fulfil a specific reporting requirement. Examples of EVs are species distribution, ground cover, precipitation, soil moisture and net primary productivity. They are the most important information we need to know about the environment; they enable us to understand how it is changing in response to biophysical impacts and our management. They sit as an intermediate layer between primary observations (including remotely sensed data) and indicators and indices.

Different types of EVs can be defined, such as essential climate variables (Bojinski et al. 2014), essential ocean variables (IOCCP 2013) and for marine ecosystems (Constable et al. 2016), essential water variables (Lawford & Boisvert 2014) and, most relevant to this report, essential biodiversity variables (Pereira et al. 2013). Essential biodiversity variables give us information on the state of biodiversity (Kissling et al. 2018; Latombe et al. 2017; McGeoch et al. 2016; Turak et al. 2017). In this report, we use the RPSB framework to include a new type of EV for monitoring ecosystem-based management. This EV provides information about how land-use and management policies and practices change over time and so quantifies our responses to pressures on biodiversity and enables monitoring of management effectiveness. This is consistent with a broadening of the EV framework proposed by Reyers et al. (2017) for monitoring of sustainable development goals.

1.5.5 Expected diversity

Expected diversity is defined as the number of features (genes, species, ecosystems) that are expected to still exist in 100 years’ time (Faith 2008). It is calculated based on Weitzman’s (1992) ‘expected diversity’ formula, which integrates any nominated diversity measure with information about species’ estimated extinction probabilities. Expected diversity provides a measure for assessing change in the threatened status of biodiversity. In this report, it is applied to species, subsets of species, ecological communities and phylogenetic diversity. It is also applied using surrogate measures of diversity from GDM.

1.5.6 Environmental diversity (ED)

Environmental diversity (ED) is a specific, surrogates-based approach to measuring biodiversity complementarity (i.e. the relative biodiversity of sets of areas) developed by Faith and Walker (1996a). It provides for some expression of environmental and/or biotic pattern so that variation among areas is seen as part of a continuum rather than partitioned into arbitrary clusters/classes. The GDM method is a modern way to express this continuum for use in complementarity-based conservation assessments and biodiversity indicators.

1.5.7 Phylogenetic diversity (PD)

Phylogenetic diversity (PD) is a measure of biodiversity which quantifies the evolutionary connections amongst a group of species. PD is calculated from a phylogenetic tree and is the sum of branch lengths connecting a set of species to the root of the tree (Faith 1992). The unit of measurement is typically in millions of years of evolutionary history. It is a measure of how unique the lineages of particular species are. Species with long, distinct lineages are potentially a greater loss to overall biodiversity than species with a lot of close relatives.

1.6 Structure of this report

This report is structured into two remaining sections:

- Section 2 includes a detailed description of the indicators themselves, including their level of readiness and how they will be reported.
- Section 3 includes a detailed description of the methods used in the indicator development process, including the scientific requirements, criteria, principles and theories behind their design and development.

2. Indicators for biodiversity and ecological integrity

More than 30 indicators have been identified to fulfil the need for measuring and monitoring change in the status and conservation of terrestrial biodiversity at statewide and bioregional scales in New South Wales. The indicators encompass measures of biodiversity and ecological integrity and represent management responses, pressures on biodiversity and the status of biodiversity. The approach used to identify the indicator set and measurement methods is detailed in section 3 of this report. Indicators will be implemented in a staged approach to reflect the readiness of data, technology and resource availability. Some indicators included in this indicator framework are aspirational and require further research and development or await the introduction of new monitoring and information technologies to confirm their feasibility.

The indicators have been designed to detect trends or changes, specifically the rate of loss of biodiversity, as well as the effectiveness of conservation actions. The indicators were developed through an extensive collaborative process with experts from CSIRO, OEH, Macquarie University and the Australian Museum. The method developed under the Biodiversity Indicator Program, including the indicators, has been independently peer-reviewed and the feedback from the review has been incorporated into this method report.

The indicators have been allocated to two classes, biodiversity and ecological integrity, as outlined in section 1. Biodiversity and the condition of supporting habitats are closely dependent, and an individual measure may be derived from or have input into either the biodiversity or ecological integrity class of indicators.

The allocation of the indicator into either the biodiversity or ecological integrity class depends on its measurement objective. If the objective is to measure the amount of biodiversity, such as the number of species expected to exist in 100 years, the indicator is assigned to a ‘biodiversity’ theme. If the indicator is measuring the extent or quality of supporting habitat, a change in management response, or the pressures that potentially threaten biodiversity, it is assigned to the relevant ‘ecological integrity’ theme.

Indicators can be expressed in different ways and at different geographic, taxonomic and temporal scales. Part of the purpose of the BC Act is to conserve biodiversity at bioregional and statewide scales. Therefore, wherever appropriate, indicator calculations are designed to reliably report status and trends at these scales. Some indicator calculations may be applied to other predefined areas, such as local government boundaries. However, some indicators can be reported only at statewide scales, for example, expected survival of listed threatened species. Some measurement methods are applied or calculated at the scale of a taxonomic group, such as vascular plants, mammals, birds, insects and so forth. These taxonomic groups may be used in reporting on the components of some indicators.

Consistent with the scientific framework used to identify the required set of indicators (as outlined in section 1), each class of indicator is grouped further into themes and families. Each family contains related and complementary sets of indicators, including direct supporting measures that facilitate an interpretation and understanding of indicator trends (Table 1). It is expected that indicators developed using a common method will be grouped for reporting purposes, with one or more providing the ‘headline’ result and others providing supporting information. Natural groupings of indicators compiled into ‘report cards’ will be used to summarise the findings published in the NSW biodiversity outlook report.

Table 1 Classification and readiness categories of the indicators

Category 1 indicators will be reported in the first NSW biodiversity outlook report and are indicated in **bold type**. Category 2 and 3 indicators are under development. See section 2.3 for a description of categories.

Theme	Indicator family	Indicator	Readiness category
		Class: Biodiversity	
1 Expected survival of biodiversity	1.1 Expected survival of listed threatened species and ecological communities	**1.1a Expected survival of listed threatened species**	1 (all taxa assessed by Scientific Committee)
		1.1b Expected existence of listed threatened ecological communities	1 (all taxa assessed by Scientific Committee)
		1.1c Expected survival of phylogenetic diversity for listed threatened species	1 (mammals, birds, frogs) 3 (reptiles, some plant families)
	1.2 Expected survival of all known and undiscovered species	**1.2a Expected survival of all known species**	1 (vascular plants)
		1.2b Expected survival of all known and undiscovered species	3 (vascular plants)
2 State of biodiversity	2.1 State of all known species	**2.1a Within-species genetic diversity (for all known species)**	1 (vascular plants)
		2.1b Extant area occupied (for all known species)	1 (vascular plants)
	2.2 State of biodiversity including undiscovered species	2.2a Within-species genetic diversity (including undiscovered species)	3 (vascular plants)
		2.2b Persistence of all species (including undiscovered species)	3 (vascular plants)
		2.2c Persistence of ecosystems (including undiscovered species)	1 (vascular plants)
	2.3 Field monitoring of species and ecosystems	**2.3a Species trends**	1 (selected locations and species)
		2.3b Ecosystem trends	1 (selected locations and ecosystems)
		Class: Ecological integrity	
3 Ecosystem quality	3.1 Habitat condition	**3.1a Ecological condition of terrestrial vegetation**	1 (method i), 3 (method ii and iii) [1]
		3.1b Ecological connectivity of terrestrial vegetation	1 (terrestrial method i), 3 (ii and iii) [1]
		3.1c Ecological carrying capacity of terrestrial vegetation	1 (method i), 3 (ii and iii) [1]
		3.1d Ecosystem function of terrestrial vegetation	3
	3.2 Pressures	3.2a Land-use and management practices	2
		3.2b Native vegetation extent	2

Theme	Indicator family	Indicator	Readiness category
	3.2 Pressures (cont.)	3.2c Inappropriate fire regimes	3
		3.2d Inappropriate hydrological regimes	3
		3.2e Invasive species (pests, weeds, disease)	3
		3.2f Altered climatic regimes, variability and extremes	3
4 Ecosystem management	4.1 Management responses	4.1a Areas managed for conservation in perpetuity	2
		4.1b Areas managed for conservation under formal or informal agreements	3
		4.1c Community appreciation of biodiversity	3
	4.2 Management effectiveness	4.2a Effectiveness of on-ground biodiversity conservation programs	3
		4.2b Community-based maintenance of biodiversity values	3
		4.2c Implemented climate-adapted conservation planning and management	3
	4.3 Capacity to sustain ecosystem quality	4.3a Capacity to maintain or enhance ecosystem quality (through local resilience)	3
5 Ecosystem integrity	5.1 Capacity to retain biological diversity	5.1a Ecosystem capacity to adapt to change and retain biological diversity under climate change	3
		5.1b Ecosystem capacity to adapt to change and retain biological diversity under land-use change	3
	5.2 Capacity to retain ecological functions	5.2a Ecosystem capacity to adapt to change and maintain ecological functions under climate change	3
		5.2b Ecosystem capacity to adapt to change and maintain ecological functions under land-use change	3

1. See indicator 3.1a and section 3.5 for a description of methods i, ii and iii.

2.1 Biodiversity indicators

The biodiversity indicators assess the change in status of biological diversity over time with regards to all plant, animal and fungi species and ecosystems, including those yet to be discovered or described. Each biodiversity indicator has the potential to be expressed through different feature types (plant and animal groups) or ecosystems (a classification map or ecological communities). In some cases, where data are available, the indicators may be calculated using historic data to determine the past-to-present trend.

Biodiversity indicators are grouped into two broad themes: expected survival of biodiversity and state of biodiversity. Expected survival of biodiversity is a measure of the number of species or ecological communities we expect will still exist in 100 years, determined from categories of risk of extinction. Indicators in the state of biodiversity theme measure the potential of biodiversity to survive and, in the case of indirect measures, are set relative to notional original conditions prior to the industrial era, c. AD1750. The indirect versions of these indicators also infer, using the present extent, condition and configuration of surrounding native habitats, the latent natural decline rates in species' population survival (i.e. their local extinction rates). The status at the commencement of the BC Act can then be interpreted in terms of biodiversity persisting in the future.

2.1.1 Theme 1: Expected survival of biodiversity

This indicator theme directly measures the rate of loss of biodiversity using long-established scientific methods. It addresses the survival, in 100 years, of both species and ecological communities that are known to be at risk of extinction, as well as those species whose risk has not been assessed. It also addresses the potential loss of evolutionary history using the phylogenetic diversity (PD) of threatened groups of species.

The expected survival (based on expected diversity, Weitzman 1992, 1998, see sections 1.5.5 and 3.3) of a set of species or ecological communities is measured using the standard categories of extinction risk established by the IUCN (Mace et al. 2008). Those extinction risk categories are equated with a probability of survival in 100 years, as used by the *Saving our Species*[1] program to prioritise species for management (OEH 2013). The indicator is determined from the sum of the probabilities of survival for each species.

The IUCN Red Lists of species and ecosystems (i.e. ecological communities) are determined based on specific scientific criteria and agreed methods of assessment that are both rigorous and comprehensive. The Red List categories are 'extinct in the wild', 'critically endangered', 'endangered', 'vulnerable', 'near threatened', 'least concern' and 'data deficient'. The process of assessment requires detailed information about individual species and ecological communities and is typically limited to those cases that are well known or researched. This makes the determination unavoidably slow and meticulous. Therefore, the great majority of biodiversity has either not been assessed for its risk of extinction or has been assessed too infrequently to detect change in extinction risk as it happens.

This indicator theme complements the rigorous IUCN assessment methods and the deliberations of the NSW Scientific Committee by also applying a 'cut-down' approach, which uses a subset of the official criteria to approximate categories of extinction risk. In order to assess both known and undescribed species, different ways to measure and

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[1] This program is an initiative of the biodiversity conservation program for threatened species and threatened ecological communities, established under s. 4.35(2) of the BC Act, 'to maximise the number of threatened species that are secure in the wild in New South Wales for 100 years' (OEH 2013).

represent all of biodiversity are employed. The resulting assessments are designed to provide a useful indication of how much biodiversity may be at risk of extinction, beyond those species and ecological communities currently listed on schedules of the BC Act.

Because extinction risk is typically a determination made within a jurisdiction (New South Wales in the case of the BC Act), the resulting measure of expected survival can be reported statewide only. It can, however, be reported by extinction risk category and relevant biological group (species, ecosystems, taxonomic or other functional grouping). Some of the limitations of this indicator theme, such as the restriction to risk categories, are addressed by the state of biodiversity theme, which provides a more general assessment of status.

2.1.2 Theme 2: State of biodiversity

This indicator theme measures, directly and indirectly, the overall amount of biodiversity (genes, species and ecosystems) that currently exists. Where possible, it is expressed as a proportion of that which existed prior to the industrial era (c. AD1750). Variants of some indicators in this theme also use knowledge of the latency in biodiversity decline (extinction lag), following loss of high-quality connected habitat, to estimate the amount of biodiversity likely to persist (Tilman et al. 1994). The precise status of biodiversity is unknown, but is within a range defined by these measurements.

Direct measures of biodiversity status also include long-term and/or wide-ranging, repeat field monitoring of species and ecosystems. While these studies collect data at local or regional scales and have been designed to address specific scientific or management objectives, they can also provide useful and complementary measures of the current status of and trends in biodiversity. A review of existing or ongoing field monitoring programs that are suitable for use in the method for New South Wales is underway.

Indirect measures to interpret biodiversity status use remote sensing and modelling of habitat extent (Geller et al. 2017), condition (Lawley et al. 2016; Harwood et al. 2016) and connectedness (van Teeffelen et al. 2012), using data on biodiversity distribution in relation to environmental gradients. The data on biodiversity distribution may be known or derived from models developed using direct observations of species' occurrence within the environment. Observations of species' occurrence can be from systematic biological surveys or from occasional surveys where the method has been recorded, so that the data can be harmonised. Statistical methods, such as GDM, then allow patterns of biodiversity distribution to be predicted from mapped characteristics of the environment such as climate, soil type and landform.

Because the choice of method for indirect measurement can influence the resulting measures of biodiversity status, different methods are employed. One approach is to use data on biodiversity distribution from a sample of species designed to represent the range of habitats occupied by all the species within a group, called a representative species set (see sections 1.5.2 and 3.4; Faith 2015; Mimura et al. 2017). The other approach employs statistical models (e.g. GDM, see sections 1.5.1 and 3.5; Ferrier et al. 2007; Drielsma et al. 2014). Both aim to remove observer bias and so represent biodiversity equally for the purpose of an indicator. They aim to account for both the known and undiscovered components of biodiversity, as outlined in section 1.2.

The data on biodiversity distribution, derived from species' occurrence records, can be classified to represent the diversity of ecosystems, or to calculate an implied amount of genetic diversity. In this way, the indirect measures can be expanded to inform on the likely amount of diversity at three levels of biological organisation. Over time, these indirect methods may be increasingly informed by direct measures of biodiversity status. The predictive modelling approaches, however, also allow future policy scenarios of climate and land-use change to be applied in forecasting the outcomes for biodiversity.

The resulting measures, having been derived from spatially explicit information, can be reported both at bioregional and state scales and other relevant predefined areas such as conservation tenures and local government boundaries. In this way they can inform biodiversity status in different contexts, enabling the relative performance of different conservation measures and regional pressures to be explored.

2.2 Ecological integrity indicators

The ecological integrity indicators establish the need for ongoing monitoring to assess both the diversity and quality of ecosystems, as well as the effectiveness of their management; and so inform their inherent capacity to adapt to change (see knowledge framework in Figure 2). Indicator set ecosystem diversity (quadrant B) in the framework is reported through the state of biodiversity theme of indicators (see section 2.1.2). The remaining indicator sets are therefore grouped into three themes that relate to measures of ecosystem quality, ecosystem management and ecosystem integrity.

2.2.1 Theme 3: Ecosystem quality

This theme comprises general measures of habitat condition indicating capacity to maintain natural functions and processes supporting terrestrial species and ecosystems in New South Wales. It includes measurement of pressures that threaten habitat condition or biodiversity, enabling some attribution of cause (observed pressures) and effect (observed state).

Indicators of habitat condition use remote sensing, land use and modelling to assess ecological condition (including ‘vegetation integrity’ as defined in the BC Act), the extent of habitat loss and the degree of habitat fragmentation. These affect the ability of habitats to adapt to climate change and support native plants and animals. The indicator theme also includes novel measures of ecosystem function related to naturalness that depict the degree of disruption from an expected climate or environmental equilibrium.

In New South Wales, the *Biodiversity Assessment Method* (OEH 2017a) defines how vegetation integrity at the site level is to be measured. The on-ground measurement of vegetation integrity is a minimum pragmatic approach to rapid assessment that can be applied consistently by trained assessors. Its application requires the definition of reference states, also known as benchmarks, to clarify what is meant by ‘near natural’ or ‘best attainable’ as a management goal; and therefore, of having an effective level of ‘integrity’ sustaining ecosystem function with minimal intervention. To be useful in an indicator, systematic observations of habitat condition at the site level need to be designed to allow interpolation across whole regions and so infer change, by integrating with remote-sensing and modelling technologies.

Indicators of pressures are necessary to understand and attribute meaning to any change in the status of ecosystem quality. A wide range of such measures can be developed and are under investigation. In the first instance, existing measures of pressures and their impact that have been developed for other purposes can be applied. These include land-use and land-cover data, and inappropriate fire regimes (where fires have been either too frequent, or not frequent enough) for sensitive ecological communities.

2.2.2 Theme 4: Ecosystem management

This indicator theme addresses the effectiveness of local-scale conservation management actions (such as through private land conservation programs) and responses, such as the introduction of new policies or actions to prevent or reduce biodiversity loss. It also considers the preparedness of managers, in their planning and implementation capacities, to facilitate ecosystems adapting to change. It allows for consideration of all types of management across all land sectors that collectively influence outcomes, such as reduced rates of loss of biodiversity or enhanced ecosystem quality, even if only indirectly influenced by the BC Act.

A number of simple measures of ecosystem management can be reported in the first instance, such as areas managed for conservation. These can further be used as reporting contexts for other biodiversity and ecosystem quality indicators and in scenarios of ecosystem adaptive capacity by inferring some level of management effectiveness.

Management effectiveness of individual programs supported by the BC Act, such as the *Private Land Conservation* program, is being assessed through direct measurement, including on-ground observations and reporting. There is potential to develop other measures, for example, related to adaptive management capacities under climate change and societal understanding and attitudes toward conservation supporting continued resourcing of sustainability and environmental management. These additional measures require research and design, in addition to methods to integrate theme 4 ecosystem management components with theme 3 ecosystem quality and report on the overall capacity to maintain or enhance ecosystem quality (as shown in Figure 2).

2.2.3 Theme 5: Ecosystem integrity

This indicator theme considers the capacity of ecosystems to retain their biodiversity and ecological functions in the face of ongoing, yet uncertain, environmental change, including both climate change and land-use change. It addresses the capacity of ecosystems to adapt to change (and so provide for the needs of future generations), which is an underpinning purpose of the BC Act (s. 1.3(b)). Supporting biodiversity conservation in the context of a changing climate is another purpose of the BC Act (s. 1.3(d)) to which this theme relates.

This indicator theme aims for the integration and synthesis across other themes of biodiversity and ecological integrity and introduces the concept of ecosystem resilience in deriving an overall measure of ecological integrity (see quadrant D in Figure 2). Indicators developed under this theme will enable estimation and reporting of past-to-present changes in ecosystem integrity. These indicators allow alternative land-use and management options to be evaluated in terms of expected consequences for adaptive capacity into the future. The indicators can apply either a plausible range of climate projections, or land-use change scenarios driven by socio-economic demand, or both. Future international research is expected to provide integrated scenarios of climate and land-use change suitable for testing the general integrity and robustness of ecological systems (Rosa et al. 2017).

Omission of this theme would lead to the inability to comprehensively measure an important component of the ecological integrity of ecosystems, that is, their capacity to adapt and to retain biological diversity and ecological functions in the face of ongoing, yet uncertain, environmental change. Models assessing the capacity of ecosystems to adapt over time will help inform policies determining what types of management response to invest in, where this should be concentrated and when it should be undertaken to make a difference.

This theme is subject to ongoing development, and alternative methods and indicators are expected to evolve as they are designed and tested. For example, there is potential to include novel measurement methods from field assessments to track and predict the diversity of ecosystems adapting to change (through indicator family 2.3).

2.3 Readiness levels of indicators

The implementation of indicators depends on their level of readiness. Some are ready now, while others require further development. In some cases, one component of an indicator may be at a different level of readiness than the other components, or a single indicator may rapidly undergo several phases of development.

We have identified three categories of indicators, or their components, based on their level of readiness:

- Category 1: the minimum viable set developed for the first assessment, where data and workflows are well-established, allowing full implementation within c. six months.
- Category 2: some development is required for full implementation, for example, testing of workflows, requiring a longer period of development, within c. 6–12 months.
- Category 3: for which the need has been identified, but the methods, science and data need to be assessed, requiring research, development and testing. The timeframe for this category is c. 1–3 years or more.

It should be noted that both category 2 and 3 indicators can be developed, measured and reported at any time before the five-year review of the BC Act. When ready, these indicators can be calculated using data from the date of commencement of the BC Act.

Many indicators have been allocated to more than one category of readiness. This reflects both the need for indicator development and continuous improvement as knowledge, data and technology improve for measuring biodiversity and ecological integrity. It also reflects a staged delivery process due to time constraints, data or method readiness. For example, some indicators are ready to be implemented for those biological groups that have sufficient data, such as vascular plants. Therefore, the category 1 component of the indicator is an analysis of vascular plant data. When data becomes available for other groups, such as reptiles, birds or mammals and some invertebrate groups, it can be incorporated into the indicator as category 2 or 3, depending on the anticipated time needed for data collection, processing and analysis.

This also applies to indicators that incorporate values or components from other indicators. For example, the ecological condition indicator is used directly in several biodiversity indicators to determine the proportional loss of habitat, from which biodiversity status is inferred. Over the next two years, the biodiversity information program will be developing new ways to use satellite, aerial remote-sensing and other data to reliably correlate and interpolate locally measured vegetation condition. As these methods are generated, the interdependent indicators based on this new information can be recalculated. Comparison of results from applying refined assessment methods for the same indicator can be reported as knowledge and technology grows.

It is also important to note that some data sources, in particular, remote sensing and field-based observations, are not available immediately. The indicators for the first assessment report will therefore often use data obtained a few years prior to the commencement of the BC Act. Some indicators may be re-run in the future to clarify their status at the first assessment, while others will have capacity to use historical data to estimate past trends.

Furthermore, the general framework in which the indicators are grouped at family level provides a basis for the development and addition of new sets of indicators to this method, for example, indicators measuring freshwater, coastal and marine species and their particular ecological communities.

2.4 Indicator descriptions

An overview of individual terrestrial indicators within each of the five themes is outlined in Tables 2–6 below. In all tables, t_0 denotes the first reference measurement of the indicator (typically the status before commencement of the BC Act or a trend where historical data are available) and t_Δ denotes the measurement of the indicator at any time in the future (or subsequent to the first measurement). Further details are provided in section 3.

2.4.1 Biodiversity indicators

Table 2 Biodiversity indicators theme 1: Expected survival of biodiversity

Indicator family 1.1: Expected survival of listed threatened species and ecological communities	
Rationale:	This indicator family allows the assessment of the survival (continued existence) in 100 years of species and ecological communities that have already been determined by the NSW Scientific Committee to be at risk of extinction. The indicator family also includes a measure of the risk of losing unique evolutionary heritage (via phylogenetic diversity). In the future, this indicator can be updated based on monitoring of successful management actions that result in secure wild populations of threatened species or ecological communities as determined by the *Saving our Species* program.
Indicator number:	**1.1a**
Indicator name:	**Expected survival of listed threatened species**
Indicator description:	**Number of listed threatened species expected to survive in 100 years** Species on the NSW Threatened Species List (see Glossary) are assigned to risk of extinction categories. Species categorised as either vulnerable, endangered, critically endangered or extinct are assigned a probability of survival in 100 years. Species that have been assessed and not listed (i.e. are considered secure) are also assigned a probability of survival. At t_0: The indicator is calculated by summing the probabilities of survival for all species on the NSW Threatened Species List. The number of species expected to survive in 100 years can be a fraction, because the index is calculated from the sum of probabilities of survival. The indicator sensitivity to list membership is also calculated. The measure can be expressed as a proportion of the total number of listed species to enable comparison with other indicators in theme 1. The indicator can also be applied to the complete history of threatened species determinations, by using the NSW Threatened Species List at a particular time in the past, to provide a trend.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • a change in the threat category of species due to a decision of the NSW Scientific Committee • a change in the probability of survival due to effective management of the species as determined by the *Saving our Species* program. NSW Threatened Species List will be standardised and the status at each assessment recalculated. Species added to the NSW Threatened Species List at t_Δ are also added to the list of past assessments t_0, and best/worst case assumptions of past status used to calculate an historical range of values. Species assessed at t_Δ as not threatened (i.e. secure) while removed from the NSW Threatened Species List, are retained on the standardised list as not threatened, for calculation purposes.
Readiness category:	1 (all taxa assessed by NSW Scientific Committee)
Reporting scale:	Statewide only (i.e. not applicable at bioregional, regional or local scales)
Taxonomic scope:	All taxa (past and present) on the NSW Threatened Species List

Indicator number:	**1.1b**
Indicator name:	**Expected existence of listed threatened ecological communities**
Indicator description:	**Number of listed threatened ecological communities expected to exist in 100 years** Ecological communities on the NSW Threatened Ecological Communities List (see Glossary) are assigned to risk of extinction categories. Ecological communities categorised as either vulnerable, endangered, critically endangered or collapsed are assigned a probability of still existing in 100 years. Ecological communities that have been assessed and not listed are also assigned a probability of existing in 100 years.
	At t_0: The indicator is calculated by summing the probabilities of existence for all ecological communities on the NSW Threatened Ecological Communities List across all categories. The expected number of ecological communities existing in 100 years can be a fraction, because the index is calculated from the sum of probabilities of existence of individual ecological communities. The indicator sensitivity to list membership is also calculated. The measure can be expressed as a proportion of the total number of listed species to enable comparison with other indicators in theme 1. The indicator can also be applied to the complete history of threatened ecological community determinations, by using the NSW Threatened Ecological Communities List at a particular time in the past, to provide a trend.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • a change in the threat category of ecological communities due to a decision of the NSW Scientific Committee • a change in existence probabilities due to effective management of the ecological communities as determined by the *Saving our Species* program. NSW Threatened Ecological Communities Lists will be standardised and the status at each assessment recalculated. Ecological communities added to the list at t_Δ are also added to the list of past assessments t_0, and best/worst case assumptions of past status used to calculate an historical range of values. Ecological communities assessed at t_Δ as not threatened while removed from the NSW Threatened Ecological Communities List, are retained on the standardised list as not threatened, for calculation purposes.
Readiness category:	1 (all taxa assessed by NSW Scientific Committee)
Reporting scale:	Statewide only
Taxonomic scope:	All taxa (past and present) on the NSW Threatened Ecological Communities List

Indicator number:	**1.1c**
Indicator name:	**Expected survival of phylogenetic diversity for listed threatened species**
Indicator description:	**The length of evolutionary history that is maintained in the species of a biological group that is expected to survive in 100 years** A complete list is obtained of all species within New South Wales for a biological (i.e. taxonomic) group for which there are species on the NSW Threatened Species List. How each species is related by shared ancestry over evolutionary timescales (in millions of years) is known as the phylogeny or evolutionary tree. The phylogeny identifies when each species evolved. For each biological group, this indicator requires a complete phylogeny for all species known from New South Wales (e.g. birds, mammals, frogs, reptiles). Species on the NSW Threatened Species List are assigned to risk of extinction categories. Species categorised as either vulnerable, endangered, critically endangered or extinct are assigned a probability of survival in 100 years. Species that have been assessed and not listed (i.e. secure) are also assigned a probability of survival. Other species in the biological group are assumed not threatened. Phylogenetic diversity (PD) is the sum of all the branches in the evolutionary tree that span all surviving species and their common ancestor, measured in millions of years. The indicator can also be applied to the complete history of threatened species determinations, by using the NSW Threatened Species List at a particular time in the past, to provide a trend. At t_0: The indicator is calculated by summing the survival probabilities for all species within the biological group, multiplied by years of evolutionary history. The indicator is reported in units of millions of years of evolutionary history expected to survive in 100 years.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • a change in the threat category of species due to a decision of the NSW Scientific Committee, or • a change in survival probability due to the effectiveness of management of populations as determined by the *Saving Our Species* program. If a phylogeny for the biological group has been revised based on new information, such as species' discoveries and technologies, the status at each assessment t_0 is also recalculated. List standardisation as for threatened species also applies.
Readiness category:	1 (mammals, birds, frogs), 3 (reptiles, some families of flowering plants)
Reporting scale:	Statewide only
Taxonomic scope:	All species within New South Wales for a biological (i.e. taxonomic) group for which there are species on the NSW Threatened Species List.

Indicator family 1.2: Expected survival of all known and undiscovered species	
Rationale:	This indicator family predicts extinction risk of all known and undiscovered species, beyond those formally assessed by the NSW Scientific Committee. It uses the IUCN Red List assessment method for criteria B2 and B2(b)(ii) for estimated area of occupancy (AOO). Different measurement methods are applied to comprehensively assess biodiversity using this risk framework and to minimise sampling bias. It can be used as a measure of the overall effectiveness of ecosystem management in securing, maintaining or improving the survival of all known and undiscovered species in 100 years' time. The habitat condition family of indicators 3.1 support this assessment.
Indicator number:	**1.2a**
Indicator name:	**Expected survival of all known species**
Indicator description:	**Proportion of all known species expected to survive in 100 years, assessed for each biological group** Species from a biological (i.e. taxonomic) group are sampled to uniformly represent the full range of natural habitats for that group. The representative species are provisionally assigned to risk of extinction categories based on the estimated proportion of their original habitat that remains intact using the IUCN Red List assessment method for criteria B2 and B2(b)(ii). This is a provisional assessment of risk using commonly available species occupancy data. The method uses species occurrence observations since 1950 in 2-kilometre map grids (each being 4 km^2) and intact area of occupancy (AOO) thresholds specified by the two criteria to discriminate four risk of extinction categories. Each species is further assessed for a reduction in AOO determined from the habitat condition indicator 3.1a. The reduction in AOO in four classes (<30%, 30–50%, 50–80% and >80%; adapted from criterion A of the IUCN Red List of Ecosystems), and the intact AOO thresholds (also using indicator 3.1a) provide the dimensions of a simple extinction risk categorisation similar to that of listed threatened species. Each category is given a probability of survival in 100 years which is applied to all representative species in that category. At t_0: The indicator is calculated by summing the probabilities of survival for the representative species across all categories and is expressed as a proportion of the total number of species representing the biological group. This serves as an indicator for all known species within the biological group expected to survive in 100 years and, by logic, extends to undiscovered species in that group. The reduction in AOO is used directly in indicator 2.1b, and is used to infer the amount of genetic diversity potentially at risk of loss in indicator 2.1a.
Detecting change:	Change in the value of the indicator at t_Δ reflects: • a change in survival probability due to a change in habitat condition determined from indicator 3.1a. If sufficient habitat is lost or degraded for a particular species its extinction risk category will be changed. Updated indicators for ecological condition 3.1a are applied as these are developed. The indicator is standardised by using the same representative sample of species. If different samples are derived or new information about a representative species changes its AOO, the status at each past assessment period t_0 is also recalculated.
Readiness category:	1 (vascular plants), 3 (other taxonomic group/s)
Reporting scale:	Statewide only
Taxonomic scope:	All taxa

Indicator number:	**1.2b**
Indicator name:	**Expected survival of all known and undiscovered species**
Indicator description:	**Proportion of all known and undiscovered species expected to survive in 100 years, assessed for each biological group** The potential existence of species at risk of extinction (both known and undiscovered) from a biological (i.e. taxonomic) group is inferred by using a model of biodiversity derived from systematic surveys of that group's co-occurring species and their associated environments (using GDM). The model is used to estimate the proportion of species provisionally assigned to risk of extinction categories based on the estimated amount of original habitat that remains intact. This is broadly consistent with the IUCN Red List assessment method for criteria B2 and B2(b)(ii) as applied to analogous indicator 1.2a for known species. This is a provisional assessment of risk, using just one set of assessment criteria adapted to work with a model of biodiversity. The analysis is conducted for a sample of locations that represent the full range of natural habitats based on the model for that biological group. At each location, the model predicts the proportion of species potentially existing within specified intact AOO thresholds (in the order <10 km^2, <500 km^2, <2000 km^2, or >2000 km^2) to assign notional risk of extinction categories (highest to lowest). The thresholds are applied using 2-kilometre map grids and a decline in habitat condition of at least 30% is used, determined from indicator 3.1a. The estimated proportion of species in the respective extinction risk category is then calculated. Each category is given a probability of survival, which is applied to all sets of locations and the proportion of species in that category. At t_0: The indicator at initial assessment is calculated by summing the probabilities of survival by the proportion of species inferred to remain for each location by category and across the sample of locations representing that biological group. The indicator is expressed as a proportion of species expected to survive in 100 years, including both known and undiscovered species. An estimate of the number of known and undiscovered species may be provided from an analysis of species discovery over time to predict an overall number of species expected to survive in 100 years. The results can also be used in indicator 2.2a to infer the amount of genetic diversity potentially at risk of loss.
Detecting change:	Change in the value of the indicator at t_Δ reflects: • a change in survival probability due to a change in habitat condition determined from indicator 3.1a. If sufficient habitat is lost or degraded for a particular sample location, the numbers of species in each threat category will be changed. Updated indicators for ecological condition 3.1a are used as these are developed. If the model of biodiversity has been refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide only
Taxonomic scope:	All taxa

Table 3 Biodiversity indicators in theme 2: State of all known species

Indicator family 2.1: State of all known species	
Rationale:	This indicator family allows the assessment of the overall diversity of all known species that exist at present, including their genetic diversity, as a proportion of that which originally existed in New South Wales prior to the industrial era (c. AD1750). The habitat condition family of indicators 3.1 support this assessment.
Indicator number:	**2.1a**
Indicator name:	**Within-species genetic diversity (for all known species)**
Indicator description:	**The proportion of within-species genetic diversity of all species known to exist, assessed for each biological group** This indicator uses a representative sample of species to assess the proportion of within-species genetic diversity that still exists, after considering loss of suitable habitats. It is an extension of indicator 2.1b. Genetic diversity is inferred from species diversity using geographic (spatial) occupancy. Species from a biological (i.e. taxonomic) group are sampled to represent the full range of natural habitats for that group (from indicator 1.2a). The occurrence data in 2-kilometre map grids define each species' AOO. Reductions in AOO due to declines in habitat condition are determined from indicator 3.1a. A power curve then relates the intact fraction of a species' AOO to the fraction of genetic diversity remaining. Two forms of the curve are used: one that simulates high genetic diversity due to high rates of population genetic divergence, and the other, low genetic diversity. The two curves equate to an upper and lower estimate of fractional within-species genetic diversity. At t_0: The indicator is an estimate of the fractional loss (or potential to gain) of genetic diversity by change in area of habitat. It can be used, for example, to show the variation in genetic diversity loss (or potential to gain) across the categories of species survival for indicator 1.2a. This serves as an indicator of within-species genetic diversity for all known species within the biological group and, by logic, extends to undiscovered species. This approach infers mainly neutral genetic diversity. Methods for inferring adaptive genetic diversity are under development.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in habitat condition determined from indicator 3.1a. Updated indicators for ecological condition 3.1a are used as these are developed. The indicator is standardised by using the same representative sample of species each time. If a different sample is derived, or new information about a representative species changes its AOO, the status at each past assessment t_0 is also recalculated.
Readiness category:	1 (vascular plants), 3 (other taxonomic group/s)
Reporting scale:	Statewide only. This indicator complements 1.2a by providing information about variance in estimated genetic diversity surviving, reported by extinction risk category.
Taxonomic scope:	All taxa

Indicator number:	**2.1b**
Indicator name:	**Extant area occupied (for all known species)**
Indicator description:	**The average fraction of original habitat presently occupied by all known species, assessed for each biological group** This indicator assesses the extant area occupied by all known species after considering loss of original suitable habitat. Species from a biological (i.e. taxonomic) group are sampled to represent the full range of natural habitats across New South Wales for that group (from indicator 1.2a). The occurrence data in 2-kilometre map grids define each species' area of occupancy, and reductions in AOO due to declines in habitat condition are determined from the ecological condition indicator 3.1a. At t_0: The indicator is the average fraction of original habitat occupied by the representative species (as a proxy for all known species) for a biological group. It can also be used to show the variation in reductions in AOOs across the categories of species survival for indicator 1.2a. It can also be used to infer the amount of genetic diversity remaining (indicator 2.1a).
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in habitat condition determined from indicator 3.1a. Updated indicators for ecological condition 3.1a are used as these are developed. The indicator is standardised by using the same representative sample of species. If a different sample is derived or new information about a representative species changes its AOO, the status at each past assessment t_0 is also recalculated.
Readiness category:	1 (vascular plants), 3 (other taxonomic group/s)
Reporting scale:	Statewide only. This indicator complements 1.2a by providing information about mean and variance in fraction of AOO for reporting by extinction risk category.
Taxonomic scope:	All taxa

Indicator family 2.2: State of biodiversity including undiscovered species	
Rationale:	This indicator family estimates the overall diversity of all known and undiscovered species existing and likely to persist, including their genetic diversity and how they assemble into ecosystems, as a proportion of that originally existing in New South Wales prior to the industrial era (c. AD1750). The habitat condition family of indicators 3.1 supports this assessment.
Indicator number:	**2.2a**
Indicator name:	**Within-species genetic diversity (including undiscovered species)**
Indicator description:	**The existing proportion of within-species genetic diversity of all known and undiscovered species, assessed for each biological group** This indicator estimates the proportion of within-species genetic diversity that may still exist and is potentially likely to persist, after considering loss of suitable habitats and the effects of fragmentation. It is an extension of indicator 1.2b. Genetic diversity is inferred from species diversity using geographic (spatial) occupancy. The potential existence of species (both known and undiscovered) for a biological (i.e. taxonomic) group is inferred by using a model of biodiversity derived from systematic surveys of that group's co-occurring species and associated environments (using GDM). The analysis is conducted for a sample of locations that represent the full range of natural habitats based on the model for that biological group. At each location, the model predicts the relative numbers of species potentially existing within different AOOs. For consistency with indicator 1.2b, the same method of defining AOO is used. Reductions in AOO due to declines in habitat condition are determined from indicator 3.1a. Further reductions in carrying capacity, due to fragmentation that restricts connectivity with surrounding suitable habitat, are determined from indicator 3.1c. At each location, the model predicts the relative numbers of species originally existing and the reduction within each species' AOO. A power curve then relates the intact fraction of each species' AOO to fractions of diversity remaining. In each case, two forms of the curve are used: one that simulates high genetic diversity due to high rates of population genetic divergence, and the other, low genetic diversity. These equate to upper and lower estimates of within-species genetic diversity. At t_0: The indicator is the fractional loss of genetic diversity by change in occupancy of original area. It can be used, for example, to show the variation in genetic diversity loss across the categories of species survival for indicator 1.2b. The upper and lower fractions of genetic diversity demonstrate the potential range and uncertainty in estimation. Alternate calculations using indicators 3.1a and 3.1c (ecological connectivity indicator 3.1b is used in indicator 3.1c) to estimate the reductions in suitable habitat due to fragmentation are presented as a range. The indicator is an expression of the proportion of genetic diversity remaining, within the biological group and, by logic, extends to undiscovered species. This approach mainly infers neutral genetic diversity. Methods for inferring adaptive genetic diversity are under development.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in habitat condition determined from indicators 3.1a and 3.1c. Updated indicators for ecological condition 3.1a and carrying capacity 3.1c will be used as these are developed. The indicator is standardised by using the same model of biodiversity for the whole biological group. If a new model is developed using refined data and methods, the status at each past assessment t_0 is also recalculated.

Readiness category:	3 (vascular plants), 3 (other taxonomic group/s)
Reporting scale:	Statewide only. This indicator complements 1.2b by providing information about variance in estimated genetic diversity that is retained and can be reported by extinction risk category.
Taxonomic scope:	All taxa
Indicator number:	**2.2b**
Indicator name:	**Persistence of all species (including undiscovered species)**
Indicator description:	**The proportion of all species including known and undiscovered species that are still living or likely to persist** The potential existence of species (both known and undiscovered) for a biological (i.e. taxonomic) group is inferred by using a model of biodiversity derived from systematic surveys of that group's co-occurring species and associated environments (using GDM). The proportion of species that may still exist, after taking into account declines in habitat condition (e.g. changes in the extent of native vegetation), is determined from indicator 3.1a. The proportion of species potentially likely to persist after accounting for further reductions in carrying capacity, due to fragmentation restricting connectivity with surrounding suitable habitat, is determined from indicator 3.1c. A power curve relates the amount of habitat available to the proportion of all species potentially persisting into the future. At t_0: The indicator is a range in values showing the uncertainty in estimating the amount of biodiversity still living and likely to persist for the given configuration and condition of suitable habitats, using indicators 3.1a and 3.1c. The values for each geographical reporting unit are individually calculated by accounting for the species predicted to be shared between regions, and so the whole value does not equal the sum of the regional values. The indicator is an expression of the proportion of species' diversity remaining within the biological group and, by logic, extends to undiscovered species.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in habitat condition determined from indicators 3.1a and 3.1c. Updated indicators for ecological condition 3.1a and carrying capacity 3.1c will be used as these are developed. The indicator is standardised by using the same model of biodiversity for the whole biological group. If a new model is developed using refined data and methods, the status at each past assessment t_0 is also recalculated.
Readiness category:	1 (vascular plants), 3 (other taxonomic group/s)
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems) by considering the species shared between each regional subunit.
Taxonomic scope:	All taxa

Indicator number:	**2.2c**
Indicator name:	**Persistence of ecosystems (including undiscovered species)**
Indicator description:	**The expected persistence of species diversity as a function of the proportion of habitat remaining in ecosystems, derived from a classification of known and undiscovered species** A classified model of biodiversity for a specified biological group depicts patterns of ecosystem diversity for a specified number of classes (e.g. 100). The model is derived from systematic surveys of that group's co-occurring species and associated environments to encompass all species (both known and undiscovered). A further statistical model predicts a probability value for each ecosystem at each location, signifying confidence in class assignment. The proportion of habitat remaining in each ecosystem, after considering declines in habitat condition, is determined from indicator 3.1a. The proportion of habitat remaining after considering further reductions in carrying capacity, due to fragmentation restricting connectivity with surrounding suitable habitat, is determined from indicator 3.1c. A power curve relates the amount of habitat available in each ecosystem to the expected persistence of species diversity for that biological group, taking into account their complementarity and irreplaceability (i.e. their inability to be replaced, often because of uniqueness). At t_0: The indicator is a range in values showing the uncertainty in estimating the expected persistence of species diversity across all ecosystems given the configuration and condition of suitable habitats, using indicators 3.1a and 3.1c. The values for each geographical reporting unit are individually calculated by accounting for the species predicted to be shared between ecosystems and across regions, and so the whole does not equal the sum of the parts.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in habitat condition determined from indicators 3.1a and 3.1c. Updated indicators for ecological condition 3.1a and carrying capacity 3.1c are used as these are developed. The indicator is standardised by using the same model of biodiversity and classification for the whole biological group. If a new model or classification is developed using refined data and methods, the status at each past assessment t_0 is also recalculated.
Readiness category:	1 (vascular plants), 3 (other taxonomic group/s)
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems) by considering the species shared among ecosystems between each subunit.
Taxonomic scope:	All taxa

Indicator family 2.3: Field monitoring of species and ecosystems	
Rationale:	Long-term and/or wide-ranging field monitoring of species and ecosystems provide useful and complementary measures of the current status and trends in biodiversity. Other indicators that rely on indirect measures of biodiversity from remote sensing and modelling use field-based observations of biodiversity from relatively intact sites.
Indicator number:	**2.3a**
Indicator name:	**Species trends**
Indicator description:	**Trends in the extent, abundance or number of native species measured from long-term or wide-ranging field monitoring** *programs* Direct measures of species' population status and trend have the potential to provide concrete evidence of change. Locations need to be situated strategically and designed to control for sampling artefacts and 'noise' variation over the time series. Criteria will be developed to identify suitable monitoring studies from which trends can be summarised to provide an initial assessment for selected locations and species. Requirements for systematic monitoring to detect change and methods to integrate across locations and species will be developed for future indicators. At t_0: The indicator for each location is the species abundance or other performance metric (such as yield, fecundity) and associated environmental conditions. The indicator may also be reported as a trend using historical monitoring data, that is, a trend since first measurement.
Detecting change:	Change in the value of the indicator at t_Δ reflects: • a statistically significant trend in species abundance or other performance metric (such as yield, fecundity) attributed to anthropogenic factors (pressures or management), after taking into account natural environmental variation. The indicator is a direct measure from continuous observations. If the statistical method used to assess trend is refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	1 (selected locations and species)
Reporting scale:	Site
Taxonomic scope:	All taxa
Indicator number:	**2.3b**
Indicator name:	**Ecosystem trends**
Indicator description:	**Trends in the extent, abundance or number of native ecosystems measured from long-term or wide-ranging field monitoring programs** Direct measures of ecosystem dynamics, status and trend have the potential to provide concrete evidence of change. Locations need to be strategically situated and designed to control for sampling artefacts and 'noise' variation over the time series. Criteria will be developed to identify suitable monitoring studies from which trends can be summarised to provide an initial assessment for selected locations and ecosystems. Requirements for systematic monitoring to detect

	change and methods to integrate across locations and ecosystems will be developed for future indicators. At t_0: The indicator for each location is the relative abundances of all species within an ecosystem (within or between biological groups) or other performance metric (such as species compositional turnover) and associated environmental conditions. The indicator may also be reported as a trend using historical monitoring data, that is, a trend since first measurement.
Detecting change:	Change in the value of the indicator at t_Δ reflects: • a statistically significant trend in community dynamics or species composition attributed to anthropogenic factors (pressures or management), after considering natural environmental variation. The indicator is a direct measure from continuous observations. If the statistical method used to assess trend is refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	1 (selected locations and ecosystems)
Reporting scale:	Site
Taxonomic scope:	All ecosystems

2.4.2 Ecological integrity indicators

Table 4 Ecological integrity indicators in theme 3: Ecosystem quality

Indicator family 3.1: Habitat condition	
Rationale:	This indicator family is an overall measure of the capacity of habitats to support the original complement of native plants and animals. By considering the condition and position of each habitat and its connection with other surrounding habitats across a region, the remaining capacity of an area to support its native plants and animals can be inferred. In the future, the terrestrial indicators will be complemented by other indicators for freshwater, coastal and marine habitats.
Indicator number:	**3.1a**
Indicator name:	**Ecological condition of terrestrial vegetation**
Indicator description:	**The ability of terrestrial habitat at each location to support its biodiversity** This indicator measures the intactness and naturalness of terrestrial vegetation as habitat to support biodiversity at each location, without considering the indirect effects of fragmentation or connections with surrounding suitable habitat. Satellite-based remote sensing is used to assess vegetation attributes related to integrity (structure, function and composition) with appropriate comparison to field-derived reference conditions and validation. The derived measure at each site (a grid cell on a map) is an index ranging from 0 (the maximum departure from a reference condition) to 1 (intact vegetation that supports biodiversity to its full potential). Three complementary modelling approaches are being developed and integrated to ensure new science and technology can be applied rapidly to refined measures. These **methods** are (see section 3.5 for detail): (i) using data integration and expert opinion to suggest the relationship between vegetation condition and remotely sensed data (ii) applying statistics to correlate the relationship and predict the disturbance distance from intact reference locations (like benchmarks) (iii) using statistics to model individual vegetation integrity attributes compared with their benchmarks and derive condition scores. At t_0: The indicator is calculated at each site (grid cell) according to the selected method. It can be reported for any geographical area as an average and variance. The indicator is an input to the biodiversity indicators that use ecological condition and models such as GDM to infer the amount of biodiversity existing. It complements the ecological carrying capacity indicator 3.1c, which incorporates the connections with surrounding suitable habitat.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • changes in the condition of vegetation relative to a NSW reference state (or benchmark). The status at each past assessment will need to be recalculated to account for new methodologies and remote-sensing data.
Readiness category:	1 (method i), 3 (method ii, method iii). All methods are as described in detail in section 3.5.
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	Terrestrial

Indicator number:	**3.1b**
Indicator name:	**Ecological connectivity of terrestrial vegetation**
Indicator description:	**The contribution each location makes to connectivity of terrestrial habitat by way of its ecological condition and relative position in the landscape (e.g. as part of a habitat corridor or a stepping stone)** This indicator accounts for the general quality of terrestrial habitats supporting biodiversity at each location, the fragmentation of habitat within its neighbourhood and how its position in the landscape contributes to connectivity among habitats across a region (e.g. as part of a habitat corridor or as a stepping stone). Ecological connectivity is based on two landscape components: (i) neighbouring locations, to assess how well ecological processes can operate at a local level, and (ii) other locations, to assess how well a location contributes to overall landscape connectivity. Each are calculated for several spatial scales to account for the range of ecological processes influencing biological movement and dispersal. The site ecological condition indicator 3.1a is used as an input to measure the ease or difficulty of dispersion through a less or more degraded landscape. At t_0: The indicator is calculated as a weighted average of the two components across spatial scales. Values for each site (grid cell) range from 0 (minimum quality, disconnected habitat) to 1 (maximum quality, fully connected habitat). It can be reported for any geographical area as an average and variance.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • a change in the condition or connectivity of habitats with neighbouring sites and the degree of fragmentation in the landscape. If the value of ecological condition indicator 3.1a is recalculated to account for new methodologies and remote-sensing data, this indicator will also need to be recalculated.
Readiness category:	1 (indicator 3.1a, method i), 3 (indicator 3.1a, methods ii and iii). All methods are as described in detail in section 3.5.
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	Terrestrial
Indicator number:	**3.1c**
Indicator name:	**Ecological carrying capacity of terrestrial vegetation**
Indicator description:	**Each location's capacity to support native species and ecosystems, considering its ecological condition and the effect of surrounding habitat loss and fragmentation** This indicator accounts for how the general quality of terrestrial habitats supporting biodiversity at each location and its connection with habitat at other locations within a neighbourhood enables biological movement such as foraging, dispersal and migration. It is used to account for the carrying capacity of a landscape to support its original complement of biodiversity and ecosystems. The indicator uses ecological condition indicator 3.1a and the neighbourhood context component of indicator 3.1b at relevant scales.

	At t_0: The indicator is calculated by summing and reporting the scores at each location, at any spatial scale. The indicator can be expressed in units of neighbourhood habitat area (i.e. the amount of connected habitat in hectares) or standardised to measure the (effective) area of connected habitat relative to fully connected habitat. Each location varies from 0 (minimum quality, disconnected habitat) to 1 (maximum quality, fully connected habitat). The indicator can be reported for any geographical area as an average and variance. The indicator is an input to the biodiversity indicators that use ecological carrying capacity to estimate the amount of biodiversity potentially persisting. It complements the ecological condition indicator 3.1a, which does not incorporate the influence on condition of connections with surrounding suitable habitat.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • a change in the condition or connectivity of habitats with neighbouring sites and the degree of fragmentation in the landscape. If the value of the ecological condition indicator 3.1a is recalculated to account for new methodologies and remote-sensing data, this indicator will also need to be recalculated.
Readiness category:	1 (indicator 3.1a, method i), 3 (indicator 3.1a, methods ii and iii). All methods are as described in detail in section 3.5.
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	Terrestrial

Indicator number:	**3.1d**
Indicator name:	**Ecosystem function of terrestrial vegetation**
Indicator description:	**A measure of the functional integrity of eco-physiological processes of terrestrial plants that cycle carbon, water, energy and nutrients** This indicator uses the relationship of plants with their environment to infer the functional condition of terrestrial native vegetation and therefore the degree of naturalness. It complements the monitoring of vegetation structure. Three interrelated resource-use concepts depict the degree of ecological disruption from an expected climatic or environmental equilibrium: (i) vegetation equilibrium, (ii) resource-use efficiency, and (iii) resource coupling. From these concepts, three component vegetation function indicators are derived: 1) foliage cover gap, as the difference between observed foliage cover and full cover under ideal conditions (predicted from an eco-hydrological equilibrium model) 2) rain-use efficiency gap, as the difference between the maximum and actual rain-use efficiency (applicable in water-limited environments) 3) resource-use efficiency gap, which combines 2) with light-use efficiency gap to include most Australian environments. At t_0: The indicator at initial assessment is based on the three component indicators. Their derivation and validation is under development. Each component indicator can be reported for any geographical area as an average and variance.

Detecting change:	Change in the value of the indicator at t_{Δ} can reflect: • changes in the functional integrity of vegetation due to disturbance (observed using remote sensing), relative to an environmental normal range. The status of the indicator will need to be recalculated to account for new methodologies and remote-sensing data.
Readiness category:	3
Reporting scale:	Terrestrial
Environmental scope:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)

Indicator family 3.2: Pressures	
Rationale:	This indicator family identifies general pressures that cause biodiversity loss or threaten the quality of ecosystems and, therefore, impacts to the survival of species or ecological communities, and provides supporting information on disturbance. The consequence of a pressure may be determined by the type of vegetation or ecosystem it is acting on and their current state and resilience and may also be linked in different ways to structural, functional or compositional components. Information about pressures informs development of the ecological condition indicator 3.1a or provides a basis for attributing cause to observed change in condition. The terrestrial indicators may be expanded to incorporate other pressures and, in future, be complemented by the respective indicators of pressures that threaten freshwater, coastal and marine habitats.
Indicator number:	**3.2a**
Indicator name:	**Land-use and management practices**
Indicator description:	**The extent of classes of land-use and management practices** Land use depicts the potential degree of modification and the impact on a ‘natural state’ (essentially, an unaltered native land cover). The standard land-use classification for Australia is three-tiered and hierarchical. Primary and secondary classes relate to the main use of the land, defined by the management objectives of the manager. Tertiary classes can include commodity groups, specific commodities, land management practices or vegetation information. Time-series data on land-use and management practices is collected by relevant agencies. If mapped accurately, it provides valuable information about the time since modification of natural areas and the intensity of use. Satellite and aerial remote sensing combined with field observations and agency databases is being used to fill gaps in the land-use time series. At t_0: The indicator is the area of each land use in primary and secondary classes, ordered by the potential degree of modification from a nominated ‘natural state’. The mapping of land use does not necessarily depict impact, as the class may indicate potential to modify rather than actual modification. The indicator may also be reported as a trend from an earlier time, such as, time since first mapping (e.g. 2003).
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in land use as mapped. If the method of detecting or classifying land use is altered or refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	2
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	All land types

Indicator number:	**3.2b**
Indicator name:	**Native vegetation extent**
Indicator description:	**The extent of native woody and non-woody vegetation cover** This indicator monitors the extent of native woody and non-woody vegetation cover based on remote-sensing and other data supporting detection of natural areas. Changes in land cover by woody vegetation or plant communities can be detected through time. Native non-woody vegetation (mostly grasslands, arid shrublands and woodlands) is less easily detected, but work is ongoing to improve this. At t_0: The indicator is the area of native woody and non-woody vegetation cover. It can be reported for any region or in relation to vegetation (plant community) type or condition class.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in woody and non-woody native vegetation cover, primarily due to clearing. Measuring regrowth/revegetation is more difficult and is yet to be incorporated in land-cover change reporting. If the method of detecting or classifying woody and non-woody native vegetation cover is altered or refined, such as measuring regrowth, the status at each past assessment t_0 is also recalculated.
Readiness category:	2
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems, plant community types, ecological condition class)
Environmental scope:	Terrestrial
Indicator number:	**3.2c**
Indicator name:	**Inappropriate fire regimes**
Indicator description:	**The extent and impact of altered fire regimes on sensitive ecosystems** A fire regime is the prevailing intensity, seasonality, frequency (i.e. interval between burns) and spatial pattern that has become established over extensive areas and through time that supports the maintenance of local species and ecosystems. This indicator is calculated from spatial data compiled from all fires across the State and as far back in recent history as possible. For each vegetation type, the mapped fire frequency is compared to the minimum and maximum thresholds predicted, based on scientific knowledge of its sensitivity. Departures from the expected appropriate regime signify the degree of impact on local biodiversity and are classed as ‘too frequently burnt’, ‘within fire thresholds’ or ‘too infrequently burnt’. At t_0: The indicator is the area of inappropriate fires and cumulative impact (departure from an appropriate regime), reported by fire-sensitive vegetation (plant community) types. This indicator will evolve as methods for detecting fire severity evolve, and with improvements in remote sensing and modelling of fire impacts on vegetation and ecological integrity.

Detecting change:	Change in the value of the indicator at t_{Δ} reflects a change in appropriateness of the fire regime (too frequently or too infrequently burnt). If the method of detecting or classifying appropriate fire regimes is refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems, plant community types, ecological condition class)
Environmental scope:	Terrestrial
Indicator number:	**3.2d**
Indicator name:	**Inappropriate hydrological regimes**
Indicator description:	**The extent and impact of altered hydrological regimes on sensitive ecosystems** A hydrological regime is determined by the prevailing climate and its seasonality and how landform and rock types influence the distribution of water across a landscape. It has components of seasonality, depth and duration of flooding and drying, and frequency of inundation. Estuarine systems are also dependent on tidal regimes. This indicator is calculated from hydrological metrics, including river flows and remotely sensed data of surface water extent and vegetation dynamics. This data quantifies the frequency and spatial extent of floodplain inundation, and it can also be used to identify vegetation response to inundation. For each ecosystem type, the mapped hydrological regime is compared to the minimum and maximum thresholds predicted, based on scientific knowledge of its requirements. Departures from the expected appropriate regime signify the degree of impact on local biodiversity. The indicator is the area of inappropriate hydrological regimes and cumulative impact (departure from an appropriate regime). The indicator may be informed by the frequency and extent of floodplain inundation and dynamic extents of wetland vegetation. This indicator will evolve as methods for detecting hydrological regimes evolve, and as remote sensing and modelling of impacts on sensitive ecosystem types improves.
Detecting change:	Change in the value of the indicator at t_{Δ} reflects a change in appropriateness of the hydrological regime. If the method of detecting or classifying appropriate hydrological regimes is refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide, bioregions and catchments
Environmental scope:	All land types that are inundated or groundwater-dependent ecosystems

Indicator no:	**3.2e**
Indicator name:	**Invasive species (pests, weeds, disease)**
Indicator description:	**The extent and impact of invasive species on sensitive ecosystems** For sensitive species and ecosystems, the associated spatial extent and density of invasive species is determined, along with detection of new invasive species with potential to impact native plants and animals, as well as the spread of emerging invasive species. At t_0: The indicator is the degree of knowledge about the extent and impact of invasive species on sensitive species and ecosystems. This indicator will evolve as methods for collating disparate data, and for monitoring and reporting on species and ecosystem impacts, are developed.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in spatial extent and density of invasive species impacting sensitive native species and ecosystems. If the method of detecting or classifying invasive species is refined, the status at each past assessment t_0 is also recalculated, if suitable historical data are available. Predominantly, change detection will represent growth in knowledge until systematic monitoring methods and biodiversity impact assessments become
Readiness category:	3
Reporting scale:	Any geographic domain (e.g. all of New South Wales, conservation areas, bioregions, landscapes or regional ecosystems) depending on data adequacy for reporting
Environmental scope:	All NSW ecosystems

Indicator no.:	**3.2f**
Indicator name:	**Altered climatic regimes, variability and extremes**
Indicator description:	**The extent and impact of altered climatic regimes on sensitive ecosystems** A region's climate is determined by the spatial and temporal variation in rainfall, temperature, humidity, atmospheric pressure, wind and other meteorological variables over long periods of time. The climatic regime is explained by normal ranges of these variables, their seasonality, frequency, duration, intensity and extent of events. Species and ecosystems are generally adapted over long periods of time to their local climates. At t_0: The indicator is the mapped extent, frequency and intensity of eco-physiological stress predicted for plants and/or animals as a result of climatic extremes and the degree of departure from pre-industrial climatic norms, reported by sensitive species and ecosystems. This indicator can also be forecast using modelled climate projections for the specific variables that exceed eco-physiological thresholds. This indicator will evolve as methods for modelling and monitoring climate change impacts on biodiversity are further developed.
Detecting change:	Change in the value of the indicator at t_Δ reflects a change in climatic regimes related to physiological stress predicted for plants and/or animals. If the method of detecting or classifying climate-related biophysical stress effects is refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems, plant community types, ecological condition class)
Environmental scope:	All NSW ecosystems

Table 5 Ecological integrity indicators in theme 4: Ecosystem management

Indicator family 4.1: Management responses	
Rationale:	A large number of Acts in New South Wales regulate how people use or interact with the environment and so influence the outcome for biodiversity. This indicator family provides information about what policies or actions are implemented and how they will prevent or reduce biodiversity loss. The indicators assess changes in management responses and potential implications for biodiversity.
Indicator number:	**4.1a**
Indicator name:	**Areas managed for conservation in perpetuity**
Indicator description:	**The extent of areas that are designated for long-term biodiversity conservation outcomes** Areas managed for biodiversity conservation in perpetuity include all categories of national parks reserved under the *National Parks and Wildlife Act 1974*, and flora reserves dedicated under the *Forestry Act 2012* and other public tenures as relevant. The indicator may also be used to assess the area that each category of ecosystem represents, to ensure that all types of ecosystem are protected within these areas. This indicator integrates area-based information about management responses. It requires the collection of spatially explicit data on: (i) what actions are proposed to be implemented and (ii) the management objectives. The objectives (e.g. aligned with IUCN conservation management category) imply a level of protection potentially afforded to biodiversity and therefore an outcome related to species persisting over time, assuming those objectives are achieved in full. At t_0: The indicator is the area under conservation management by level of protection and can be reported as a trend using historical data on land parcels (e.g. annually). The indicator can also be expressed as a proportion of any geographic domain, using spatial allocation rules to account for overlapping boundaries. It is used with indicator family 2.2 to measure how well biodiversity is represented in conservation areas and how that representation changes over time. This indicator does not directly measure the effectiveness of conservation management actions as a result of any agreement. Those outcomes are addressed through indicator family 4.2.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • changes in the location and size of places designated for conservation in perpetuity • new, changed and revoked protected areas • changes in purpose and level of protection afforded to biodiversity. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	2
Reporting scale:	Statewide, bioregions, landscapes or regional ecosystems (spatial allocation rules may apply where boundaries overlap)
Environmental scope:	All NSW ecosystems

Indicator number:	**4.1b**
Indicator name:	**Areas managed for conservation under formal or informal agreements**
Indicator description:	**The extent of areas managed for biodiversity conservation under formal or informal agreements** This indicator measures the extent of areas managed for biodiversity conservation under formal or informal agreements, including private land conservation agreements under the BC Act (i.e. biodiversity stewardship agreements, conservation agreements and wildlife refuges) and Land for Wildlife. The indicator may also be used to assess the area that each category of ecosystem represents, with a goal of protecting all types of ecosystem within these areas. The duration and security of the agreements may also be assessed. This indicator integrates area-based information about management responses. It requires the collection of spatially explicit data on: (i) what actions are proposed to be implemented, (ii) the management objectives, and (iii) the term of agreement (i.e. start and end dates). The objectives (e.g. aligned with IUCN conservation management category) imply a level of protection potentially afforded to biodiversity and therefore an outcome related to species persisting over time, assuming those objectives are achieved in full. At t_0: The indicator is the area under conservation management, by level of protection, and can be reported as a trend using historical data on land parcels assigned to conservation uses (e.g. annually). The indicator can also be expressed as a proportion of any geographic domain, using spatial allocation rules to account for overlapping boundaries. It is used with indicator family 2.2 to measure how well biodiversity is represented in conservation areas and how that representation changes over time. This indicator does not directly measure the effectiveness of conservation management actions as a result of any agreement. Those outcomes are addressed through indicator family 4.2.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • changes in the location and size of places designated for conservation • new, varied and terminated conservation agreements, and term of agreements • changes in purpose and level of protection afforded to biodiversity. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide, land sector
Environmental scope:	All land types

Indicator number:	**4.1c**
Indicator name:	**Community appreciation of biodiversity**
Indicator description:	**The level of community understanding of and support for biodiversity conservation** This indicator measures community attitudes and understanding of biodiversity, and engagement in and level of support for biodiversity conservation measures, including climate-adapted management and the programs implemented under the BC Act. Data are systematically collected through structured surveys of the general population, such as the OEH Who Cares about the Environment? survey, and through landholder surveys. At t_0: The indicator requires development. Data requirements and measurement methods will follow a review of previous surveys.
Detecting change:	Change in the value of the indicator at t_Δ can reflect changes in community attitudes, analysed demographically and regionally. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide (statistical regions)
Environmental scope:	All land types

Indicator family 4.2: Management effectiveness	
Rationale:	Measures the effectiveness of implemented policies or actions to reduce the rate of biodiversity loss, including societal attitudes leading to actions (e.g. volunteer engagement in on-ground programs) and planning for adaptation under climate change that is being implemented to support ecosystems. The indicators in this family build on data collected through indicator family 4.1 and provide a basis for improving predictions of biodiversity persistence across whole landscapes (though indicator family 4.3).
Indicator number:	**4.2a**
Indicator name:	**Effectiveness of on-ground biodiversity conservation programs**
Indicator description:	**The individual and collective effectiveness of programs delivering conservation outcomes on the ground** This indicator compiles and harmonises data and information from direct (on-ground) observation, monitoring and reporting of management effectiveness delivering conservation outcomes for biodiversity and ecological integrity. It includes *Saving our Species* projects and private land conservation under the BC Act, all types of conservation areas (e.g. national parks and forest reserves), natural resource management projects and actions under formal agreements, and codes of practice for vegetation management. At t_0: The indicator requires development. Data requirements and measurement methods will follow a review of individual program monitoring, evaluation and reporting methods.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • increased area of effective conservation actions • increased reporting on outcomes. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide (program-specific reporting regions)
Environmental scope:	All land types
Indicator number:	**4.2b**
Indicator name:	**Community-based maintenance of biodiversity values**
Indicator description:	**The collective effectiveness of voluntary community-based management of biodiversity in maintaining or enhancing natural values** This indicator identifies, compiles and harmonises management effectiveness information across volunteer networks and stewardships to enable statewide and regional reporting on outcomes for biodiversity and ecological integrity from direct (on-ground) observations. Better outcomes for biodiversity can be achieved through community-based collectives to improve the longer-term outlook for sustaining biodiversity locally. At t_0: The indicator requires development. Data requirements and measurement methods will follow a review of community engagement activities and skills in monitoring, evaluation and reporting of on-ground outcomes.

Detecting change:	Change in the value of the indicator at t_{Δ} can reflect: • increased area of effective conservation actions • increased reporting of outcomes. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide (community-specific reporting regions)
Environmental scope:	All land types
Indicator number:	**4.2c**
Indicator name:	**Implemented climate-adapted conservation planning and management**
Indicator description:	**Effectiveness of conservation management actions in facilitating biodiversity adaptation to climate change** This indicator tracks the adoption and implementation of conservation management principles and actions and their perceived effectiveness for facilitating biodiversity adaptation to climate change. Increased outcomes for biodiversity are expected from on-ground management actions that are adaptive to climate, thus improving the longer-term outlook for sustaining biodiversity locally. At t_0: The indicator requires development. Data requirements and measurement methods will follow a review of climate-adapted options included in existing conservation management plans and agreements across the private and public sector. The information collected provides a basis for developing scenarios of management and informing projections of biodiversity persistence across whole landscapes under climate change (though ecosystem integrity theme 5).
Detecting change:	Change in the value of the indicator at t_{Δ} can reflect: • increased uptake of climate adaptation principles in conservation planning and implemented actions • increased area under conservation management adopting and implementing climate adaptation principles. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide (program- and community-specific reporting regions)
Environmental scope:	All land types

Indicator family 4.3: Capacity to sustain ecosystem quality	
Rationale:	This indicator family measures the change in adaptive management capacity to maintain or enhance ecosystem quality and so improve the longer-term outlook for sustaining biodiversity. It does this by integrating specific measures of ecosystem quality and ecosystem management. All types of information influencing biodiversity outcomes are incorporated, including land management that moves toward ecologically sustainable development (i.e. responses in the response–pressure–state–benefit, RPSB, framework, see Figure 4).
Indicator number:	**4.3a**
Indicator name:	**Capacity to maintain or enhance ecosystem quality (local resilience)**
Indicator description:	**The degree to which the present ecological carrying capacity of habitats can be maintained or enhanced into the future, considering effective management** While acknowledging uncertainty, this indicator forecasts the near-term outlook for ecosystem quality and therefore biodiversity, based on the present situation. It integrates management response and management effectiveness data to develop a measure of local system resilience. Local system resilience is the capacity of adaptive management to maintain and enhance the condition of ecosystems in the face of processes that threaten the maintenance of ecosystem quality. Locations where ecosystems are presently managed for conservation are predicted to be sustained, based on their present quality and the effectiveness of present management, which is assumed to continue for the duration of each agreement. Other locations, not managed for conservation outcomes, are assumed to be maintained or to be degrading at a rate consistent with historical trends, taking into account new regulations supporting ecologically sustainable development across land sectors. At t_0: The indicator requires development of data integration methods consistent with an understanding of ecosystem dynamics, states and transitions interacting with management. The outcomes of management effectiveness from indicator family 4.2 are combined with ecosystem quality information from indicator family 3.1 to predict or forecast the degree to which ecosystem quality can be maintained or enhanced across whole landscapes. The results inform ecosystem integrity theme 5.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • increased area of effective conservation actions or reporting on outcomes • increased uptake of climate adaptation principles in conservation planning and implemented actions or area under conservation management • changes in the location and size of places effectively managed for sustainable outcomes supporting the conservation of biodiversity and ecological integrity. If databases are updated retrospectively to include new information relevant to the assessment, or methods are refined, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide, bioregions, landscapes or regional ecosystems (spatial allocation rules may apply where boundaries overlap)
Environmental scope:	All land types

Table 6 Ecological integrity indicators in theme 5: Ecosystem integrity

Indicator family 5.1: Capacity to retain biological diversity	
Rationale:	This indicator family measures the capacity of ecosystems to retain biodiversity in the face of ongoing, and uncertain, environmental change, including climate change and land-use change. It is a measure of the capacity of ecosystems to adapt to change and provide for the needs of future generations (i.e. ecological integrity). It aims for the integration and synthesis across other themes of biodiversity and ecological integrity and introduces the concept of ecosystem resilience. Particular indicators may apply a plausible range of climate projections or land-use change scenarios. Additional indicators may be developed for other pressures.
Indicator no.:	**5.1a**
Indicator name:	**Ecosystem capacity to adapt to change and retain biological diversity under climate change**
Indicator description:	**The ability of ecosystems to adapt and retain their biodiversity under climate change, facilitated by effective management** This indicator measures and reports on a key component of ecological integrity. It integrates two dimensions of resilience: (i) local system resilience, derived from local-scale management of processes that threaten the maintenance of integrity from indicator 4.3, and (ii) spatial resilience, derived from the spatial and environmental connectedness of ecosystems exhibiting high local resilience. Initial development of the indicator will focus largely on the spatial-resilience dimension, using ecological carrying capacity indicator 3.1c as a proxy for local system resilience. The indicator dimension of spatial resilience will be generated by assessing the spatial and environmental connectedness of ecosystems under a plausible range of climate projections. This assessment will be undertaken using the observed (existing) spatial condition and configuration of natural habitats, from the ecological carrying capacity indicator 3.1c, and will assume no future change in that capacity under the climate projections evaluated. A GDM (from indicator 2.2b) is projected under climate change to inform the environmental connectedness of ecosystems. At t_0: The indicator requires development, building on and extending existing analytical techniques and models (including GDM) as employed in indicator 2.2b, and habitat connectedness analysis similar to that employed in indicator 3.1b. It is being developed in two stages. Stage 1 will assess spatial resilience informed by indicator 3.1c and Stage 2 will also incorporate the effectiveness of conservation management actions through indicator 4.3, thereby providing a fully integrated measure of ecological integrity.
Detecting change:	Change in the value of the indicator at t_Δ reflects how any observed change in the condition and spatial configuration of habitat (from indicator 3.1c) is expected to affect the capacity of ecosystems to retain biological diversity under a plausible range of climate projections. The indicator is standardised by using the same model of biodiversity for the biological group and the same climate change scenario/s. If a new model is developed using refined data and methods, or climate scenarios change, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	Terrestrial

Indicator number:	**5.1b**
Indicator name:	**Ecosystem capacity to adapt to change and retain biological diversity under land-use change**
Indicator description:	**The ability of ecosystems to adapt and retain their biodiversity under land-use change, facilitated by effective managemen***t* This indicator measures and reports on a key component of ecological integrity. It extends indicator 5.1a by including plausible land-use change scenarios. At t_0: This indicator requires research and development. It is in preliminary stages of development and requires consultation and design of methods.
Detecting change:	Change in the value of the indicator at t_Δ reflects how any observed change in the condition and spatial configuration of habitat (from indicator 3.1c) is expected to affect the capacity of ecosystems to retain biological diversity under a plausible range of climate projections and land-use scenarios. The indicator is standardised by using the same model of biodiversity for the biological group and the same climate/land-use change scenario/s. If a new model is developed using refined data and methods, or climate/land-use scenarios change, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope	Terrestrial

Indicator family 5.2: Capacity to retain ecological functions	
Rationale:	This indicator family measures the capacity of ecosystems to retain ecological functions in the face of ongoing, and uncertain, environmental change, including climate change and land-use change. It is a measure of the capacity of ecosystems to adapt to change and provide for the needs of future generations (i.e. ecological integrity). It aims for the integration and synthesis across other themes of biodiversity and ecological integrity. Particular indicators may apply a plausible range of climate projections or land-use change scenarios. Additional indicators may be developed for other pressures.
Indicator number:	**5.2a**
Indicator name:	**Ecosystem capacity to adapt to change and maintain ecological functions under climate change**
Indicator description:	This indicator is analogous to indicator 5.1a but addresses the capacity of ecosystems to maintain ecological functions rather than their capacity to retain biological diversity. It draws on information about the capacity to maintain or enhance ecosystem quality (from indicator 4.3a) which, in turn, incorporates information about climate-adapted conservation management (from indicator 4.2c) and an assessment of ecological functions from indicator 3.1d. Eco-hydrological models are coupled with a plausible range of climate projections to assess the local resilience of ecological functions, taking into account current capacities of management (from indicator 4.3a) and system status (from indicator 3.1d). System status may also be informed by the ecological condition indicator 3.1a. At t_0: The indicator requires development of data-model integration methods consistent with best-available understanding of socio-ecological system interactions, and of processes underpinning maintenance of ecological functions.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • changes in natural ecological functions determined from indicator 3.1d, or • changes in management capacity to sustain ecological functions determined from indicator family 4.3. The indicator is standardised by using the same model of eco-hydrology and the same climate/land-use change scenario/s. If a new model is developed using refined data and methods, or climate/land-use scenarios change, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	Terrestrial

Indicator number:	**5.2b**
Indicator name:	**Ecosystem capacity to adapt to change and maintain ecological functions under land-use change**
Indicator description:	**The ability of ecosystems to adapt and retain their natural ecological functions under land-use change, facilitated by effective management** This indicator measures the ability of ecosystems to adapt and retain the natural dynamics of ecological functions in the face of ongoing, and uncertain, environmental change, in particular land-use change. This indicator extends indicator 5.2a by including plausible land-use change scenarios. Eco-hydrological models are coupled with a plausible range of climate projections and land-use scenarios to assess the local resilience of ecological functions, taking into account current capacities of management (from indicator 4.3a) and system status (from indicator 3.1d). At t_0: This indicator requires research and development. It is in preliminary stages of development and requires consultation and design of methods.
Detecting change:	Change in the value of the indicator at t_Δ can reflect: • changes in natural ecological functions determined from indicator 3.1d • changes in management capacity to sustain ecological functions determined from indicator family 4.3. The indicator is standardised by using the same model of eco-hydrology and the same climate/land-use change scenario/s. If a new model is developed using refined data and methods, or climate/land-use scenarios change, the status at each past assessment t_0 is also recalculated.
Readiness category:	3
Reporting scale:	Statewide and regional (e.g. protected areas, bioregions, landscapes, regional ecosystems)
Environmental scope:	Terrestrial

How biodiversity and ecological integrity indicator workflows are related

Combining the two classes of indicator, biodiversity and ecological integrity, Figure 5 shows how some of the indicator workflows are related. Within the two classes, five themes reflect the two overarching frameworks. The specific indicators within each family may evolve over time as data, technology and scientific knowledge accrue.

The two classes of indicators interact primarily at the family level through the RPSB framework (see Figure 4) and in some cases specific indicators are interdependent. For example, the ecological condition and carrying capacity indicators (ecosystem quality theme) provide information about the quality of habitats and their capacity to support biodiversity. They are then used with models of biodiversity distribution to infer the amount of biodiversity (genes, species, ecosystems) that may be represented or is likely to persist in a particular region or other reporting context (state of biodiversity theme). Various pressures may contribute directly to the assessment of ecological condition, or provide a basis for evaluating and interpreting the likely causes of declines in condition.

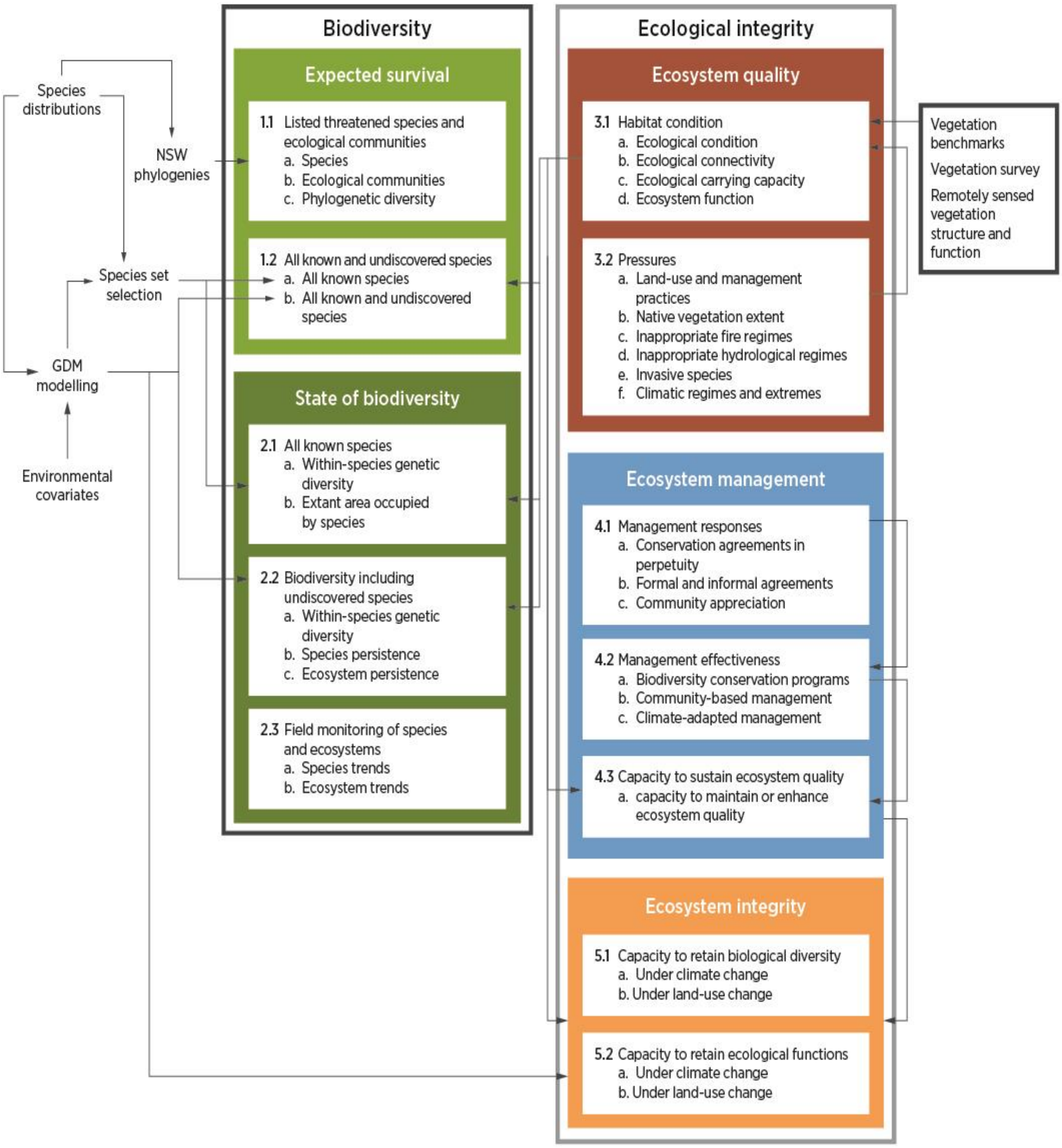

Figure 5 An overview of the data and process linkages among the indicators

2.4.3 Category 1 indicators

The indicators with component measures that fall into readiness category 1 and which are being implemented for the first NSW biodiversity outlook report are listed in Table 7.

Table 7 Category 1 indicators

Theme	Indicator family	Indicator	Component ready as of June 2018
Class: Biodiversity			
1 Expected survival of biodiversity	1.1 Expected survival of listed threatened species and ecological communities	1.1a Expected survival of listed threatened species	Taxa assessed by Scientific Committee
		1.1b Expected existence of listed threatened ecological communities	Ecological communities assessed by Scientific Committee
		1.1c Expected survival of phylogenetic diversity for listed threatened species	Mammals, birds, frogs
	1.2 Expected survival of all known and undiscovered species	1.2a Expected survival of all known species	Vascular plants
2. State of biodiversity	2.1 State of all known species	2.1a Within-species genetic diversity (for all known species)	Vascular plants
		2.1b Extant area occupied (for all known species)	Vascular plants
	2.2 State of biodiversity including undiscovered species	2.2c Persistence of ecosystems (including undiscovered species)	Vascular plants
	2.3 Field monitoring of species and ecosystems	2.3a Species trends	Selected locations and species
		2.3b Ecosystem trends	Selected locations and ecosystems
Class: Ecological integrity			
3. Ecosystem quality	3.1 Habitat condition	3.1a Ecological condition of terrestrial vegetation	Method i [1]
		3.1b Ecological connectivity of terrestrial vegetation	Method i
		3.1c Ecological carrying capacity of terrestrial vegetation	Method i

1. Method i is described in detail in section 3.5.

2.5 Reporting on the indicators

OEH will publish the results of the first assessment in a NSW biodiversity outlook report to fulfil the requirements of the BC Regulation which states 'the Environment Agency Head is to publish from time to time on a website maintained by the Agency Head a NSW biodiversity outlook report on the results of the programs...' (NSW Government 2017).

The first NSW biodiversity outlook report is scheduled to be published in mid-2018 and will include the measures of the category 1 indicators (see Table 7) to create an initial biodiversity assessment near to the commencement of the BC Act.

The results of category 2 indicators will be reported as a supplement to the biodiversity outlook report as they become available. Category 3 indicators will be developed further and added to future reports.

Five years after the commencement of the BC Act, in 2022, a review is to be undertaken 'to determine whether the policy objectives remain valid and whether the terms of the Act remain appropriate for securing those objectives' (s. 14.11 BC Act). Relevant indicators will be recalculated to assess the performance of the BC Act in slowing the rate of biodiversity loss and any changes in indicator status will be reported.

When indicators are measured in the future, the values arising from the first assessment for some indicators may be recalculated as data availability and technology improves to better align with the commencement date of the BC Act and to ensure consistency for assessing trends over time.

3. Methods for developing indicators

The approach used to identify the indicators and measurement methods is summarised in this section. It involved extensive collaborative workshops with relevant experts from CSIRO, OEH, Macquarie University and the Australian Museum. The workshops covered topics such as:

- understanding the legislative requirements and existing indicator frameworks, such as response–pressure–state–benefit (RPSB) and environmental monitoring assessment and reporting (eMAR) as outlined in section 1
- clearly interpreting the BC Act, its definitions of biodiversity and the requirements of the indicators under the legislation
- exploring concepts of biodiversity and ecological integrity and proposing frameworks for the indicators (themed workshops)
- examining alternative methods and indicator design for ecological condition, expected survival and inferring the state of all biodiversity (specific workshops)
- scoping what data (essential variables, EVs) and monitoring programs will contribute to the indicators (workshops with other Biodiversity Reform programs)
- reviewing existing data in the public domain and its spatial and temporal coverage.

The intent and extent of these workshops and meetings highlight the thoroughness of the consultation process. This ensured that the most up-to-date scientific theories and/or data or innovative new ideas were captured, with a focus on the requirements of the BC Act. The consultation within OEH involved policy, management and science staff, ensuring input across relevant stakeholders and knowledge domains.

Four peer reviewers offered a range of perspectives on the draft method for developing biodiversity indicators. The reviewers' comments were addressed either through incorporation into this final version of the method, by providing additional clarification, or by explaining why some suggested changes could not be incorporated due to time or resourcing constraints, lack of suitable data, or consistency with legislative requirements.

The following sections provide further detail about the method development process.

3.1 Scientific requirements for biodiversity measurement

The information gathered through the workshops, complemented by reviews of the literature, determined that the indicator sets for biodiversity and ecological integrity needed to address the requirements listed in Table 8.

Table 8 List of key requirements to be addressed by sets of biodiversity and ecological integrity indicators

Indicator class	Key requirement
Biodiversity	Be inclusive of all levels of biological organisation: diversity within and between species and diversity of ecosystems (within the meaning of the BC Act)
	Represent all plants (including fungi and lichens) and animals native to New South Wales, including those yet to be discovered and catalogued, and the variety of ecosystems that self-organise (e.g. plant community types)
	Evaluate the rate of loss of biodiversity and extinction risk beyond those species and ecological communities currently listed as threatened
	Be sensitive to change in the rate of loss of biodiversity and the amount of living diversity, over five years
Ecological Integrity	Measure the quality of ecosystems across whole landscapes, regions and statewide, including interactions with land management and pressures
	Account for the complexity of ecological and evolutionary processes that support the capacity of ecosystems to adapt: population viability, demography, interactions, genetic diversity and the persistence of component species and their need for mobility (dispersion, migration etc.)
	Integrate with information about the diversity of ecosystems that represents the variety of habitats that support biodiversity (i.e. all plants and animals native to New South Wales, including dispersion from surrounding areas under climate pressure)
	Explicitly integrate the activity of people as part of a broader interpretation of ecosystems and of adaptive management in the context of a changing climate and of continuing pressures
	Account for potential overriding influences of climate change interacting with policy. Climate change is a pervasive threat, with implications for ecosystem quality, the spatial resilience of ecological networks and regional capacity to retain biological diversity

3.1.1 Addressing the scientific requirements

How each of the requirements listed in Table 8 might be addressed is outlined below, using examples of biodiversity measurement and biodiversity indicators from the scientific literature.

Be inclusive of all levels of biological organisation

Biodiversity is usually explored at three levels of organisation: genetic, species and ecosystem diversity. A single integrated measure of biodiversity that encompasses all of these elements for all types of living things, without bias, is simply not possible with current levels of knowledge and inventory. It is necessary therefore to analyse these levels by exploring how biodiversity is observed and classified and what suite of indicators may be designed to encompass all levels.

The first requirement is addressed by adopting the general model of biodiversity proposed by Faith (1994a, b, 2017), which interprets biodiversity as living variation at multiple levels of organisation, quantified by the number of different units represented by a given set of 'objects' (e.g. 'how many different species are in this set of protected areas?'). This general model allows the flexible use of measurement methods, such as phylogenetic diversity (PD, see section 1.5.7 and Faith 1992) and environmental diversity (ED, see section 1.5.6 and Faith & Walker 1996a), which provide the foundation for a wide range of biodiversity indicators that can be developed for reporting on variety at multiple levels (genes, species, ecosystems) and across whole areas or regions. For example, PD can be expanded to show how ecosystems are related in a hierarchy by their shared species (Nipperess et al. 2010; Woinarski et al. 1996) and used in predictive models (Rosauer et al. 2014).

In addressing this first requirement, all available information and knowledge of biodiversity should be used in developing measures of variety, including genetic diversity within species, species diversity, phylogenetic or taxonomic diversity between species, ecosystem diversity and assemblage similarity (e.g. shared species) among ecosystems. This approach ensures distinctiveness can be demonstrated at all levels of biological organisation through the indicators.

Represent all plants and animals native to New South Wales

As mentioned in section 1.2, typically much of what we want to know about biodiversity is unknown. Many species are yet to be discovered and many features of species are undescribed (Faith 2016a). This second requirement therefore establishes the need to address data adequacy and acknowledges the inevitable growth of knowledge about biodiversity over time.

Assessments concerning overall biodiversity often require the use of an inferential model or estimation, to fill knowledge gaps and so effectively complement data from the monitoring of species that are known to science (Faith & Walker 1996a, b; Ferrier 2002, 2012). The use of surrogate measures of biodiversity (see section 1.5.3) in evaluating species representation, for example, is an accepted approach in biodiversity conservation to overcome inherent knowledge gaps and data bias (Beier et al. 2015; Engelbrecht et al. 2016; Faith et al. 2004; Faith & Walker 1996a, b). Such surrogates, which allow for consideration of overall biodiversity, are a suitable complement to assessments and indicators based on currently discovered and described sets of species.

This requirement is addressed by including indicators that utilise accepted surrogates for overall biodiversity by applying models (e.g. GDMs, see section 1.5.1), based on observations of species' co-occurrence, to represent compositional patterns at fine scale (Faith & Walker 1996a; Ferrier et al. 2002; Ferrier et al. 2007). These models allow the existing observation data to be interpolated across whole regions for consistent estimation of biodiversity. Rigorous model and data evaluation procedures are essential parts of the indicator workflows. They provide information about prediction robustness and reliability for decision-making. In addition, they can be used to highlight areas of uncertainty related to data collection gaps with potential for model improvement (see section 3.2.1 below). Review, refinement and acceptance of modelled biodiversity patterns by ecological specialists is a critical step in the indicator development workflow.

To account for the growth of knowledge, different approaches to measuring biodiversity need to be explored and compared, including direct approaches from local monitoring, as well as indirect approaches using sets of described species or ecosystems and models to include undescribed diversity. The models can also inform the strategies for selecting new monitoring locations and gap-filling surveys (Ferrier 2002; Funk et al. 2005).

Evaluate rate of loss of biodiversity

A number of different approaches are needed to evaluate the rate of loss of biodiversity. One of these approaches is extinction risk. The IUCN Red List of Threatened Species™ (IUCN 2017) is the standard adopted by countries around the world for assessing extinction risk and the companion standard for ecological communities is the IUCN Red List of Ecosystems™ (IUCN 2016b). The results of IUCN Red List assessments have been used to generate indicators for reporting on change over time using a representative sample to minimise bias resulting from: i) dominance of attractive, spectacular, high profile or better-known species on lists, and ii) growth of knowledge mainly contributing to change in status (Butchart et al. 2005; Mace et al. 2008). However, the sampled Red List index approach is unable to remove all such bias and remains relatively insensitive to change (Butchart et al. 2006; Brummitt et al. 2008; Brooks et al. 2016).

Another approach is the Living Planet Index which uses species abundance data (Loh et al. 2005). However, this approach is limited to the set of species subject to monitoring and the evidence suggests data deficiency masks more concerning declines (McRae et al. 2017).

Nonetheless, indicators reflecting extinction risk can help account for the gains arising from on-ground actions to mitigate pressures and manage populations of threatened species and ecological communities.

Taking into account the two requirements outlined above, two approaches were explored for developing indicators of the rate of biodiversity loss: i) measuring extinction risk in units of ‘expected diversity’ (Weitzman 1992; Faith 2008) using the IUCN Red List assessment methods, and ii) measuring living variation and its likely persistence using more continuous assessment methods. For example, some of the limitations inherent to the sampled Red List index approach can be addressed using representative sets of species known to science (following Mimura et al. 2017). These approaches apply specific IUCN criteria and assessment methods, allowing use of data on species distributions and habitat loss to approximate risk categories. The categories can then be equated with extinction probability over 100 years and expected diversity calculated from the numbers of species (or ecological communites) in each category. This approach provides a common assessment framework that can be applied in the same way to representative species sets and to surrogate measures of biodiversity (e.g. from models such as GDM) for relevant biological (i.e. taxonomic) groups. The same measurement units (expected diversity) enable comparison between indicators based just on threatened species, on a representative sample of all known species, or using a model to repesent all of biodiversity including undescribed species.

The models of biodiversity further allow the principles of extinction debt and extinction lag, which is the irreversible, and time-delayed loss of sensitive species in remnant natural areas following clearing (Rosenzweig 1999; Dullinger et al. 2013; Halley et al. 2016) to be used when estimating extant (existing) biodiversity (Allnutt et al. 2008; Ferrier & Drielsma 2010).

Be sensitive to change over five years

Arguably, the most definitive information on change derives from in situ monitoring of individual species’ population abundances to show statistically significant trends, aggregated into indices such as the Living Planet Index (Loh et al. 2005; McRae et al. 2017) and biotic intactness (Faith et al. 2008; Newbold et al. 2016b). Population abundance is an essential biodiversity variable that clearly provides more information than species’ distribution data and is consequently more sensitive to change. However, abundance data vary widely in observation and measurement standards and are relatively sparse, even allowing for novel approaches such as camera traps (Ahumada et al. 2016; Rovero & Ahumada 2017) and citizen science campaigns (Callaghan & Gawlik 2015). The most globally complete use of abundance data, the Living Planet Index, further highlights the significant spatial and temporal gaps in monitoring vertebrates and requires extensive processing of records to minimise bias (McRae et al. 2017; Proença et al. 2017).

A complementary approach to detecting change, where specific monitoring data are limited, is to use empirical knowledge relating population abundance to distribution ranges, and occupancy for equating population declines with habitat loss (Böhm et al. 2016; Gaston et al. 2000; Hui et al. 2012; McGeoch & Latombe 2016). There is strong empirical evidence for such abundance–occupancy relationships across a wide range of ecological systems and taxa (Bean et al. 2014; Buckley & Freckleton 2010; Gaston & Warren 1997; Verberk et al. 2010; Zuckerberg et al. 2009). These relationships are robust to declines in occupancy by human agency (e.g. Werner et al. 2014) and so are applicable in indicators of extinction risk (McCarthy et al. 2014; Murray et al. 2017). Murray et al. (2017) concluded that current methods for measuring range size were the best spatial metrics for estimating risks from stochastic threats. Such approaches nevertheless will miss some elements of biodiversity that are still at risk, including those where geographic distribution does not link well to species' threat status.

By extension, occupancy relationships can also be used to infer genetic diversity (Faith et al. 2008). Globally, many taxa have been evaluated using inference of abundance methods for IUCN Red List criteria by applying species' geographic range information (Brooks et al. 2016; Gaston & Fuller 2009; IUCN 2017; Maes et al. 2015). These analyses use data on species' distributions and habitat loss to infer extinction risk. They thus provide more temporally sensitive indicators of change enabling broader, more systematic monitoring of biodiversity loss rates (Balmford et al. 2003). While not necessarily explicit about declines in genetic diversity, these proxy indicators, when developed at high resolution (Stephens et al. 2015), can show trends that may trigger concern where declines are expected to be greatest. Strategic investigative surveys at such foreshadowed locations might best complement a network of monitoring sites to determine cause and effect relationships and so trigger appropriate policy or management responses.

This requirement is therefore addressed using measures of ecosystem quality, such as data on changes in the extent of native vegetation and land degradation from calibrated remote sensing, to infer declines in species' occupancies. The results then apply to indicators that indirectly measure the rate of biodiversity loss (see the third requirement above). The derivation of habitat loss and condition data for this assessment is discussed in more detail below and in the context of the ecological integrity indicators (see section 3.5).

Measuring ecosystem quality

The first requirement in developing ecological integrity indicators is the measurement of the present state of ecosystem quality or condition. At the local level, this is the 'biodiversity value' of vegetation integrity in the BC Act. Vegetation integrity in this context can be equated with site-level observations of vegetation condition (e.g. Bleby et al. 2008; Lawley et al. 2016; Minato 2009; Mucina 2009). In New South Wales, the *Biodiversity Assessment Method* (OEH 2017a) defines how vegetation integrity is to be measured (for details, see section 3.5.1). The measurement of vegetation integrity is a minimum pragmatic approach to rapid assessment that can be applied consistently by trained assessors. Its application requires the definition of reference states, also known as benchmarks, to clarify what is meant by 'near natural' or 'best attainable' as a management goal; and therefore of having an effective level of 'integrity' to sustain ecosystem function with minimal intervention. To be useful in an indicator, systematic observations of habitat condition at the site level are needed to allow interpolation across whole regions, by integration, for example, with remote sensing and modelling technologies.

With the advent of satellite-based monitoring of land at high resolution and with sufficient time series, habitat loss and condition or functional integrity can be inferred by calibrating remote-sensed signals with field observations of land-cover change over relatively long time series (Geller et al. 2017). With the rapid evolution of remote technologies to accurately detect cryptic systems (e.g. grasslands and other non-woody systems or ground under canopy), an ever-widening range of ecological applications is becoming possible (Pettorelli et al. 2014; Pettorelli et al. 2016a; Pettorelli et al. 2016b; Skidmore et al. 2015). Remote-sensing data can be further calibrated with observations of intact ecosystems (Harwood et al. 2016; Nagendra et al. 2013; Zlinszky et al. 2015) or empirical data on species richness response to disturbance (Newbold et al. 2016b; Newbold et al. 2015) to model habitat quality for intact biodiversity more explicitly (see section 3.5). Models representing levels of habitat degradation and loss, related to capacity to support their original diversity (e.g. Sinha et al. 2014), can then be combined with information about biodiversity distribution at the species or community level to estimate the amount of biological diversity still living and expected to persist (see section 3.5.1).

It is expected that data, technology and modelling methods will evolve rapidly over the next few years and so advance the scale and accuracy with which ecosystem quality can be measured routinely and support attribution of change processes.

Appropriately representing ecological and evolutionary processes

This requirement involves summarising how ecological and evolutionary processes, across whole landscapes and dynamically in space and time, interact with site-level condition. Vegetation integrity and habitat condition at the site level are necessarily influenced by the context in which they occur. Position within a surrounding landscape may either isolate or connect component species with varying benefits and trade-offs (Bailey et al. 2010; Grilli et al. 2015; Johst et al. 2011). The concept of extinction debt is important here (Tilman et al. 1994). The observed integrity of vegetation or habitats at the site level at the time of measurement may not necessarily represent equilibrium. Places that are presently in disequilibrium with the surrounding landscape following habitat loss may appear to retain most of their original biodiversity, but, over time, certain populations will decline and some species will no longer be found locally. To know where species' populations may have stabilised or are continuing to decline requires information about land-use change histories and relaxation rates (time to first extinction and for half the extinction debt to be paid). Lag effect parameters are crucial to modelling and forecasting species' decline and to inform timing of conservation actions. Based on a meta-analysis of published data for different taxonomic groups, Halley et al. (2016) found that characteristic rates of biodiversity decline can be inferred using only area, initial species' richness, average per species' population density and average generation time. There is a need for such specific information from representative ecosystems to better understand their biodiversity status and change over time, and where timely interventions may prevent local extinctions.

As an interim measure, the context, configuration and connectedness of habitats across whole landscapes provides a simplifying framework for a wide range of interacting processes and network dynamics across ecological scales (Gonzalez et al. 2011; Hagen et al. 2012). Loreau et al. (2003), for example, concluded that 'knowledge of spatial processes across ecosystems is critical to predict the effects of landscape changes on both biodiversity and ecosystem functioning and services'. When such spatial processes are combined with information about the suitability and quality of habitats it becomes possible to estimate the ecological carrying capacity for biodiversity and, by inference, the amount of regional diversity likely to persist given those configurations (Drielsma & Ferrier 2009; Drielsma et al., 2014; Ferrier & Drielsma 2010; van Teeffelen et al. 2012).

Representing the diversity of ecosystems supporting biodiversity

To meet this requirement, ecological integrity must take into account the complementarity and diversity of ecosystems to provide supporting habitat for biodiversity. The key requirement is to ensure the choice of measurement is an effective surrogate for overall biodiversity (see section 1.5.3 and above). Surrogates for different biological (i.e. taxonomic) groups may be needed for comprehensive consideration of biodiversity. Complementarity applies in two ways: i) the complementary traits and interactions among species that contribute to overall ecosystem function and stability in time and space (Allan et al. 2011; Cadotte et al. 2011; Fargione et al. 2007; Loreau & Hector, 2001), and ii) complementarity of different components of biodiversity explicitly retained in the landscape to represent variety through various conservation management actions (Faith et al. 2003; Margules & Pressey 2000). Here it is assumed that managing landscapes for complementary representation of biodiversity over large areas also retains essential ecosystem function (Loreau et al. 2003). Therefore, it will be important to conduct desktop assessments of: i) how well different facets of biodiversity are represented within areas managed specifically for conservation, and ii) how other forms of management facilitate the retention of unique biodiversity.

The role of people in managing ecosystem integrity

This requirement acknowledges both the importance of people interacting with the environment as well as the need to evaluate how effectively ecological science knowledge, applied through management interventions, mitigates risk of ecosystem collapse (Morton et al. 2009). All ecosystems are managed by people to greater or lesser extents. Other legislative instruments also guide how people interact with the environment, consistent with the principles of ecologically sustainable development. These actions collectively facilitate the capacity of ecosystems to adapt to change. Interventions vary from intensive in situ and ex situ support to recover threatened species populations from the brink of extinction, to landscape-scale management of fire regimes to avoid collapse of sensitive ecosystems, and to widespread control of invasive species.

Using scenarios to explore the implications of climate change

Finally, indicators of ecological integrity need to account for, and where possible partition, interactions between altered climate regimes, shifting land-use requirements and the continuing presence of other pressures such as invasive species (DECCW 2010). Such indicators need to be capable of both retrospective and forecasting trends to show where ecosystem collapse is most imminent or at risk due to altered and alien disturbance regimes. Scenarios and models provide a powerful basis for evaluating the varying effectiveness of alternative policy instruments interacting with climate change (Ferrier et al. 2016a, b; Drielsma et al. 2017).

3.2 Principles underlying the development of indicators

The scientific requirements described above were integrated to derive two biodiversity indicator themes and three ecological integrity themes, as outlined in section 2. The first biodiversity indicator theme applies the ‘expected diversity’ framework (see section 3.2.2 below), quantifying change in risk of extinction status of species or ecosystems over time and is labelled expected survival of biodiversity. The second biodiversity indicator theme is broader and applies to all biodiversity to quantify change in the amount of diversity over time and is labelled state of biodiversity. The ecological integrity indicators focus on quantifying change in ecosystem quality, management and resilience that influence and interact with adaptive capacity. They link to the biodiversity indicators through the ecosystem quality, ecosystem management and ecosystem integrity themes (as shown in Figure 5).

3.2.1 Biodiversity measurement

To fully assess biodiversity at statewide and bioregional scales, indicators need to be capable of representing all species within a particular biological group of interest (i.e. taxonomic group), including undiscovered species (e.g. using surrogates, as defined in section 1.5.3). To address this requirement, two types of indicator are relevant that are either:

- representative of species within a group, based on species that have been discovered, described and catalogued, or
- representative of all species, including those yet to be discovered, using models.

In order to avoid the bias inherent to many indicators (e.g. as outlined in McCarthy et al. 2014), the principle of representation is applied. Representation may be applied to a range of biological groups that are relatively well known from surveys and monitoring, or via models developed using the field data to fill knowledge gaps. Both approaches are applied to provide different lines of evidence for biodiversity measurement. They are adaptive to growth of knowledge (e.g. through gap-filling surveys and monitoring) and can be updated either incrementally or though step-change improvements in data and modelling methods.

How a representative sample of species is derived

A preliminary step for several biodiversity indicators is the identification of a representative set of species for a nominated taxonomic group. The rationale (Faith 2015; Mimura et al. 2017) for such a set is as follows. Typically, proposed indicators simply use those species that happen to be in a database (e.g. McRae et al. 2017). Naturally, this is not a representative sample of all the species that make up biodiversity. An indicator calculated on that set of species therefore does not tell us much about biodiversity in general.

A representative sample of all species means that a given index calculated on that subset is a good indicator of the index value we would have obtained if we had been able to calculate the index for all species, including those not yet known to science, for the nominated taxonomic group. Careful attention is therefore given to how we determine representativeness of the subset of species. Early work (Faith & Walker 1996a and references within) points to good indicator sets of species as spanning the environmental space of key gradients related to habitat that determine species' occurrence. GDM (see section 1.5.1) provides this biotically scaled environmental space for a nominated taxonomic group. The general model underlying GDM and environmental diversity (ED, see section 1.5.6) links the idea of spanning the environmental space to the representation of a variety of species (Faith & Ferrier 2002; Ferrier 2002; Ferrier et al. 2002).

Based on this framework, there is a simple way to derive a representative sample of species for robust use in indicators that extends the method of Mimura et al. (2017). The approach uses the environmental diversity – survey gap analysis methodology (ED–SGA) to define 'demand points'; which are used by ED's *p*-median algorithm to calculate distances to geographic 'locality sites' (Faith et al. 2004; Faith & Walker 1996a). The number and location of demand points are critical. Demand points are uniformly distributed locations in continuous environmental space (e.g. GDM-scaled space) and so when projected back into geographic space (e.g. a map) are non-randomly distributed sites which represent the real diversity of ecological environments. To implement this approach, a workflow extension of the ED–SGA software (Ferrier 2002; Manion 2016; Manion & Ridges, 2009) is used. The ED–SGA software has been applied widely to guide the filling of gaps in biological surveys across New South Wales and elsewhere (e.g. Bell et al. 2014; Ferrier et al. 2007; Funk et al. 2005).

The process is as follows (see equation 1 below). Suppose we want *k* representative species, then the first step corresponds to the normal procedure to create *k* demand points (Faith et al. in prep.). Then we sort through the full available set of species (each species is associated with a defined list of locations where it has been observed). We find for each species, *j*, its closest demand point, P_j (the distance from a species to a demand point is the average dissimilarity of all of species *j*'s observed locations to that demand point). If that demand point does not already have a species assigned to the set, we add that species to the representative set and continue until all *k* demand points are represented by a species. Iteratively, we may update the assignment of species so that, for a given demand point, a new species replaces the existing one if that new species is closer. The rationale for deriving this representative sample of species is consistent with the ED method (Faith & Walker 1996a).

Suppose species j, has n_j areas, called a_t indexed by *t* where *t* goes from 1 to n_j. The distance, dist(*j*, p_i), from a species *j* to a demand point, p_i is

$$dist(j, p_i) = \left(\sum_{t=1}^{n_j} \frac{D(p_i, a_t)}{n_j}\right) \qquad \text{equation 1}$$

where *D* is a distance in our environmental space. We then use dist(*j*, p_i) values to assign, as described, each demand point a representative species.

The representative set of species is then used in a variety of indicators. This set of sampled species (for a given biological or taxonomic group) is selected once and only those species are used for the indicators at initial assessment and to assess change in the future. Given the representative species set, the value for any nominated indicator is the average (or other summary) of the individual scores for the sample of *k* species. For example, if we want to track over time the fractional loss of the geographic range of a species in New South Wales, our indicator score would be calculated as an average of the values found over the members in the representative species set. In the future, with growth of knowledge, additional locations may be discovered for one or more species in the representative set or be mobilised into databases or rigorously validated. Therefore, the values at initial assessment as well as the current change analysis (e.g. in five years' time) would be recalculated for each indicator using the representative set.

How models are used to quantify overall biodiversity

Models of biodiversity can be used to predict patterns of diversity within a biological group including, by extension of the logic, undiscovered species. The GDM method is well established (Ferrier et al. 2002) and makes extensive use of field observations of species' occurrence data, integrated with environmental and remotely mapped land information (see also Ferrier et al. 2007). This approach has been demonstrated to be a foundation for quantifying biodiversity (Faith & Ferrier 2002) and an efficient alternative to modelling individual species when collective knowledge of biodiversity is needed for assessment (Ferrier et al. 2009; Ferrier & Guisan 2006).

Models are most often derived using species-level observation records for an individual taxonomic group, although different groupings can be applied (e.g. all vertebrates or functional groups) where it can be argued that comparable survey methods have been used to detect individual species' occurrences. Candidate environmental and geographical predictor variables are compiled that have ecological meaning in explaining species' distribution patterns and tested for statistical fit (e.g. see Williams et al. 2012). Specifically, GDM uses the Bray-Curtis dissimilarity index (Bray & Curtis 1957) to measure turnover in species composition between pairs of sites scaled between 0 (site pairs have the same species) and 1 (no shared species) and applies generalised linear models (GLMs) to relate compositional dissimilarity to predictor variables.

Implementation of the approach using large sets of biological records over large areas at fine scales requires appropriate (e.g. stratified random) subsampling of site pairs to both reduce observation bias and address computation limits (e.g. Rosauer et al. 2014; Williams et al. 2010). Rosauer et al. (2014) extended the approach to include the use of species' phylogenies, in this case applied to amphibians for testing evolutionary hypotheses. Mokany et al. (2011) then integrated models of species' richness (alpha diversity) with GDM (beta diversity) to fill gaps in multi-species occurrence matrices for meta-community modelling of dispersal and community assembly (Mokany et al. 2013; Mokany et al. 2012). These extensions were foreshadowed by Faith and Ferrier (2002), Ferrier et al. (2002) and Ferrier (2002) as an integration of GDM with ED.

ED as a biodiversity measurement strategy has been demonstrated to perform well if implemented correctly, for example, using GDM (Engelbrecht et al. 2016). This approach provides a suitable test of bias in indicators developed using only the records of currently described taxa. Under Faith's (2017) general framework for biodiversity, GDM provides the pattern/process model that is then used to infer biodiversity gains and losses by applying the ED method to estimate relative feature numbers (e.g. species, ecosystems). The GDM–ED approach to biodiversity measurement (Faith & Ferrier 2002; Ferrier 2002) is used in the derivation of representative sets of known species and to estimate known and undescribed species and ecosystem diversity as inputs to the respective indicators.

Why models are essential to the biodiversity information program

Computer models, such as those described above, are powerful tools used by the biodiversity information program, for example, to fill data and knowledge gaps and to limit the influence of sampling bias. They are mathematical representations of natural systems and can range from very simple to very complex. It is important to find a balance between the many strengths and benefits of using a model and the limitations that are inherent in their use. These are outlined in Table 9.

Table 9 Benefits, strengths and limitations of the use of models in the biodiversity information program

Benefits/strengths	Limitations
Can extrapolate data in space and time	Involve assumptions
Can simulate different scenarios	Only represent aspects that are understood and quantifiable
Can capture vast amounts of knowledge from diverse sources	Scalability of application, both spatially and temporally
Provide a venue for different disciplines to interact	Can be data-hungry
Offer transparency, i.e. all analysis, data etc. is captured	Only approximate real-world systems
Can analyse vast amounts of data quickly	Reliability assessment tests are required

Proxies for measuring within-species genetic diversity

Explicit accounting for genetic diversity within species is a fundamental goal of biodiversity assessment, yet suitable population-level data for reporting on the status of multiple species are often lacking. Proxy methods have therefore been developed and empirically proven to be effective (e.g. Hermoso et al. 2016). In the future, however, new genomic methods for rapidly assessing the genetic composition of whole ecosystems may revolutionise what is possible (Bragg et al. 2015).

In a review of the science, Bruford et al. (2017) outline a range of proxies for measuring change in genetic diversity. They note that while genomic technologies will gradually reduce reliance on proxies, well-designed within-species genetic diversity proxies will continue to be useful for reporting on overall biodiversity at broad scales. Faith et al. (2008) also looked at proxies and developed a genetic diversity representativeness index as an analogue to the species-level biodiversity representativeness index based on species–area relationships.

The challenge therefore is to choose a proxy or set of proxies to approximate genetic diversity. Two fundamental components of genetic diversity need to be addressed in the development of proxies. One equates to the fractional loss of a species' range in environmental space (i.e. environmental occupancy) and the other in geographic space (i.e. spatial occupancy). These two components simulate different, albeit overlapping, aspects of genetic diversity that are well-founded in theory and experimental data. As outlined by Mimura et al. (2017), a species' coverage of environmental space provides a proxy for non-neutral genetic variation, reflecting adaptation to environmental variation across the range of the species. Whereas loss of geographic range extent also considers the consequences of neutral variation. These two drivers of genetic diversity (adaptive and neutral) both need to be taken into account. However, as they are overlapping ecological processes they are not additive. Neutral genetic diversity results from processes such as gene flow, migration or dispersal which are influenced by the spatial configuration of habitats and their relative connectivity across whole landscapes. Adaptive genetic diversity results from different evolutionary processes not directly linked to neutral genetic diversity, but can be influenced by spatial connectedness and so one cannot act as a proxy for the other (Holderegger et al. 2006).

Therefore, another important use of the representative species set and GDM–ED environmental space modelling is in the development of indicators of fractional genetic diversity loss (Mimura et al. 2017). For neutral genetic diversity we may simply use fractional loss of geographic range extent (e.g. using area of occupancy, AOO), or simulate loss using more elaborate indicators based on change in spatial configuration and connectedness of habitats with land use (see habitat condition indicators, section 3.5.1). For adaptive (non-neutral) genetic diversity, a proxy estimate might be based on fractional genetic variation loss for a given pattern of loss of sites in a species' environmental space. As Mimura et al. (2017) explain, the same amount of fractional loss can have different consequences depending on whether the sites are clumped or evenly spread in the species' environmental space. If sites are clumped, the loss of adaptive genetic variation is higher. Similar approaches could be used in interpreting the consequences of estimated neutral genetic variation loss in geographic space (with consideration of spatial configuration and connectedness). The two forms of genetic diversity would then need to be presented as separate (non-additive) components within an indicator.

For occupancy in environmental space as a proxy for adaptive genetic diversity loss, Mimura et al. (2017) show how ED is used to convert loss of coverage of biotically scaled environmental space to fractional genetic diversity loss (following standard ED methods in Faith et al. 2004). Support for this application of ED is founded in the unimodal relationship of genetic variants to environmental gradients (Faith et al. 2009). As noted previously, GDM is an appropriate model for ED.

3.2.2 Expected diversity framework for assessing risk of biodiversity loss

While a crucial focus of the BC Act is listed threatened species and ecological communities, there remains the need to also account for the many species and the ecosystems that support them. These are species and communities that may be at risk of decline and potentially threatened, and for which there has been no formal scientific assessment (due to data deficiency or cost of comprehensive assessment processes). Applying the biodiversity framework presented in Figure 1, the expected survival of biodiversity indicators therefore must consider gaps in the four types of knowledge linking biodiversity discovery with conservation concern (i.e. assessing threat of extinction).

The NSW Scientific Committee determines the extinction risk listing of species and ecological communities and may initiate a listing as well as consider public nominations. This is an independent committee of scientists appointed by the Minister for the Environment. Threatened species or ecological communities are listed as extinct (or extinct in the wild), critically endangered, endangered or vulnerable or not threatened, based on the published interpretation of the IUCN Red List criteria (following Kindvall & Gärdenfors 2003). Lists are ideally reviewed at least every five years to determine whether changes to threat status are necessary (to a higher or lower concern category).

Considering the four types of biodiversity knowledge (see Figure 1) and the two levels of biodiversity required for reporting (species and ecosystems, see Figure 6), four categories of indicators are suggested for measuring the degree to which biodiversity conservation actions slow the rate of biodiversity loss. Although some risk assessments are conducted at the population level of species (e.g. lists of threatened populations under the BC Act), most assessment apply to the species and subspecies level. Therefore, the expected diversity indicator framework is not yet applied to threatened populations within a species, while acknowledging this possibility in future assessments.

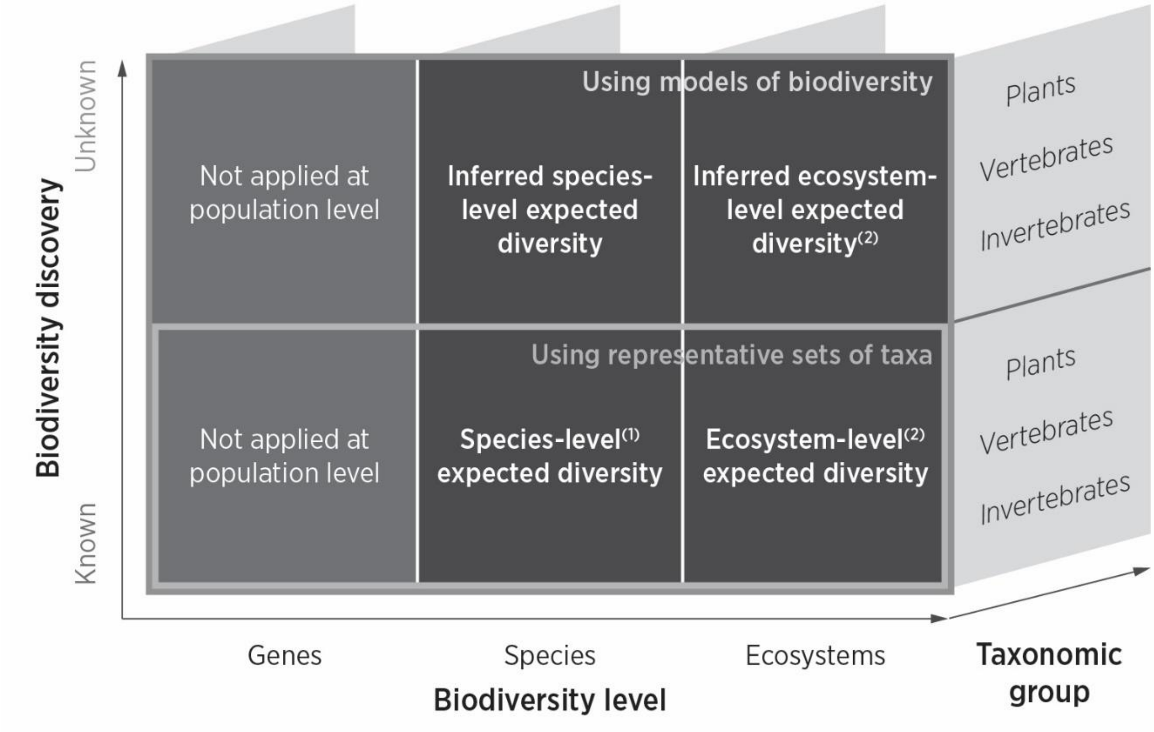

Figure 6 Classification of biodiversity knowledge status applied to indicators developed using the expected diversity framework based on probability of extinction

Indicators derived using information in the lower row (inner light grey surround) are nested within indicators derived using models of biodiversity (outer dark grey surround) for overall biodiversity. Note (1): where a phylogeny is available, the indicator can measure expected phylogenetic diversity (PD) for estimating evolutionary distinctiveness, or substitute with taxonomic classification. Note (2): ecosystems equate with community level; where an ecosystem or community classification hierarchy is available, the indicator considers relatedness for estimating distinctiveness

Calculating expected diversity

Expected diversity is a calculation (see equation 2) first proposed by Weitzman (1992) in order to integrate any nominated diversity measure, *D*, with information about estimated species' extinction probabilities (e.g. based on IUCN Red List categories). Each possible subset or combination, *c*, of species (or other objects) has some diversity value, *D(c)*. That combination also has some estimated probability, *q(c)*, that it will not be lost. Typically, estimated probability, *q(c)*, is calculated based on the individual estimated species' extinction probabilities, with an assumption of independence. The expected diversity retained is the sum, over all possible combinations, of the *q(c)∗D(c)* values. Changes in individual estimated species extinction probabilities (e.g. as a result of successful

conservation management of an endangered species) will change the expected diversity value. Conservation priorities among species typically focus on achieving an increase in expected diversity (Faith 2008; Weitzman 1992). At any given time, we may have a set of new probabilities, *q'*, implying a change in expected diversity:

$$change\ in\ expected\ diversity = \sum_c (\{q(c)D(c)\} - \{q'(c)D(c)\}) \quad \text{equation 2}$$

In principle, this approach can use information on changes in threatened status or can use other estimated changes in extinction probability. Expected diversity can be used to integrate the outcomes of various conservation programs that aim to change species' status (threat category) into a single indicator by inferring changes in probabilities of extinction for each managed species. Those probabilities can be assigned based on expected outcomes for the purpose of prioritising conservation actions or be based on observed outcomes as a result of monitoring management effectiveness.

In this context, for any nominated set of elements of biodiversity (e.g. species, ecological communities) we define the current expected diversity as the expected number or proportion persisting in 100 years' time. This time frame, consistent with that considered by the *Saving our Species* program (OEH 2013), is linked to the use of probabilities of extinction in 100 years.

Probability of extinction in 100 years

The use of extinction probabilities provides a common basis for prioritising species for management or as a means of reporting on outcomes of management effectiveness. The latter purpose is used by the indicators for reporting on known or potentially threatened biodiversity.

While the true extinction probabilities of individual species are not known, especially in the absence of population viability analyses, the IUCN Red List does give qualitative estimates for probability of extinction for criterion E for specific threat categories (vulnerable, endangered and critically endangered) for both the Red List of Species and the Red List of Ecosystems (i.e. ecological communities). Based on these estimates, Kindvall and Gärdenfors (2003) and Mooers et al. (2008) suggest specific extinction probabilities for IUCN categories. Following from Kindvall and Gärdenfors (2003), the *Saving our Species* program (OEH 2013) derived extinction probabilities for a 100-year period in the development of a priority score for selecting projects. These probabilities are listed in Table 10. The probabilities are converted to a probability of survival as 1 minus the probability of extinction. Probabilities of survival for the presumed extinct class are assumed closer to 0.01, based on the sighting models of Solow and Roberts (2003) and can be validated using historical data on rate of species rediscovery.

Table 10 Suggested extinction probabilities for IUCN categories

IUCN category	Extinction probability for species				For ecosystems
	Annual [1]	Over 50 years [1]	Over 50 years [2]	Over 100 years [3]	Extrapolated over 100 years [4]
Least concern			0.00005		0.05
Near threatened			0.004		
Vulnerable	0.00105	0.05117	0.05	0.10	0.10
Endangered	0.01110	0.42771	0.42	0.70	0.35
Critically endangered	0.06697	0.96876	0.97	0.95	0.75
Presumed extinct					

1. See Kindvall & Gärdenfors (2003).
2. See Mooers et al. (2008).
3. See OEH (2013).
4. From criterion E of Bland et al. (2017).

Developing the expected survival of biodiversity indicators

Combining the principles of biodiversity measurement with the expected diversity framework, the following points guided development of the expected survival of biodiversity theme of indicators:

- Marginal gains and losses in biodiversity at risk of extinction and persisting in 100 years' time are calculated using the expected diversity framework (see section 3.3).
- Gains can be predicted using information about management responses (see section 3.6) ascribed to individual programs where spatially explicit information is available; and with monitoring of management effectiveness, some threatened species and threatened ecological communities may be determined 'secure' (applying *Saving our Species* definition, see section 3.3).
- Probability of extinction scores can be equated with conventional IUCN threat-based categories of extinct, critically endangered, endangered and vulnerable, or least concern (determined 'secure').
- Approximate extinction risk assessments informing specific components of IUCN Red List criteria B and D can be applied to all species within a representative set to assign (provisional) risk categories, regardless of listed status.
- To assess the provisional risk status of all species within a particular taxonomic group (e.g. plants), species are selected to be representative of the range of environments over which that taxonomic group is distributed across New South Wales.
- Phylogenies, where available and complete for a taxonomic group, can be used to calculate expected phylogenetic diversity (PD), relating species diversity to evolutionary distinctiveness (i.e. *D* in equation 2 equals PD, see also section 3.3). Or as in interim measure, substitute with taxonomic hierarchies.
- Biodiversity models generated using existing occurrence records for a taxonomic group can be used to derive a companion set of indicators to fill knowledge gaps in the distribution of known and undiscovered species.
- The same suite of indicators and principles can potentially be applied to measure expected diversity of ecosystem variety (to broadly equate with ecological communities).
- There is potential to also apply the framework to measure expected genetic diversity, leveraging theory and empirical knowledge relating species' occupancy, abundance and range loss.
- There is potential to create sub-indicators as desired with dissection into details, such as taxonomic or functional groups of species.

Applying the above considerations, the expected survival of biodiversity indicator theme is composed of two indicator families: i) expected survival of listed threatened species and ecological communities, and ii) expected survival of all known and undiscovered species.

3.2.3 Extant diversity framework for state of biodiversity reporting

In addition to indicators measuring the degree to which biodiversity is threatened with extinction (applying the expected diversity framework, see section 3.2.2), the existence status of all biodiversity, that which remains extant (still living) and is likely to persist, is also of interest. We call this the extant diversity framework.

A fundamental indicator is one that reports on the estimated number of biodiversity features (genes, species or ecosystems) that presently exist in New South Wales, compared with numbers that existed prior to the introduction of intensive land-use practices (e.g. following the history of land settlements since the industrial era in Australia, c. AD1750), or for any intervening period. For the BC Act, we are interested primarily in relative numbers at commencement (c. 2017), including the trajectory of historical change up to that time, and change in future years. The estimation of numbers of biodiversity features is similar to the well-known representation problem in conservation assessment and systematic planning founded on the principle of complementarity (Kirkpatrick 1983; Margules & Pressey 2000; Vane-Wright et al. 1991)

In addition to direct monitoring of biodiversity at specific locations, the state of biodiversity indicators use models and complementarity-based representation calculations to report on the proportion of biodiversity that exists in New South Wales and in each bioregion. This approach also enables the conservation management status of biodiversity to be calculated using spatially explicit management response data (see indicators 4.1a and 4.1b in section 3.6.1), so that the balance of gains and losses in biodiversity attributed to management, changes in the extent of native vegetation or habitat degradation can be reported.

Considering the three levels of biodiversity for reporting (genes, species and ecosystems) and the requirements outlined in section 3.1, we identified three families of indicators: state of all known species, state of biodiversity including undiscovered species, and field monitoring of species and ecosystems. These provide comprehensive coverage of representation-related concerns (see Figure 7). Some of these are analogues of the expected survival of biodiversity indicators (see Figure 6). Here, we include the ability to infer total extant (existing) within-species genetic diversity using biodiversity models (top-left in Figure 7). In the case of genetic diversity, we envisage two complementary approaches (neutral and adaptive) as outlined in section 3.2.1. The calculation of total extant (existing) ecosystem diversity (lower-right quadrant in Figure 7) requires complete coverage (consistent regional or statewide mapping) of ecosystems, or can be estimated using models (top-right).

Calculating extant diversity using complementarity-based representation

Extant (existing) diversity derives from calculations first proposed by Kirkpatrick (1983). Extant diversity explicitly recognises the complementarity of biodiversity in assessing representation of areas and setting conservation priorities. Knowing how many species are found in any single location, or set of places, is not a sufficient basis for deciding how to value the biodiversity and set priorities between locations. The specific units or components of biodiversity that are present (e.g. which species or ecosystems) also needs to be taken into account. This is the foundation principle of complementarity in conservation assessment and planning (Kirkpatrick 1983; Margules & Pressey 2000; Vane-Wright et al. 1991).

Complementarity assessment can be applied to any set of locations to evaluate how well they represent regional biodiversity, given suitable biological feature data. The established approach uses models of biodiversity to ensure that counting of the relative total number of features (e.g. species) is comprehensive (in principle, it considers all species or other features/units) for a region. Example assessments include reporting on the estimated proportion of biodiversity that may have been lost (i.e. area-based reduction in suitable habitats, e.g. Allnutt et al. 2008) or protected (i.e. area-based conservation management, e.g. Ferrier 2002; Faith et al. 2003; Ferrier et al. 2004), or some combination of these.

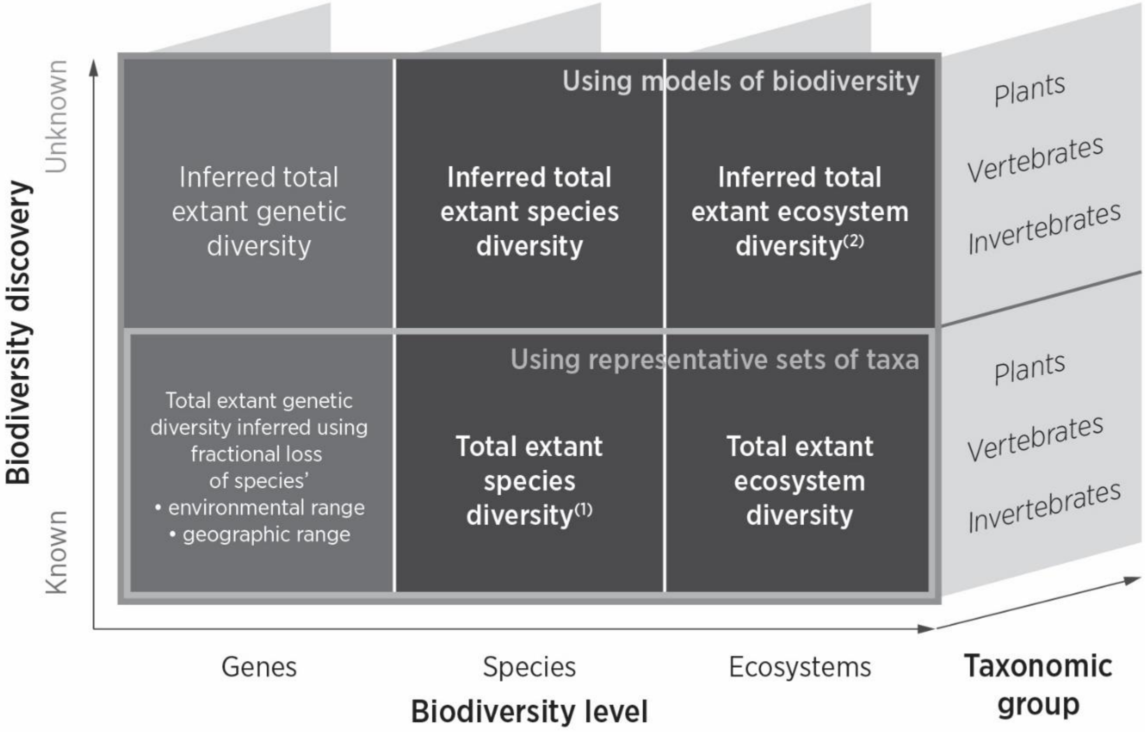

Figure 7 **Classification of biodiversity knowledge status applied to indicators developed using the extant diversity framework incorporating the principle of complementarity (representation)**

Indicators derived using information in the lower row (inner light grey surround) are nested within indicators derived using models of biodiversity (outer dark grey surround) for overall biodiversity. Note (1): where a phylogeny is available, the indicator can measure total phylogenetic diversity (PD); or substitute with taxonomic classification. Note (2): ecosystems equate with community level; where an ecosystem or ecological community classification hierarchy is available or can be derived, the indicator considers relatedness for estimating distinctiveness

Here we define areas as varying from a single place or sets of locations, thus allowing any configuration or policy scenario to be assessed. For example, the contribution to total biodiversity (representativeness) could be evaluated based on sets of locations managed successfully by different conservation programs under the BC Act and by National Parks and Wildlife Service, both statewide and regionally. Consequently, estimates of the total relative feature diversity (e.g. genes, species or ecosystems), that is, the complementarity value, within a defined location or locations relative to a region (or statewide) is a key integrative indicator of biodiversity across different programs. An important feature of biodiversity complementarity is that the values cannot simply be summed to provide any meaningful score, as specific calculations are required in each case (e.g. for each location, sets of locations or areas). The balance between gains and losses of relative living diversity can be reported for each case separately or in combination (for sets). For example, the proportion of biodiversity represented by conservation management relative to the proportion in suitable quality habitat, or relative to the proportion that existed originally can be reported.

The environmental diversity (ED) method (Faith & Walker 1996a, b; Faith et al. 2004; Faith 2017) is a well-tested model-based method for calculating the relative total biological feature diversity of a set of areas, or alternatively the biodiversity complementarity of the features in a given area relative to those in a given set of areas (see equation 3 below).

The total relative species diversity, T_s of a set, s, of areas is MAX minus SUM, where SUM is the sum, overall demand points p_i in our environmental space, of the distance, D, from the demand point to its nearest member, m_i, of the set of areas: $T_s = \sum_{i=1}^{n} D(p_i, m_i)$. The complementarity value, C, for a newly added area, k, is then

$C_j = \sum_{i=1}^{n} D(p_i, m_i) - \sum_{i=1}^{n} D(p_i, m'_i)$ equation 3

where m'_i now considers k as a possible closest area to a demand point, i counts over all demand points (totalling n), and j counts over all possible areas, k, that can be evaluated for complementarity. Notice that we do not have to actually estimate MAX (the number of species in the case where every demand point has an area in its same location in environmental space) because MAX cancels out in the subtraction.

In this method, GDM can substitute as the model of biodiversity pattern for the purpose of calculating feature complementarity.

Calculating biodiversity persistence, taking into account extinction debt

The amount of biodiversity persisting in a region is a function of multiple pattern-related and process-related factors. As outlined in section 3.1.1, one of the key requirements of the indicators is to account for the complexity of ecological and evolutionary processes that support the capacity of ecosystems to adapt to change. This is achieved in two ways (see Ferrier & Drielsma 2010; Drielsma et al. 2014). Firstly, the ecological carrying capacity of a location relative to an intact system is estimated by taking into account the configuration of habitats, their quality and connections with surrounding areas (see indicator 3.1c, section 3.5.1). Secondly, using the species–area relationship (see equation 4 below), the proportion of species expected to persist within a region is estimated from the effective area of suitable quality habitat, under the assumption of equilibrium dynamics (i.e. the balance between establishment and extinction of species in a patch of habitat depends on its effective carrying capacity related to size, shape, isolation and quality). See Ferrier et al. (2004) for an earlier application of the species–area relationship in this context.

The total relative species diversity, BD_R, expected to persist within an ecosystem, E_i, across its range, R, is calculated as the difference between the proportion originally expected to persist, BD_{Ei}, in the intact ecosystem (the original habitat area, OHA) and the proportion expected to go extinct, given reductions in ecosystem area and quality (the effective habitat area, EHA). z determines the departure of the species–area relationship from a linear relationship:

$$BD_R = BD_{E_i} - \left(\frac{EHA_{E_i}}{OHA_{E_i}}\right)^z \qquad \text{equation 4}$$

A z-value of 0.25 for the species–area relationship is commonly used, though Drielsma at el. (2014) use 0.27 for plants, based on a regional analysis of floristic survey data (Ferrier 2002, Ferrier et al. 2002). Higher z-values imply larger numbers of species can be supported within a given area (e.g. higher incidence of endemics or specialists) and lower values imply fewer species (e.g. more generalists) (see Matthews et al. 2014 for a discussion). It may be prudent therefore to use a range of z-values to portray the uncertainty in estimating the amount of biodiversity persisting within a region. Where suitable field survey data are available, the appropriate range of values can be derived empirically or otherwise derived from theory as a global maximum and mimimum.

When applied across whole regions, the calculation is not simply the sum of the individual ecosystem values but takes into account the compositional overlap (inferred species shared, including undiscovered) between ecosystems (see equation 2 in Drielsma et al. 2014).

These two calculations (indicator 3.1c and equation 2 in Drielsma et al. 2014), when used together, predict the extinction debt outcome, expressed as the proportion of biodiversity persisting. In the absence of specific land-use histories, such as the time since modification and intensive use of natural areas following patterns of settlement and other processes contributing to the loss of biodiversity for a patch of habitat, it is difficult to estimate accurately the amount of biodiversity that remains across a region at a particular point in time. Given this inherent uncertainty, a range of values is used to express the potential existence of biodiversity represented within a given region.

Developing the state of biodiversity indicators

Combining the principles of biodiversity measurement with the extant diversity framework, the following points guided development of the state of biodiversity theme of indicators:

- Marginal gains and losses in extant (existing) biodiversity can be calculated for a given point in time.
- Gains are attributed to area-based biodiversity conservation actions and their effectiveness, which can be ascribed to individual programs (see the indicator theme for ecosystem management, section 3.6). These gains can be used to infer the proportion of species 'represented'.
- Losses are attributed to changes in the extent of native vegetation or habitat degradation, determined for example from remote sensing of habitat condition and land-use mapping (see the indicator theme for ecosystem quality, section 3.5). These losses can be inferred from the proportion of species 'removed'.
- Representation of total biodiversity within a region or statewide is calculated using the complementarity principle, where species removed from an area may be represented elsewhere.
- Estimates of relative total extant diversity are applied to all species within a representative set or using a model of biodiversity (as a surrogate for that group). Both methods provide indicators for overall biodiversity and to fill knowledge gaps.
- In some cases, relative measures may be scaled to estimate total extant diversity by knowing or estimating what that total diversity (e.g. total number of species) is for a region using rarefaction methods (species accumulation curves) or other predictive models.
- The same suite of indicators and principles has the potential to be applied to ecosystems.
- Within-species genetic diversity can be inferred from species distributions (occupancy and range) applied to relevant taxonomic groups, as a proxy measure.
- A wide range of area-based contexts, or assessments, can be generated to investigate different aspects of representativeness, related to gains, losses and complex combinations.
- Direct monitoring of biodiversity (species and ecosystems) and biological surveys provide a foundation for modelling and predictive inference of biodiversity state.

Clearly there is no perfect indicator; a suite of indicators is necessary to fill knowledge gaps and there will be some overlap (portrayed by the green boundary nested within the red boundary in Figure 7). In making explicit this unavoidable redundancy, we acknowledge that two of the indicator families (family 2.1 and family 2.2) are not direct measurements of variety. The preferred data for measuring the variety of genes, species and ecosystems derives from comprehensive monitoring and survey of multiple aspects of biodiversity distribution and abundance in both space and time, and over many years. Indicators derived directly from field observations of species and ecosystems are therefore one of the three families in this theme. The other two are split by method: state of all known species applies representative sets of species, and state of biodiversity including undiscovered species applies GDM-based models (the surrogates approach). The field monitoring of species and ecosystems family provides important information that will, over time, improve the basis for estimating the parameters, such as the *z*-value used in the species–area relationship to predict the proportion of biodiversity persisting given the availability of suitable quality habitat.

3.2.4 Ecological integrity framework

Ecological integrity provides an overarching framework for integrating much of what we know and understand about how ecosystems work, which is fundamentally based on the dynamics of interactions among species and with the environment. Ecological integrity, alongside biodiversity, is a crucial focus of the BC Act and its measurement and reporting provide a means by which the broader achievements of biodiversity conservation can be assessed.

Figure 2 in section 1 presented a framework for ecological integrity. This framework brings together the five scientific requirements for ecological integrity indicators outlined in Table 8. The framework shows how measures of ecosystem quality and diversity combine to define the present state of ecosystems. Then, with the addition of effective management across all scales of action to facilitate the maintenance or enhancement of diversity and resilience among ecosystems, the capacity of the present ecosystem state to adapt to change can be estimated and ecological integrity reported.

The link between the present state of the ecosystem and its capacity to adapt represents a requirement for management response where remedial actions to enhance ecosystem quality are needed to avoid ecosystem degradation and collapse. Alternatively, maintenance objectives may apply where ecosystems retain sufficient adaptive capacity for integrity to be evident and resilient in the face of ongoing, and uncertain, environmental change.

In order to evaluate and report on the present state of ecosystems, incorporating both quality and diversity, assessment methods have been developed that initially investigate these separately. Indicators for ecosystem diversity are included in the biodiversity class of indicators, whereas indicators for ecosystem quality, management and resilience are included in the ecological integrity class. As explained in section 2, this is due to the different measurement objectives of the indicators.

Separate evaluation enables the state of different aspects of biodiversity to be assessed. For example, to evaluate the quality of ecosystems, attributes of local habitat (such as vegetation, or other primary supporting structures of an ecosystem) are typically monitored. Equivalent approaches also apply to monitoring habitat integrity in rivers, lakes and wetlands, and in marine systems. This monitoring is often coupled with assessment of diversity and abundance of resident species (the field monitoring family of biodiversity indicators). Accumulated ecological research over many decades provides theory and empirical data relating diversity and abundance of species to the quality of supporting habitats and environmental conditions (e.g. the PREDICTS project database compiled by Hudson et al. 2017). To quantify and report on outcomes for biodiversity across whole regions and more broadly (e.g. for a biological group of interest), models of present ecosystem quality and natural diversity (i.e. potential biodiversity distribution) can be derived separately and then combined to estimate amounts of biodiversity within a region or likely to persist for a given configuration of habitat remnants (see biodiversity indicator family 2.2).

Ecosystems with sound ecological integrity are well-placed to provide for the development and wellbeing needs of future (human) generations. To address uncertainty around the last requirement in Table 8, ecological integrity outcomes derived using models can be further explored using climate and land-use/management change projections and scenarios based on existing or alternate policy settings. Ecosystems presently in a near-natural state, require less management intervention to facilitate their adaptation to change. Their integrity is upheld. They are more likely to have retained essential intrinsic ecological mechanisms that can provide for the needs of future generations (Lavorel et al. 2015; Williams 2000). Degraded ecosystems, however, require more active management to enhance their quality and suitability to support the species underpinning critical ecological networks (interactions) and functions and so provide adaptive resilience in the face of global change (Prober et al. 2012). How to do this requires discussion across community and government to agree on a set of guiding principles supporting flexible adoption of adaptation actions by land managers, customised for each context (Prober et al. 2016, 2017a, b; Prober & Dunlop 2011). The development of indicators for ecological integrity may provide a mechanism for prioritising management interventions depending on the biodiversity value (e.g. irreplaceability) and success (e.g. likelihood of recovery) relative to costs and consequences.

With the incorporation of ecosystem diversity into the biodiversity class of indicators, three themes remain within the ecological integrity class: ecosystem quality (quadrant A of Figure 2), ecosystem management (quadrant C of Figure 2) and ecosystem integrity (quadrant D of Figure 2). The framework diagram (see Figure 2) and its arrows depict the nested relationship between the four indicator families showing how each indicator set provides information that becomes an input toward an increasingly comprehensive measure of ecological integrity and provides a predictive capability. That is, outputs from quadrant A bcome inputs to quadrant b. Outputs from quadrant A become inputs to quadrant C and outputs from quadrants B and C become inputs to quadrant D

Ecosystem quality

Reporting on ecosystem quality requires information about local habitat condition and the landscape context of surrounding pressures in which it is situated. Landscape context may directly or indirectly influence site-level habitat condition depending on the size, shape, isolation or connectedness with other habitat within a matrix of varying unfavourable conditions. Here the matrix refers to areas that have been cleared of native vegetation for other land uses such as forestry, agriculture and infrastructure; or the carrying capacity has been degraded in some way (e.g. salinisation, erosion, mine tailings). Information about how these component measures interact across the range of ecosystems in New South Wales is needed for ecosystem quality to fully account for suitable habitat and its carrying capacity for supporting viable populations of native flora and fauna. This requires a broader collation and integration of land information from multiple sectors and their interpretation in relation to ecosystem quality impacts. In order to understand why and where habitats are becoming degraded, we need this supporting information about land use, management practices and how they relate ecosystem response to disturbance regimes as indicators of proximal and distal processes driving land degradation and biodiversity decline. The most pervasive or locally intense pressures in New South Wales have been listed as key threatening processes (Schedule 4 of the BC Act) because of direct causal links to species extinction risk or ecosystem degradation.

Therefore, this theme consists of two families of indicators, habitat condition and pressures, that contribute to a suite of measures related to ecosystem quality and support attribution of cause and effect impacts (though note the link and inherent feedback with ecosystem management in Figures 2 and 4 in section 1).

Ecosystem management

Indicators in this theme use information about the effectiveness of local-scale conservation management actions, overarching conservation objectives and ecologically sustainable natural resource-use practices in general. Land-use and management practices that collectively strengthen regional ecosystem quality are more likely to maintain habitats, thus supporting retention of regional diversity (native plants and animals) and productivity through a sustained period of climate variability and environmental change. Information about management intent, land management responses and their effectiveness in maintaining or enhancing ecosystem quality and diversity are therefore essential inputs to a measure of ecological integrity. In this indicator theme we include all types of information relating to management for the conservation of biological diversity (i.e. responses in the RPSB framework, see Figure 4) which require an understanding also of the forces driving pressures (e.g. industry, tourism, economy) and the sustainability of development.

This theme consists of three families of indicators: management responses, management effectiveness and capacity to sustain ecosystem quality. The latter family integrates information about ecosystem management and ecosystem quality as shown in the ecological integrity framework (see Figure 2) and so builds toward a more complete measure of ecological integrity.

Ecosystem integrity

To comprehensively measure ecological integrity, we need to assess the capacity of ecosystems to retain biological diversity and ecological functions in the face of ongoing, yet uncertain, environmental change, including climate change and land-use change. In many instances, the natural association between species and their habitats, which are evident as ecosystems, will be disrupted and new associations will form. Monitoring of these changes and use of models to assess the spatial resilience of ecosystems over time will help inform policies determining what types of management response to invest in, where this should be concentrated and when it should be undertaken to make a difference. Ensuring ecosystem adaptation and resilience, through maintenance of ecological integrity and supporting biodiversity conservation in the context of a changing climate, are purposes of the BC Act.

This indicator theme aims for the integration and synthesis across other themes of biodiversity and ecological integrity and introduces the concept of ecosystem resilience in deriving an overall measure of ecological integrity. Two elements of resilience (as defined by Cumming 2011) are considered: i) local resilience, equated with the capacity of adaptive management to maintain and enhance the condition of ecosystems (from quadrant C in Figure 2), and ii) spatial resilience, equated with the spatial connectedness and diversity of ecosystems (from quadrant B in Figure 2). These two elements are combined to assess the capacity of ecosystems to retain biodiversity and ecological functions in the face of uncertain environmental change (quadrant D in Figure 2).

Indicators developed under this theme will enable estimation and reporting of past-to-present changes in ecosystem integrity (for an example applied to biodiversity, see Ferrier et al. in prep. and Hoskins et al. in prep.). These indicators will also allow scenarios of alternative land-use and management options to be evaluated in terms of expected consequences for adaptive capacity into the future. The indicators therefore apply either a plausible range of climate projections or land-use change scenarios driven by the balance between socio-economic demand and regulation.

This theme consists of two indicator families: capacity to retain biological diversity and capacity to retain ecological functions. Both families integrate across components of the ecological integrity framework (see Figure 2). These may evolve as component indicators are designed and tested, and scenarios, particularly of land-use change and impacts, are developed (e.g. the multi-scale scenarios for nature futures proposed by Rosa et al. 2017). Aspects of the approach developed by Drielsma et al. (2017) are likely to be adaptable to parts of this indicator. There is also potential, for example, to include novel measurement methods from field assessments that aim to track the diversity of ecosystems adapting to change (reported through indicator family 2.3).

Developing the ecological integrity indicators

Considering the components of ecological integrity (as outlined in the framework, see Figure 2) the following points guided the development of the three indicator families and their relationship with the biodiversity indicators:

- Present ecosystem quality requires information about site ecological condition and landscape context, including integrating what is known about pressures, including key threatening processes (e.g. clearing of native vegetation, climate change, a range of invasive species, and high frequency fire).

- The two component measures of ecosystem quality (site condition and landscape context applied through a measure of connectivity) combine to provide an estimate of effective ecosystem quality, also known as effective habitat area or availability (e.g. see Drielsma et al. 2012a; Neel et al. 2014; Sinha et al. 2014; Westaway et al. 2004). In this report, we call this integrated measure ecological carrying capacity.
- Present ecosystem diversity requires additional information about the natural variety of species in the absence of pressures (i.e. estimated from empirical benchmarks or modelling of original ecosystem diversity) and then combined with the measure of present ecosystem quality. This is reported through indicator family 2.2.
- The addition of information on landscape context and pressures supports estimation of biodiversity persistence (calculated in indicator family 2.2) by considering factors associated with extinction debt.
- Capacity to sustain ecosystem quality requires additional information about the appropriateness and effectiveness of local-scale management actions in response to what is known of pressures, and their relationship to drivers and impacts causing ecosystem quality decline, and preparedness to facilitate ecosystems adapting to change. This capacity is a form of local system resilience (following Cumming 2011).
- Capacity to maintain ecosystem diversity requires additional information about adaptive capacity such as through spatial resilience (Cumming 2011) addressing, in particular, the roles that spatial and environmental connectedness of habitat may play in facilitating persistence of biological diversity and ecological functions under climate change or other pressures.
- Information about management actions and objectives that integrate policy and operational response information provide a basis for developing and evaluating scenarios of management effectiveness and can be applied in models in terms of the benefits to biodiversity (following Drielsma et al. 2014) for evaluating change in ecosystem integrity into the future (e.g. Drielsma et al. 2017).

3.2.5 Summary of indicator themes

In summary, five indicator themes were identified as shown in Table 11.

Table 11 Indicator themes within the two indicator classes

Indicator class	Indicator theme
Biodiversity	1. Expected survival of biodiversity
	2. State of biodiversity
Ecological integrity	3. Ecosystem quality
	4. Ecosystem management
	5. Ecosystem integrity

The following sections describe the individual indicators within each theme and indicator family and allow for new or alternative indicators to be identified as knowledge and data grow and monitoring and assessment methods evolve.

3.3 Theme 1: Expected survival of biodiversity

Expected survival of biodiversity is a measure of the number of species or ecological communities we expect will still exist in 100 years and may be determined from their listed (indicator family 1.1) or provisional (indicator family 1.2) conservation status (i.e. extinction risk). It is the sum of survival probabilities (see Table 12) across biodiversity features (e.g. genes, species or ecosystems) where each has a probability of surviving until some future point (see section 3.2.2). For consistency with the *Saving our Species* program, we use expected survival in 100 years (OEH 2013).

Table 12 Survival probabilities of species and ecological communities by risk categories

Risk category	Probability (q) of survival in 100 years	
	Species	**Ecological communities**
Secure	0.95	0.95
Vulnerable	0.90	0.90
Endangered	0.30	0.65
Critically endangered	0.05	0.25
Presumed extinct (or collapsed)	0.01	– [1]

1. Probability not yet determined.

Overall reporting on expected survival of biodiversity indicators is limited to gain/loss (as a number or proportion, varying 0–1) statewide. This limitation is because extinction risk at the species or ecological community level is inherently assessed statewide, nationally or globally, depending upon the requirements of a jurisdiction and the extent of known occurrences. The indicators can be reported as single numbers or by extinction risk category and/or biological groups. Ecological communities could similarly be grouped and presented by higher levels of a hierarchical classification by biological group (e.g. assemblages of plants, fungi, vertebrates or invertebrates) or by location (e.g. known bioregional occurrence).

Expected phylogenetic diversity (PD), a measure of the amount of evolutionary history of threatened groups of species, is also addressed by this indicator theme.

3.3.1 Indicator family 1.1: Expected survival of listed threatened species and ecological communities

Threatened species and ecological communities are listed as presumed extinct, critically endangered, endangered, vulnerable or secure, as determined by the NSW Scientific Committee and published under Schedule 1 (species), Schedule 2 (ecological communities) and Schedule 3 (extinct species or collapsed ecological communities) of the BC Act. Secure species are those which have been assessed by the Scientific Committee and found not to fall within one of the extinction risk categories.

By expressing extinction risk in terms of expected diversity, using probabilities of survival assigned to each category, the indicator places categorical information on a common scale and simplifies the process of reporting and comparisons of change.

Three indicators are derived:

- indicator 1.1a: expected survival of listed threatened species
- indicator 1.1b: expected existence of listed threatened ecological communities
- indicator 1.1c: expected survival of phylogenetic diversity for listed threatened species.

At initial assessment, these indicators use the listed numbers of species or ecological communities. After five years, additional information about the effectiveness of management in reducing the extinction probability of a particular species (provided through the *Saving our Species* program or other source) will be used to update the probabilities. This is additional to determinations by the NSW Scientific Committee. A trajectory of change can also be derived using the history of determinations since 1995. Modelling of uncertainty is conducted to identify the likely range in values that may be applicable in making assumptions about the threatened status of species or ecological communities prior to their first listing.

Indicator 1.1a: Expected survival of listed threatened species

Overall expected diversity is calculated at the species level and summed for all listed threatened species. It is reported as the fractional number of species expected to survive in 100 years, with some estimate of uncertainty. It can also be presented as the proportion of species expected to survive for comparison with indicators in family 1.2. Over time, the indicator could go up or down, and losses (determined by the NSW Scientific Committee) may balance gains (from effective management to mitigate threats and secure populations in the wild).

The key cause of a gain in expected diversity is the documented effectiveness of on-ground management actions through one or more programs that protects a listed threatened species, so creating a change to a lower risk category for the purposes of calculating the indicator. Other changes follow the determinations of the NSW Scientific Committee. The indicator has the potential to summarise the information delivered by multiple programs under the BC Act and related acts (e.g. *National Parks and Wildlife Act 1974*) that specifically address the effectiveness of habitat management that promotes the viability of one or more threatened species.

To assist interpretation, supporting information would include tabulation of numbers of threatened species expected to survive by risk category and biological (i.e. taxonomic) group. A trajectory of values, developed using historical listing data, will be used to evaluate the trend, taking into account uncertainty in category assignment of listing data.

Indicator 1.1b: Expected existence of listed threatened ecological communities

This indicator is calculated in a similar way to 1.1a, allowing the expected diversity framework to be applied to ecosystems (ecological communities). The *Saving our Species* program has developed a similar process of identifying locations where successful management of threatened ecological communities implies a change in threat risk status (OEH 2017b). The expected existence of threatened ecological communities in 100 years is therefore also treated in much the same way as for species, with benefits accrued through effective on-ground management.

Indicator 1.1c: Expected survival of phylogenetic diversity for listed threatened species

This indicator is an extension of indicator 1.1a using relatively complete phylogenies, where these are available, or taxonomic hierarchies as a substitute (Faith 1994a, b). Initially, this indicator is limited to those groups with known evolutionary relationships, such as birds, mammals and frogs. It is anticipated these groups will be followed by lizards and snakes, and some families of flowering plants. The extinction risk category of all listed threatened species within the group is determined, as for indicator 1.1a. Other species in the group are categorised as not threatened (assumed ‘secure’). Each category is given a survival probability as described previously.

Phylogenetic diversity (PD) is calculated from a phylogenetic tree and is the sum of branch lengths in millions of years connecting a set of species to the rest of the tree (Faith 1992). Thus, PD captures information on both species' richness and evolutionary distinctiveness. Following Witting and Loeschcke (1995), we can calculate the expected loss of PD as:

$$\mathbb{E}[\Delta PD] = \sum_j^T \left[L_j * \prod_i^{S_j} p_i\right] \qquad \text{equation 5}$$

where T is a phylogenetic tree connecting S species and L_j is the length of each branch segment (connecting nodes in the tree). A branch will be lost only if all members of the subset of species descended from it (S_j) are lost and thus the probability of losing a branch is the product of the extinction probabilities of descendent species.

If combined with the locations in which threatened species live, this indicator can be a measure of irreplaceable biological distinctiveness. A declared area of outstanding biodiversity value (under the BC Act) that makes a significant contribution to the persistence of irreplaceable biological distinctiveness will therefore also contribute to an improvement in the expected phylogenetic diversity surviving in 100 years.

This approach is consistent with globally accepted phylogenetic criteria for prioritising among threatened species (Faith 2016a, b; Mooers et al. 2008 and references within) and has been proposed for Australia by Laity et al. (2015). It matches that suggested for Key Biodiversity Areas in referring to an area that makes a significant contribution to the persistence either of multiple species or irreplaceable biological distinctiveness (IUCN 2016a). The criterion of 'a large increase in expected (phylogenetic) diversity' is also the revised criterion for global priority setting for threatened species (the EDGE program; see Faith 2008 and Nunes et al. 2015). With regards to threatened species priority setting, priorities might change for some threatened species if the gain in expected diversity due to effective management is even larger when calculated as a gain in phylogenetic diversity.

3.3.2 Indicator family 1.2 Expected survival of all known and undiscovered species

This indicator family predicts extinction risk of all biodiversity (both known and undiscovered species), beyond those formally assessed by the NSW Scientific Committee, to address gaps in knowledge related to both biodiversity discovery and conservation concern (see Figure 1). Different measurement methods apply to comprehensively assess biodiversity using a common risk framework and to minimise sampling bias. Those methods are:

- representative species sets, as an indicator for all known species (within a taxonomic group)
- a model of biodiversity (e.g. using GDM), as an indicator for all known and undiscovered biodiversity (within a taxonomic group).

To generalise the application of the expected diversity framework beyond the limited set of listed threatened species and ecological communities, an approximated extinction risk assessment is undertaken using the IUCN Red List criteria B2 and B2(b)(ii) (IUCN 2017, see Table 13). The IUCN method for defining area of occupancy (AOO) is adopted in the case of representative species sets or adapted to work with a model of biodiversity. The habitat condition family of indicators 3.1 support this assessment by providing information about the reduction in habitat extent or quality, to infer continuing decline (criterion B2(b) in Table 13).

Table 13 Criteria for assessing conservation concern using B2 and B2(b)(ii)

Adapted from the IUCN Red List (see Table 2.1 in IUCN 2017). AOO = area of occupancy, defined as the 2-kilometre grid cells containing species occurrence records. EOO = extent of occurrence, defined as the minimum convex polygon enclosing the AOO. For comprehensive assessment of risk, additional considerations apply (a, b, c). EX = extinct; CR = critically endangered; EN = endangered; VU = vulnerable

Equivalent Red List criteria	CR	EN	VU
B2. Geographic range in the form of area of occupancy (AOO)	<10 km^2	<500 km^2	<2000 km^2
And at least two of the following three additional criteria:			
(a) Severely fragmented or number of populations	=1	≤5	≤10
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence (EOO), (ii) area of occupancy (AOO), (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) extent of occurrence (EOO), (ii) area of occupancy (AOO), (iii) number of locations or subpopulations; (iv) number of mature individuals			

The indicator can inform trends but does not replace rigorous risk assessments for each species informing listing processes specified under regulations. The degree to which generalised indicators can provide meaningful information for individual species will depend on the rigour applied to individual species' records in preparing the data for use.

Expected survival of all known and undiscovered species includes two indicators:

- indicator 1.2a: expected survival of all known species
- indicator 1.2b: expected survival of all known and undiscovered species.

Indicator 1.2a: Expected survival of all known species

For this indicator, a representative sample of species is derived from each of the taxonomic groups of interest to be assessed, applying the method outlined in section 3.2.1. The initial group is vascular plants. The representative sample of species may also include listed threatened species, but for this analysis all taxa are treated equally. For a species to be selected for inclusion in the representative set it must also have at least three occurrence records in New South Wales observed since 1950.

The original extent of suitable habitat is defined by the occurrence records observed since 1950 applied to a 2-kilometre grid across New South Wales. The intact extent of suitable habitat is determined from ecological condition (indicator 3.1a, see section 3.5.1). This information provides an estimate of the (intact) AOO of each species through its range. The AOO is calculated for a species as the sum of its grid cells, where each cell is weighted by the fractional loss of suitable habitat (from indicator 3.1a) and is related to criterion B2 in Table 13. Where there has been a significant reduction in the original 2-kilometre gridded extent of suitable habitat, the AOO is used to infer extinction risk, otherwise species are categorised 'not threatened' for the purpose of this indicator. Significant reduction in AOO is assessed in four classes measured by the proportion of the original AOO remaining (<30%, 30–50%, 50–80% and >80%, adapted from criterion A of the IUCN Red List of Ecosystems) and is related to subcriterion B2(b)(ii) in Table 13. These classes and the AOO thresholds provide the dimensions of a simple extinction risk categorisation similar to that of listed threatened species. Each category is given a probability of survival in 100 years which is applied to all representative species in that category. The analysis of AOO proportion remaining is applied at the finer gridded resolution of the ecological condition indicator 3.1a.

We can then apply the calculation of expected diversity. The representative species in each taxonomic group that do not meet a provisional risk status are given the corresponding probability of extinction (extinction = 0; viability = 1). The expected survival of known species is derived from the sum of extinction probabilities for both the provisionally at risk of extinction and other (assumed secure) species comprising the representative set. The indicator is reported as a proportion of the total number of species in the representative set, as an indicator of the overall extinction status for all the species in that biological group. By extension, it can be reported as a number by scaling up the total number of species known from that group, or as the number of species (including those yet to be discovered) using rarefaction methods or rates of species discovery (Chao et al. 2014).

Indicator 1.2b: Expected survival of all known and undiscovered species

This indicator adapts the AOO (B2) thresholds in Table 13 for use with a model of biodiversity to estimate the number of inferred species potentially assigned to each category of extinction risk. The model of biodiversity is used to identify a nominated number of locations of interest that evenly span the species diversity predicted for that taxonomic group. For each location of interest, the extinction risk thresholds are used to estimate the number of inferred species (centred at that location of interest) that notionally fall into each category. For example, using the threshold for highest risk (AOO <10 km^2 from CR in Table 13), we find the set of N cells predicted to be most similar in species diversity to the location of interest, where N is defined as the number of grid cells that total 10 km^2. The ecological distance to the N^{th} cell from the location of interest is a measure of how different they are in predicted species diversity. (Ecological distance is defined by a GDM of compositional differences in species between pairs of locations as a function of their environmental distances.) This ecological distance provides a relative measure of how many species are provisionally at highest risk of extinction. We repeat this process for other risk thresholds (i.e. AOO < 500 km^2, AOO < 2000 km^2), noting that the ecological distance to the N^{th} cell is the total estimate of, relatively, how many species are below the threshold. The difference in numbers between successive risk thresholds informs, relatively, how many species are provisionally in that risk category (highest <10 km^2; higher <500 km^2; lower <2000 km^2). The relative numbers are scaled 0 to 1.

The provisional calculation assumes all potentially suitable habitat cells (the locations on a grid) could contribute to the AOO of a species. The provisional categories can be assigned a notional extinction risk if also associated with habitat loss (related to subcriterion B2(b)(ii) in Table 13). Using ecological condition indicator 3.1a, this requirement is met if at least 30% additional grid cells are needed to meet each AOO risk threshold (30% as a minimum is adapted from criterion A of the IUCN Red List of Ecosystems). If the decline is less than 30%, the relative number of inferred species provisionally associated with that category are considered at lowest risk. The number of grid cells needed to meet the intact AOO threshold for each category, and therefore the ecological distance to the N^{th} cell (relative inferred number of species), is increased. For each extinction risk threshold (highest to lower and including lowest – not meeting minimum 30% decline threshold), the updated distance to the N^{th} cell and the relative number of inferred species is recorded, and the process repeated for each location of interest.

The expected diversity framework is then applied, that is, each risk of extinction category (equated with the intact AOO thresholds in Table 13) is given a probability of survival (Table 12) which is applied to all sets of locations in that category. The results for each location of interest are summed as the indicator value.

3.4 Theme 2: State of biodiversity

This indicator theme measures, directly and indirectly, the overall amount of biodiversity (genes, species and ecosystems) that currently exists. These measures also take into account likely future loss of biodiversity due to the impact of extinction lag (see sections 3.1.1 and 3.3.4). They encompass estimates of known and undiscovered biodiversity and measures at genetic, species and ecosystem scales. This theme also encompasses analyses of trends of species and ecosystems from long-term or wide-ranging field monitoring studies.

3.4.1 Indicator family 2.1: State of all known species

This indicator family includes two indicators that measure the proportion of original total species diversity and associated genetic diversity that currently exists. The method uses representative species sets (section 3.2.1). Habitats vary in their capacity to support biodiversity, and these indicators show how well current patterns of suitable habitat support the original complement of species and their genetic diversity within a taxonomic group at the site scale (grid cells). The ecological condition indicator 3.1a supports this analysis.

For consistency with indicator 1.2a, which also uses representative species sets, these indicators apply the IUCN method of defining area of occupancy (AOO) to species' occurrence records. The results can then be used with indicator 1.2a, as supporting information, to report more generally on species and genetic diversity using the same representative species sets.

The two indicators are:

- indicator 2.1a: within-species genetic diversity (for all known species)
- indicator 2.1b: extant area occupied (for all known species).

Indicator 2.1a: Within-species genetic diversity (for all known species)

This is an extension of indicator 2.1b and assesses the proportion of within-species genetic diversity that still exists, after considering loss of suitable habitats. The rationale for using proxy methods to measure genetic diversity is outlined in section 3.2.1.

This indicator uses reductions in environmental range associated with a species occupancy (applied in 2-kilometre grids), due to declines in habitat condition (using indicator 3.1a), to calculate adaptive genetic diversity and direct reductions in area of occupancy (using AOO) to calculate neutral genetic diversity. For each AOO, the environmental range is determined from a model of biodiversity for that group (e.g. using GDM to biotically scale environmental space). A power curve then relates the intact fractions of a species' environmental range and AOO to the respective fraction of genetic diversity remaining. Two forms of the curve are used: one that simulates high genetic diversity due to high rates of population divergence, and the other low genetic diversity. The two curves equate to an upper and lower estimate of fractional within-species genetic diversity and signify population health risk. The calculation could be repeated using indicator 3.1c, and so provide a range of values based on uncertainty in the estimation of a landscape's capacity to support its original within-species genetic diversity. Because neutral and adaptive diversity overlap, the two forms of within-species genetic diversity are not additive. Both are reported. Neutral genetic diversity is calculated in the first instance, while methods are tested and modified to additionally calculate adaptive genetic diversity.

This indicator is reported along with indicator 2.1b as supporting information for indicator 1.2a.

Indicator 2.1b: Extant area occupied (for all known species)

This indicator assesses the extant area occupied by all known species, as a proxy for diversity, after considering loss of suitable habitats. Reductions in AOO are assessed using the ecological condition indicator 3.1a. The intact range extent is the sum of the species' original grid cells, where each has been weighted by its ecological condition. The fractional range extent is calculated for each species in the representative set and summed to give an overall statewide estimate. The calculation could be repeated using indicator 3.1c, and so provide a range of values based on uncertainty in the estimation of a landscape's capacity to support its original diversity.

The indicator is reported as the proportion of the extant area for species in the representative set, as an indicator of the overall status for all the species in that biological group. It is reported along with indicator 2.1a as supporting information for indicator 1.2a. By extension, it can be reported as a number by scaling by the total number of species known from that group, or by the number of species including those yet to be discovered using rarefaction methods or rates of species discovery (Chao et al. 2014).

3.4.2 Indicator family 2.2: State of biodiversity including undiscovered species

This indicator family includes three indicators that use a model of biodiversity (principally GDM) to estimate genetic, species and ecosystem diversity. All measures are presented as a range of values to account for the uncertainty in estimation. Those ranges are derived from using two alternative indicators of ecosystem quality (3.1a and 3.1c) and by varying the parameters used in power curves that relate diversity (genetic or species) to the extent of suitable habitats or environmental range. The resulting measures account for the potential existence and persistence of biodiversity represented within a region. The complementarity principle is applied in calculating relative amounts of biodiversity retained (e.g. within a bioregion) or conserved (e.g. within national parks).

The three indicators are:

- indicator 2.2a: within-species genetic diversity (including undiscovered species)
- indicator 2.2b: persistence of all species (including undiscovered species)
- indicator 2.2c: persistence of ecosystems (including undiscovered species).

Mapped ecosystem boundaries, such as New South Wales landscapes (Mitchell 2002; OEH 2017c) and plant community types (OEH 2017d) are reported through the habitat condition family of indicators (section 3.5.1). They can also be used as context for reporting on all biodiversity, along with conservation areas provided through the management response indicator family (section 3.6.1).

Indicator 2.2a: Within-species genetic diversity (including undiscovered species)

This indicator estimates the proportion of within-species genetic diversity that may still exist and is potentially likely to persist, after considering loss of suitable habitats and the effects of fragmentation (from ecosystem quality indicators 3.1a and 3.1c, respectively). It is an extension of the surrogates approach to indicator 1.2b, using a model of biodiversity, and considers both neutral and adaptive forms of genetic diversity. The rationale for using proxy methods to measure genetic diversity is outlined in section 3.2.1.

The analysis is conducted for a sample of locations that represent, in a balanced way, the full range of natural habitats based on the model for that biological group (e.g. using GDM). At each location the model uses environmental distances to predict the relative numbers of species potentially existing within different AOOs. For consistency with indicator 1.2b, the same methods of defining AOO and thresholds are used.

Reductions in AOO due to declines in habitat condition (e.g. changes in the extent of native vegetation) are determined from the ecological condition indicator 3.1a. Further reductions in carrying capacity due to fragmentation restricting connectivity with surrounding suitable habitat are determined from the ecological carrying capacity indicator 3.1c. Reductions in AOO are equated with fractions of the original environmental range occupied (determined from the GDM) for estimating adaptive genetic diversity. Areal reductions in AOO are also used directly as fractions of the original AOO extent for estimating neutral genetic diversity. At each location of interest, the model predicts the relative numbers of species originally existing and the reduction for each AOO threshold.

A power curve then relates the intact fraction of each AOO threshold to the fraction of neutral genetic diversity remaining, and another relates the fractions of the original environmental range based on its AOO to fractions of adaptive diversity remaining. In each case, two forms of the curve are used: one that simulates high genetic diversity due to high rates of population divergence, and the other low genetic diversity. These equate to upper and lower estimates of fractional within-species genetic diversity and signify population health risk. The neutral and adaptive components of genetic diversity are multiplied by the relative numbers of species inferred in each case. Because neutral and adaptive diversity overlap, the two forms of within-species genetic diversity are not additive. Both are reported. Neutral genetic diversity is calculated in the first instance, while methods are tested and modified to additionally calculate adaptive genetic diversity.

This indicator is reported as supporting information for indicator 1.2b. The approach used in the estimation of within-species genetic diversity may evolve as alternative model-based inference methods are explored and adapted.

Indicator 2.2b: Persistence of all species (including undiscovered species)

The indicator employs a GDM of biodiversity to summarise how the species found at different locations vary with changes in environmental variables (such as climate, soils and landform) for a particular biological (usually taxonomic) group. The GDM interpolates across all sites using environmental variation mapping, including across locations without survey data, and so accounts for poorly known and undiscovered species. The model predicts the biological similarity between sites, that is, the proportion of species shared, assuming all the sites are high-quality natural areas able to support their original complement of species. Biological similarity varies continuously between 1 (all species are the same) and 0 (all species are different). The rationale for using models is outlined in section 3.2.1. The same model is used in other relevant indicators for that biological group (for example, including the method used to select representative species sets, see section 3.2.1).

The resulting model of biodiversity is used to estimate the species diversity retained, given the remotely sensed change in the ecological condition and carrying capacity of habitat (indicators 3.1a and 3.1c, respectively). The effective proportion of suitable habitat remaining for each individual, same-sized grid cell within a region is calculated as a weighted average of habitat condition in all cells that are biologically similar to the cell of interest from the model of biodiversity. The weighted average is an average resulting from the multiplication of each component by a factor reflecting its importance. The proportion of habitat remaining within a given region is converted to the proportion of species originally occurring there, that are expected to persist into the future, by assuming no change to that habitat condition over the longer term. This projection is performed using the species–area relationship (see section 3.2.3) which determines, from the effective area of a patch of habitat, the number of species expected to be found there. A further statistical model of the predicted number of species originally occurring in each location sets a maximum value for the estimate of species numbers. It is derived from the counts of species at a site (from the same systematic survey data of species' co-occurrences) and their associated environments.

The resulting indicator measures the proportion of inferred total species diversity at each location or grid cells that is projected to persist locally into the future as 0 (no naturally occurring species are expected to persist), a fractional value representing the proportion of the original species persisting, up to a value of 1 (all native species originally occurring are expected to persist into the future). The indicator can be reported for any geographic domain (e.g. all of New South Wales, protected areas, each bioregion, each landscape, each regional ecosystem) by taking into account the similarity in co-occurring species predicted to be shared between spatial (i.e. map) units. For example, this indicator can be reported by protected areas to infer the proportion of total species diversity represented under conservation management. The values for each spatial unit are individually calculated and so, because of shared species, the resulting whole does not equal the sum of the parts.

Indicator 2.2c: Persistence of all ecosystems (including undiscovered species)

This indicator assesses the expected persistence of species diversity as a function of the proportion of habitat remaining in ecosystems given the remotely sensed change in the ecological condition and carrying capacity of habitat (from indicators 3.1a and 3.1c, respectively). It is a variant of indicator 2.2b and uses the same GDM, which is extended to a classification to approximate the extent and variety of ecosystems in New South Wales for a given biological group of interest.

Ecosystems are defined as classification units derived from a model of biodiversity (using GDM). A systematic and hierarchical classification of predicted species diversity from this model is used to derive patterns of ecosystem diversity for a specified number of classes (e.g. 100 across New South Wales). The actual number of ecosystems derived from a classification of the model can be varied depending on the requirements of the application. The model also predicts the pattern of biological similarity (i.e. proportion of species shared) between each ecosystem class and every other class. A classification tree, or dendrogram, shows the class structure and its relationships through shared species, illustrated by equating similarity with colours on a map. These patterns of ecosystem diversity and between-class biological similarities initially assume that all habitats are high-quality natural areas able to support the original complement of species within all ecosystems. A further statistical model (using kernel regression) assigns each class a probability value varying from 0 (definitely not in that class) to 1 (an exact match to that class) to each grid location. The probabilities represent varying levels of confidence in a location's assignment to a distinct class of ecosystem diversity.

The resulting classified model of biodiversity is used in the calculation of the proportion of species within each ecosystem that may still exist, after considering declines in habitat condition determined from indicator 3.1a. The proportion likely to persist after considering further reductions in carrying capacity due to fragmentation restricting connectivity with surrounding suitable habitat is determined from indicator 3.1c. The species–area relationship uses the amount of habitat available to predict the proportion of component species within ecosystems to persist into the future, taking into account their complementarity and irreplaceability (i.e. the inability to be replaced, often because of uniqueness).

The resulting statewide indicator measures the expected persistence of species diversity as a function of the proportion of habitat remaining in ecosystems. In addition, each grid cell is given a value reflecting its statewide contribution to the amount of biodiversity projected to persist, for the biological group of interest, when the cell is viewed in isolation. It is calculated as the amount of biodiversity lost relative to the statewide indicator immediately following hypothetical removal of all natural habitat in that cell. The individual cell values can be summed across various domains, such as bioregions. However, due to a complement of species shared among ecosystems between cells, which is accounted for in the statewide indicator, a simple sum of individual cell values does not equal the statewide indicator. In locations or grid cells with a value of 0, all originally occurring ecosystems and their component species have already been lost (in ecological terms, collapsed). Fractional values represent both the cell's condition and how irreplaceable it is to the maintenance of diversity within and between ecosystems. A value of 1 indicates that the cell represents unique types of diversity.

The indicator can be reported for any geographic domain (e.g. all of New South Wales, conservation areas, each bioregion, each landscape, each regional ecosystem) by also taking into account complementarity in the class relationships (similarity through species shared) among ecosystems within and between regions. For example, this indicator can be reported by protected areas to infer the proportion of total species diversity represented within ecosystems under conservation management. The values for each region are individually calculated and so, because of complementarity in shared species between ecosystems, the resulting whole does not equal the sum of the parts.

3.4.3 Indicator family 2.3: Field monitoring of species and ecosystems

Data collected from field surveys and site monitoring are critical for biodiversity assessment in three primary ways:

- to generate and validate models of biodiversity based on records of occurrence
- to develop case studies that demonstrate what the results of model outputs might look like on the ground
- as stand-alone indicators of biodiversity that demonstrate trends in the extent, abundance or number of native species (indicator 2.3a) or ecosystems (indicator 2.3b).

Indicators based on a strategic selection of time-series data showing trends in representative populations of species or ecosystems support a 'multiple lines of evidence' approach and allow the results to be scaled spatially and thematically. There is also potential to extend site monitoring data collection protocols to include components of genetic diversity, for example through novel application of metagenomics, as methods and technologies evolve.

OEH and its partners have invested in long-term datasets that show temporal trends in biodiversity and trends in response to pressures or management. These studies will be examined for their suitability to contribute to the first assessment report and will initially be presented as a series of case studies. Although these case studies will not be fully representative of all NSW biodiversity, there are sufficient time-series data available in select studies to support informative insights into important biodiversity trends and their drivers in some key ecosystems of New South Wales (e.g. woodlands, river red gum forests, alpine systems, heathlands, wetlands). Some of these species and ecosystems may not be explicitly represented in other indicators that use remote sensing or statistical modelling approaches. Incorporating field-based monitoring studies is an important component of the suite of indicators supporting the BC Act and helps to demonstrate the link between these other indicators and on-ground activities.

Another advantage of using field-based monitoring results is that they reflect observations of species or places that the public care about and relate to. Thus, they are also important as the basis of communication products.

Selection of existing field monitoring datasets will be based on a number of criteria, including:

- their public accessibility, length of historical time series and likelihood of ongoing collection
- statistical confidence that trends in the data can be detected and explained

- that the taxa/ecosystems within them are good indicators of biodiversity, that is, they are either keystone species, sensitive to changes or perform an important ecological function (e.g. pollination), or are representative of their type
- that the taxa/ecosystems within them are not likely to be well-represented or sampled by remote sensing or ecological modelling methods used in other indicators
- that the taxa/ecosystems within them are of interest to the general public and stakeholders and help inspire personal connections with nature
- that the taxa/ecosystems within them fit into or fill gaps in OEH's environmental monitoring assessment and reporting and the essential biodiversity variables framework.

The most sensitive studies of change are designed to make strategic comparisons by using consistent sampling methods, by sampling frequently and regularly, as well as directly measuring response variables (see Lindenmayer & Likens 2010; Lindenmayer et al. 2013). While these datasets will be used directly as indicators in the short term, it is envisaged that they will also be incorporated into other indicators to support interpretation of remotely sensed data and modelling to understand, for example, the relationship between management actions and biodiversity responses.

Some of the studies may be reported more appropriately through the management effectiveness indicator family (e.g. the impact of grazing regime on threatened species populations) or through the Pressures indicator family (e.g. change in incidence or abundance of invasive plants). Each monitoring project would need to be assessed for its best placement in the indicator framework. Some may contribute data relevant to several families and inform cause and effect relationships.

Two biodiversity indicators are proposed within which different studies may be reported:

- indicator 2.3a: species trends
- indicator 2.3b: ecosystem trends.

Indicator 2.3a: Species trends

This indicator assesses trends in the extent, abundance or number of native species measured from long-term or wide-ranging field monitoring programs.

The indicator for each location is the species abundance or other performance metric (such as yield, fecundity) and associated environmental conditions. Change in the value of the indicator reflects a statistically significant trend in species abundance or other performance metric (such as yield, fecundity) attributed to anthropogenic factors (pressures or management), after taking into account natural environmental variation.

Indicator 2.3b: Ecosystem trends

This indicator assesses trends in the extent, abundance or number of native ecosystems measured from long-term or wide-ranging field monitoring programs.

The indicator for each location is the relative abundances of all species within an ecosystem (within or between biological groups) or other performance metric (such as species compositional turnover) and associated environmental conditions. Change in the value of the indicator reflects a statistically significant trend in community dynamics or species composition attributed to anthropogenic factors (pressures or management), after taking into account natural environmental variation.

3.5 Theme 3: Ecosystem quality

Reporting on ecosystem quality requires information about local habitat condition, landscape context and exposure to pressures that threaten biodiversity. Landscape context relates to the size, shape and quality of habitat to which a site belongs; and to the site's isolation or connectedness with surrounding habitat as well as sources of pressures. The most pervasive or locally intense pressures in New South Wales have been listed as key threatening processes (Schedule 4 of the BC Act) because of direct causal links to species' extinction risk or ecosystem degradation or collapse. High-resolution, multi-sensor satellite and aerial surveillance are used increasingly for widespread, monitoring of landscape change. We consider two families of indicators separately (habitat condition and pressures) and describe how they contribute toward a measure of ecosystem quality.

3.5.1 Indicator family 3.1: Habitat condition

A necessary step for biodiversity and ecological integrity indicator development is the scaling up (to whole bioregions and statewide) of site-based measures of vegetation condition using satellite remote-sensing data and modelling. To support decisions about the readiness levels of new remote-sensing products, Donohue et al. (2016) undertook a brief review of suitable data for use in biodiversity habitat condition modelling. That review considered the contribution remote sensing can make to assessments of vegetation structure, function and composition, and included recommendations for novel ecosystem function indicators (see indicator 3.1d, below). For the purpose of indicator development, we broadly define habitat condition as being related to the capacity of an area to provide the structures and functions necessary for the persistence of all interacting species naturally expected to occur there in an intact state.

While alternative approaches are under development and being compared, an initial pragmatic assessment of ecosystem quality, using native vegetation extent and land-use mapping derived from remote sensing and field observations, is being developed with minimal assumptions embedded in heuristic tools, to ensure transparency and avoid confounding interactions (Drielsma et al. 2012b). This will be followed by concurrent development of modelling using site data applied to individual condition attributes (McNellie et al. 2015) and to condition assessment scores (Harwood et al. 2016). All three approaches are being developed in tandem and integrated to provide multiple lines of evidence. An interdisciplinary group of collaborators is guiding the process of continuous improvement toward reliable, validated, consistent measures of vegetation condition for ecosystem quality determination.

Habitat condition includes four indicators:

- indicator 3.1a: ecological condition of terrestrial vegetation
- indicator 3.1b: ecological connectivity of terrestrial vegetation
- indicator 3.1c: ecological carrying capacity of terrestrial vegetation
- indicator 3.1d: ecosystem function of terrestrial vegetation.

Ecological condition 3.1a is one of the most important indicators in the framework due to its use in the biodiversity indicators to estimate habitat losses and it is a foundation dataset in the ecological connectivity 3.1b and ecological carrying capacity 3.1c indicators. It complements ecological carrying capacity 3.1c, which incorporates the connections with surrounding suitable habitat and considers the effects of fragmentation on habitat condition. These indicators provide a general interpretation of the dynamics and change in habitat condition and functions through the capacity of habitats to support their original complement of species and are not designed for application to any particular species or ecosystem.

The concept of effective habitat area is relevant to these indicators. Effective habitat area (EHA) is defined as the proportion of residual habitat quality at a site following the impacts of habitat loss, degradation and fragmentation at the site and in its neighbourhood. It can be calculated using any of the three habitat condition indicators 3.1a–c. Protecting a single area or areas that is/are already in good condition and which is not threatened in any way will not change the EHA, either in the short or long term. However, when accounting for or assuming (through scenario analysis) the presence of pressures that can be confidently mitigated through effective management, the averted biodiversity loss can be included in the estimate of future outcomes and this can be applied through the biodiversity indicators 2.2b and 2.2c. Change in habitat condition may be detected locally through site performance monitoring, although changes to EHA across New South Wales will only be detectable when many multiple local changes become evident across whole landscapes and statewide. EHA therefore evaluates the context around the site, not just the site itself. Remote sensing and modelling support scaling up from individual sites to whole regions and statewide.

At the site level of habitat condition measurement, the aspiration of a reference condition state is one in which the ecological mechanisms and processes underpinning ecosystem function are effective with minimal intervention. This includes capacity to retain regional complements of native species and their interactions in all the forms (living and dead) that collectively provide habitat structure, ecological resilience and integrity. The aspiration of a reference state to aim for in maintaining or enhancing ecosystem quality requires consideration of how ecological systems interact dynamically with climate and management legacies (Prober et al. 2013; Smith et al. 2012; Smith et al. 2013), and may include concepts of states and transitions (e.g. McIntyre & Lavorel 2007; Lavorel et al. 2015). The habitat condition indicators therefore naturally interact with the ecosystem management theme of indicators for reporting. Interpretation and attribution of broad areas of change detected through the habitat condition indicators is supported by the pressures family of indicators (section 3.5.2 below).

Habitat condition indicators for freshwater, coastal and marine ecosystems can be described using the four indicators listed above for terrestrial ecosystems. For some bioregions, the habitat condition indicators (and methods for derivation) are well-established due to existing biodiversity information programs (direct measures) and subsequent modelling (indirect measures) to help extrapolate across the bioregion. For example, data from past field monitoring programs have been used to directly report and/or infer the condition of inland and coastal rivers using OEH's aquatic biodiversity forecaster (see Turak et al. 2011) and the NSW Department of Primary Industries River Condition Index (Healey et al. 2012). A similar example for the habitat condition of many bird species can be derived from field data collected in OEH's estuary health monitoring program and associated indirect measures of catchment, hydrodynamic and ecological response models.

Indicator 3.1a: Ecological condition of terrestrial vegetation

Ecological condition of terrestrial ecosystems is the integrity of native vegetation, measured at a site level, as its departure from appropriate structural, functional and compositional benchmarks (dynamic reference state/s). Ecological condition indicates the ability of a site's habitat to support biodiversity to its full potential, without considering the beneficial or detrimental influence of neighbouring sites.

This indicator integrates site-level observations of vegetation condition with remote-sensing data and other land information to predict ecological condition across all sites.

At the site level, observed levels of ecological condition are measured, ideally using the vegetation integrity method developed for terrestrial biodiversity assessments (OEH 2017a), or are consistent with this concept of vegetation condition. Vegetation integrity is defined as the condition of native vegetation assessed for each vegetation zone against the benchmark (reference state/s) for its plant community type. There are 17 field attributes that are easily observed on the ground are equated with aspects of native vegetation structure, function and composition (see Table 14). A quantitative measure of condition, the vegetation integrity score, determines how the 17 field attributes are combined (see equation 15 and 16 in OEH 2017a). The score ranges from 0 (maximum departure from the benchmark) to 1 (most like the benchmark). Most vegetation surveys collect data equivalent to the vegetation integrity attributes, allowing condition scores to be derived from existing survey data and verified for currency.

Table 14 Ecosystems features of vegetation integrity observed and measured at the site level, as details in the *Biodiversity Assessment Method* (OEH 2017a)

Ecosystem feature type	Measurement variable
Structure	Foliage cover by six plant growth forms: • tree • shrub • grass/like • forb • fern • other, such as, palms, vines, tree ferns, cycads
Composition	• number of native plant species observed present (i.e. richness) by six growth forms • exotic plant cover (high threat across all strata)
Function	Surrogate measures (structural attributes) for function in treed systems: • number of large trees • tree stem size diversity • tree regeneration • length of fallen logs • litter cover

Many other state agencies across Australia have adopted similar measurement standards, customised to meet their requirements for managing native vegetation (e.g. Crossman & Smith 2006; Eyre et al. 2015; Harvey & Keighery 2012; Michaels 2006).

Over the next two years, OEH will be improving how it uses satellite and aerial remote-sensing and other data to reliably correlate and interpolate locally measured vegetation condition. Taking a systematic and comprehensive approach to vegetation integrity assessment across New South Wales will involve employing site observations to calibrate remote sensing and interpolate condition more precisely. Vegetation condition assessment and modelling is a developing field of science that is maturing rapidly with the availability of longer time series remote-sensing and site-observation data (Lawley et al. 2016; Harwood et al. 2016; Tehrany et al. 2017).

Three complementary approaches (or methods) are being developed:

(i) integrating data and expert opinion in a heuristic classification of various sources of vegetation cover and land-use data to infer a condition score (e.g. Amis et al. 2007; Bohnet et al. 2011; Dillon et al. 2011; Drielsma et al. 2012a; Newbold et al. 2015; Williams et al. 2010)

(ii) using statistics to model individual vegetation integrity attributes compared with their benchmarks and then derive condition scores (Cunningham et al. 2009; Kocev et al. 2009; McNellie et al. 2015; Newell et al. 2006)

(iii) applying statistics to correlate the relationships with environment and calibrate to predict the remote-sensing distance from intact reference locations (like benchmarks) (Cunningham et al. 2009; Harwood et al. 2016; Kocev et al. 2009).

The first of these methods is being developed for the first assessment report using a grid of locations approximating 90 metres. At each grid cell, ecological condition will be measured as an index ranging from 0 (the maximum departure from a benchmark) to 1 (intact vegetation that supports biodiversity to its full potential). The results will be verified and improved iteratively as new field observations of condition and remote-sensed data become available. Each of these methods variously use remote-sensing data directly, or data derived from remote sensing, such as land-use and land-cover mapping.

The habitat condition assessment system method (HCAS, see Harwood et al. 2016) is a novel approach to environmental modelling designed to work with sparse site data to calibrate remote sensing applied across large areas. The method works in joint environmental and remote-sensing space to allow comparison between good and poor condition sites. It partitions variation due to environment and so does not require vegetation to be classified. The approach uses the remote-sensing signature of a reference site with known best-attainable condition (equivalent to vegetation benchmarks) which is compared to the signature of a test site in a similar physical environment. The difference in the remote-sensing signatures of the two sites provides an indication of the condition of the test site. The approach allows habitat condition to be modelled and interpolated across large areas, given a representative sample of reference-condition training data. Repeat assessments using different temporal epochs of remote-sensing data enable change to be compared. A more dynamic approach to condition assessment, for example, spatial-temporal modelling, would be more accurate for change detection, but requires extensive research and development to assess feasibility and exploration of new remote-sensing capabilities.

Indicator 3.1b: Ecological connectivity of terrestrial vegetation

Ecological connectivity of terrestrial native vegetation is the degree to which a landscape retains ecological functions and processes that enable biological movement (such as foraging, dispersal and migration) at a range of spatial scales. Ecological connectivity accounts for the generalised quality of habitats for biodiversity at each location, the fragmentation of habitat within its neighbourhood and how its position in the landscape contributes to connectivity among habitats across a region, for example, as part of a habitat corridor or as a stepping stone.

Ecological connectivity is measured by combining two landscape aspects of connectivity: (i) neighbourhood context, which measures how well ecological processes can operate at a location and within its surrounding neighbourhood, and (ii) link value, which measures how well a location contributes to overall network connectivity and therefore to ecological processes operating between other locations. A site’s neighbourhood context is defined by the single-source shortest network of paths from the site to all surrounding locations within a given radius. A site’s link value is an estimate of its contribution to the set of shortest paths between all pairs of locations in a region. A location’s neighbourhood is the adjoining region within a given radius.

The generalised quality of habitats, from ecological condition indicator 3.1a, defines the ease or difficulty (resistance) potentially experienced by any species or its dispersal agents (such as seed, pollen, spores) in entering, leaving or passing through each location.

Ecological connectivity is measured across a range of spatial scales to fully account for the range of ecological processes influencing biological movement, varying from local to landscape to interregional. The scales are sampled by systematically halving the resolution and doubling the movement distance for both neighbourhood context and link value facets. Each facet is range-standardised between 0 and 1 and then summed across scales for each location. Outputs of individual scales and facets are weighted and summed to produce a single ecological connectivity layer.

The resulting indicator of ecological connectivity ranges from 0 (minimum quality, disconnected habitat) to 1 (maximum quality, fully connected habitat) for an individual

90-metre grid cell. The indicator and its components can be summed by adding values for grid cells across New South Wales and reported for any geographic domain (e.g. all of New South Wales, conservation areas, bioregions, landscapes, regional ecosystems and plant community types). It is a generic measure of landscape ecological function supporting biological movement and the consequences of habitat fragmentation.

The ecological connectivity indicator is not used directly in any indicators. The neighbourhood context facet of this indicator is used in deriving the ecological carrying capacity indicator 3.1c, which is then used in relevant biodiversity indicators to account for the gradual loss of species where populations are not self-maintaining due to the limiting size of remnant habitats, movement isolation and other fragmentation effects.

A range of methods have been employed to measure neighbourhood context. Drielsma et al. (2007a, b) found, that at that time, there was no single measure (e.g. from the collection of FRAGSTATS metrics, see McGarigal et al. 2002; McGarigal et al. 2012) that encapsulated the closely related issues around landscape pattern of habitat quality, patch size, inter-patch distances and patch shape. Moreover, they found that the patch concept was inappropriate to many contemporary Australian landscapes, which are better characterised as heterogeneous or variegated (McIntyre & Hobbs 1999). Drielsma et al. (2007a, b) therefore developed the cost–benefit approach to spatial context, which applies metapopulation theory (Hanski 1999) and could employ raster (grid cell) data.

These measures can be mapped across regions or summed across a region. The approach has been extensively applied, especially in New South Wales, as a measure of landscape context and as an integral part of higher level community- and species-level assessment methods (Drielsma & Ferrier 2009; Drielsma et al. 2014; Williams et al. 2012). The species-level applications are divided between species-specific (Taylor et al. 2016), or even species-process-specific assessments, generic assessments (Foster et al. 2016; Drielsma et al. 2017), assemblage assessments (Drielsma et al. 2016) and, more recently, generic focal species-based assessment (Foster et al. 2017). In each case, distance-decay parameter(s) must be selected which also effectively set the neighbourhood of each site. The critical parameter, the average movement ability (in hectares), is usually depicted as $1/\alpha$ and is chosen based on ecological knowledge of the species, process or group of interest. This parameter varies with composition and structure across a landscape and in accordance with the needs of the biological entity or ecological/evolutionary process. For the purposes of a generic assessment and for consistency, a value corresponding to those developed for individual ecosystems, as part of the *Biodiversity Assessment Method* landscape context assessment (OEH 2017c), can be adapted within the cost–benefit approach.

Indicator 3.1c: Ecological carrying capacity of terrestrial vegetation

Ecological carrying capacity of terrestrial native vegetation accounts for how the generalised quality of habitats for biodiversity at each location and its connection with surrounding habitat enables biological movement such as foraging, dispersal and migration. It is used to account for the capacity of a landscape to support its original complement of biodiversity comprised of interacting species, populations and ecosystems. In this indicator context, ecological carrying capacity is defined as the ability of an area to maintain self-sustaining and interacting populations of all species naturally expected to occur there, given the habitat resources (such as food and water) and connections to other habitat needed for persistence.

This index uses only the neighbourhood context facet of ecological connectivity (from indicator 3.1b) and so does not consider how a location’s position in the landscape contributes to connectivity among habitats across a region (e.g. as part of a habitat corridor or as a stepping stone). Neighbourhood context is used with the generalised quality of habitats, from ecological condition indicator 3.1a, which defines the ease or difficulty potentially experienced by any species or its dispersal agents (such as seed, pollen, spores) in entering, leaving or passing through each location.

Neighbourhood context measures how well ecological processes can operate at a location and within its surrounding habitat. It is defined as the single-source shortest network of paths from a location to all surrounding locations within a defined neighbourhood. Path values are weighted by the habitat value of each neighbourhood location and then summed at the source location. A location's neighbourhood is the adjoining region within a given radius.

The indicator can be expressed in units of 'neighbourhood habitat area' (i.e. the amount of connected habitat in hectares) or standardised to measure the effective area of connected habitat relative to fully connected habitat. The process is repeated across a range of spatial scales and resolutions relevant to a range of ecological processes.

The range-standardised form of the ecological carrying capacity indicator varies from 0 (minimum quality, completely disconnected habitat) to 1 (maximum quality, fully connected habitat). The indicator can be summed and reported for any geographic domain (e.g. all of New South Wales, conservation areas, bioregions, landscapes, regional ecosystems and plant community types).

Ecological carrying capacity is used in the biodiversity indicators (e.g. 2.2b, 2.2c) to account for the gradual loss of species where populations are not self-maintaining due to the limiting size of remnant habitats, movement isolation and related fragmentation effects.

Indicator 3.1d: Ecosystem function of terrestrial vegetation

This indicator uses the stability and degree of coupling of plants with their environment to infer the functional condition of native vegetation as a complement to the remote sensing monitoring of vegetation structure. Applying remote sensing, three interrelated resource-use concepts depict the degree of ecological disruption from an expected climatic or environmental equilibrium: i) vegetation equilibrium, ii) resource-use efficiency, and iii) resource coupling.

Remote sensing can provide information about the functional integrity of ecosystems through monitoring the cycling of carbon, water, energy and nutrients by plants, driven through eco-physiological processes such as photosynthesis, respiration and transpiration. These dynamic processes have daily, seasonal, annual and longer cycles and are closely coupled with climatic variability, soil structure and availability of mineral nutrients. The dynamic nature of plant physiological processes through their interaction with the environment means much higher temporal frequency remote sensing is needed than required to monitor the often more slowly changing structural attributes, such as vegetation cover.

The three interrelated resource-use concepts listed above provide the basis for developing a new generation of indicators that depict the degree of disruption from an expected environmental equilibrium, and thus support the detection and attribution of habitat condition. The objective is to separate the effects of natural cycles (such as rain events or drought) and anthropogenic disturbances.

i Vegetation equilibrium

The structure and function of mature vegetation is generally a dynamic equilibrium with local growing conditions (Larcher 2003). In water-limited environments it is known as the eco-hydrological equilibrium (Eagleson 1982; Grier & Running 1977; Hatton et al. 1998; Pierce et al. 1993; Specht 1972; Woodward 1987). Disturbance processes force vegetation out of this equilibrium into a response phase typified by net vegetation (re)growth and by structural and functional dynamics that depend at least as much on vegetation age as on local growing conditions. The eco-hydrological equilibrium concept provides a basis for interpreting functional integrity by comparing predictions of what the 'mature' vegetation structure and function should be against the observed structure and function (e.g. Boer & Puigdefabregas 2003).

2 Resource-use efficiency

Another aspect of vegetation integrity is the efficiency with which vegetation utilises the most limiting local growth resources. In tropical rainforests, for example, light-use efficiency is the primary determinant of gross primary productivity and so productivity is maximised only when light-use efficiency is maximised. In contrast, in arid environments, water-use efficiency is critical. It follows from eco-hydrological equilibrium theory that highly disturbed vegetation will exhibit resource-use efficiencies out of balance with the expected efficiencies. Therefore, for a given set of growing conditions (climate, soils, nutrients), high levels of rain-use efficiency, which is the ratio of foliage cover to rainfall, are known to be associated with undisturbed vegetation (Donohue et al. 2013). Changes suggest a disruption and may imply temporary or permanent loss of integrity, depending on capacity to adapt or recover (Bai et al. 2008; Geerken & Ilaiwi 2004; Holm et al. 2003; Huxman et al. 2004; Wessels et al. 2004).

3 Resource coupling

If the structure and function of mature vegetation exists in a dynamic equilibrium with local growing conditions, then the temporal dynamics of each should display some degree of temporal coupling. For example, in sunlight-limited environments, the temporal variability in cover may be strongly correlated with dynamics in potential evaporation (Cihlar et al. 1991); Throughout water-limited environments, cover and rainfall most strongly correlate (Wellens 1997; Kogan 1990; Nicholson et al. 1990), although with time lags of several weeks. Changes in lag time, rates of green-up or brown-off, magnitude and timing of peak greenness (all of which measure phenology) can be indicative of changes in ecosystem resilience or stability (Geerken & Ilaiwi 2004; Graetz et al. 1988; Wessels et al. 2004).

These resource-use concepts are applied to develop a provisional suite of vegetation function variables:

- rain-use efficiency (RUE), light-use efficiency (LUE), or a general resource-use efficiency index that combines RUE and LUE
- rainfall-cover lag correlations or times
- rate of cover green-up post-rainfall event
- maximum cover peak post-rainfall event
- rainfall-cover pulse ratio (i.e. the ratio of water mass in a rain event to the integral of the associated cover pulse).

Those variables are then used to derive specific vegetation function indicators relevant to habitat condition assessment:

a) foliage cover gap, which is the difference between observed foliage cover and the natural cover predicted from an eco-hydrological equilibrium model
b) rain-use efficiency gap, which is the difference between the maximum cover, as defined by the maximum RUE capacity and the actual RUE (this index is applicable only to water-limited environments)
c) resource-use efficiency gap, which is a combination of the RUE gap concept and the equivalent LUE capacity gap concept (this is a more generic index that is applicable to almost all Australian conditions).

The derived variables provide a basis for regularly monitoring ecosystem function and can be reported in their own right. They may also be used as inputs in future enhancements of ecological condition indicator 3.1a or to facilitate interpretation of those results, along with vegetation disturbance monitoring (such as fire regimes, see indicator family 3.2). Varying degrees of research and development are needed (some variables are well developed, some are prototype), and all require validation using site-level observations of vegetation integrity.

3.5.2 Indicator family 3.2: Pressures

Methods for measuring ecosystem quality directly or indirectly use information about pressures. In this report, 'pressures' are threats in the landscape that cause biodiversity loss and threaten the quality of ecosystems, including key threatening processes listed under Schedule 4 of the BC Act as well as other threats not listed on the BC Act.

The most pervasive pressures in New South Wales are clearing of native vegetation (NSW SC 2001), over-exploitation of ecosystem products (e.g. timber, firewood, grazing, bush rock, seed collection), altered fire frequencies and intensity (Murphy et al. 2013), altered hydrological regimes (e.g. water abstraction), invasive species disrupting biological interactions and climate change (Auld & Keith 2009).

Key threatening processes are listed under Schedule 4 of the BC Act and are determined separately or in conjunction with the listing of species or ecological communities as threatened (see BC Act Part 4, Division 5). A key threatening process is 'a process that threatens, or that may threaten, the survival or evolutionary development of species or ecological communities' (s. 1.6 BC Act). A threatening process is eligible to be listed as a key threatening process if, in the opinion of the NSW Scientific Committee it: (a) adversely affects threatened species or ecological communities, or (b) could cause species or ecological communities that are not threatened to become threatened (s. 4.32 of the BC Act).

Upon commencement of the BC Act (25 August 2017), 38 key threatening processes were listed in Schedule 4. Most relate to impacts on biodiversity in terrestrial and freshwater environments (see Table 15). They vary in scale and type from anthropogenic climate change which impacts biodiversity across terrestrial, freshwater and marine realms, to alteration of natural flow regimes across inland aquatic systems, to native habitat invasion by escaped garden plants and marine mammal injury in shark nets.

Many of the terrestrial key threatening processes are attributed to alien invasive plants, animals and diseases (see Table 15) and these vary in impact from established and widespread (e.g. feral mammals and lantana) to local infestations that could become more pervasive (e.g. yellow crazy ants). These impacts are often exacerbated by habitat loss and degradation processes including other key threatening processes, such as clearing of native vegetation, removal of bush rock, dead wood and dead trees; and high frequency fires. Removed or disturbed vegetation provides pathways for feral and weed species to invade and so compounds the process of habitat degradation.

Table 15 Grouping of 38 key threatening processes listed under Schedule 4 of the *Biodiversity Conservation Act 2016*

Type of threat [1]	Terrestrial [2]	Freshwater [2]	Marine [2]
Habitat loss/change	8	2	1
Pest animal	13	2	
Weed	7	1	
Disease	3	1	
Other	1		2
TOTAL	32	6	3

1. Source data for type of threat: http://www.environment.nsw.gov.au/threatenedspeciesapp/.

2. Some threats are across all three realms (e.g anthropogenic climate change) and some are shared across terrestrial and freshwater realms (e.g. invasion and establishment of the cane toad, habitat by invasion of escaped garden plants). As such, totals do not combine to equal 38.

While changes in vegetation due to cumulative impacts of multiple pressures can be detected over large areas using remote sensing (Coops et al. 2009; Lawley et al. 2016; Sulla-Menashe et al. 2014), impacts related to other non-natural disturbances, such as infestations of invasive plant species, disease and feral animal predation and herbivory, may still require local detection methods or modelling. In addition, supporting studies attributing cause to effect are needed for appropriate impact assessment and adaptive management response (Auld & Keith 2009; Oliver & Morecroft 2014). The results of such direct modelling of pressures and their impacts can then be used to model processes and, with suitable spatial data, predict the potential distribution of pressures and consequences.

Ongoing monitoring and field data collection related to pressures will help inform development of models and predictions of processes that threaten biodiversity. Remote sensing is most effective at detecting direct causes of structural habitat loss attributed to clearing of native vegetation (Danaher et al. 2001; Fisher et al. 2017; Fisher et al. 2016a; Gill et al. 2010). This information is a critical underpinning of the BC Act and so emphasis has been placed on accuracy and resolution of detection methods informing vegetation management (Danaher & Flood 2015; Fisher et al. 2015; Flood et al. 2013; Gill et al. 2017).

Beyond changes in the extent of native vegetation, different satellite sensors offer detection of a variety of other ecosystem function–related disturbances such as fire and decoupled vegetation–climate responses (Donohue et al. 2016). Some of these new approaches, such as fire intensity and frequency mapping, are ready to be applied with minimal further development. Whereas others, related to vegetation equilibrium with climate and resource-use efficiency, require validation and operational testing to determine their sensitivity (see indicator 3.1d). Fire disturbance is of course essential to the integrity of many ecosystems and component species have co-evolved to promote or survive particular regimes (Bowman et al. 2016). Fire provides some species with a competitive advantage and facilitates regeneration strategies if returned at the right intensity and frequency, thereby maintaining regional diversity (Murphy et al. 2013). Additional information is therefore needed to clarify which regimes, on the balance of evidence, are a pressure that potentially leads to ecosystem collapse (Burgman et al. 2007).

All the indicators in this family require development. Monitoring and data collection programs focused on gathering spatially explicit information, or remote-sensing detection and modelling of pressures, will help improve focus and effectiveness of environmental management responses (for the latter, see discussion in section 3.6.1). Depending on technology and resources for routine detection, minimum supporting information about changes in vegetation extent, invasive species and changes in regimes of fire, hydrology and climate, is needed. McGeoch et al. (2016) and others, for example, have identified minimum information requirements (essential variables, EVs, see section 1.5.4) for monitoring biological invasions (Latombe et al. 2017; McGeoch & Squires 2015), although more work is needed to ensure fitness for use (McGeoch et al. 2016). In the case of invasive species, for example, those minimum requirements are: alien species' occurrence (i.e. distribution records), alien species' status (i.e. risk) and alien species' impact (i.e. consequence). The same type of information needs to be gathered as relevant to each pressure in order to shape how the available data is applied to derive an indicator.

Remote-sensing indicators of woody and to some extent non-woody vegetation cover are well-advanced and underpin regulation of native vegetation and its management. However, accurate detection of native vsnon-native woody and non-woody vegetation components (including environmental weeds) requires more development and cross-referencing with several lines of evidence (Fisher et al. 2016a). Remote detection of vegetation composition has the potential to distinguish native and non-native spectral signatures, for example, using high resolution, multi- or hyper-spectral sensors and is an emerging field of research (Cavender-Bares et al. 2016; Lawley et al. 2016; Li & Guo, 2015; Mairota et al. 2015). Satellite monitoring of land surface fire (e.g. Atwood et al. 2016; Edwards et al. 2013; Russell-Smith et al. 2007) and hydrology events (Fisher & Danaher 2013; Fisher et al.

2016b) has also reached a level of maturity and sufficiently long time series, and has the potential to enable regime naturalness to be evaluated (Silcock et al. 2016). These information sources, combined with long-term weather monitoring and climate forecasting (Olson et al. 2016), provide an opportunity to develop indices and assessments of more direct relevance to ecological systems distinguishing anthropogenic-driven and natural disturbance regimes (Auld & Keith 2009; Driscoll et al. 2010). More careful assessment of pressures and their interactions will improve assessment of ecosystem quality with potential to forecast change informed by short-term climate modelling.

While more work is needed to shape these indicators, six have been identified for initial review and development (others may be identified subsequently):

- indicator 3.2a: land-use and management practices
- indicator 3.2b: native vegetation extent
- indicator 3.2c: inappropriate fire regimes
- indicator 3.2d: inappropriate hydrological regimes
- indicator 3.2e: invasive species (pests, weeds, disease)
- indicator 3.2f: altered climatic regimes, variability and extremes.

Indicator 3.2a: Land-use and management practices

This indicator monitors the extent of classes of land-use and management practices using data aligned with the standard classification applied nationally (ABARES 2016a).

Land use depicts the potential degree of modification and the impact on a putative ‘natural state’ (essentially, a native land cover). The standard classification for Australia is three-tiered and hierarchical. Primary and secondary classes relate to the main use of the land, defined by the management objectives of the manager. Tertiary classes can include commodity groups, specific commodities, land management practices or vegetation information.

Time-series data on land-use and management practices is collected by relevant agencies. If mapped accurately, it provides valuable information about the time since modification and intensive use of natural areas (e.g. Sinclair et al. 2012). Satellite and aerial remote sensing combined with field observations and agency databases is being used to fill gaps in the time series of land-use change in New South Wales. The data, once complete, enables the latency in biodiversity decline (extinction lag) following loss of high-quality connected habitat to be systematically monitored to determine local impact and develop predictive estimates for use in models (e.g. biodiversity indicator 2.2a). Time series land-use mapping (e.g. 2003, 2007, 2012 for New South Wales) also enables the historical trends to be evaluated and used in retrospective analyses of habitat condition (indicator family 3.1). Stratification of biodiversity surveys or monitoring across land uses will enable a predictive relationship with impact to be derived (e.g. change in species abundance or numbers).

The area of each land use can be reported across the six primary classes which distinguish increasing levels of intervention or potential impact on the natural landscape and for each bioregion (or other theme boundary). Those six classes are, in order of potential impact: i) conservation and natural environments, ii) production from relatively natural environments, iii) production from dryland agriculture and plantations, iv) production from irrigated agriculture, v) plantations and vi) intensive uses. The mapping of land use does not necessarily depict actual impact, as the class may indicate potential to modify rather than actual modification. Future strategic assessment of biodiversity impacts might be achieved from stratified sampling across land uses to derive a predictive relationship with impact, such as change in species’ abundance or numbers (e.g. by applying the PREDICTS approach; Newbold et al. 2012, 2016a, b; Hudson et al. 2017).

While initial assessments based on land-use mapping can be reported, this indicator requires further consultation and methods design.

Indicator 3.2b: Native vegetation extent

This indicator monitors the extent of native woody and non-woody vegetation cover based on the remote-sensing products developed to underpin the native vegetation regulatory map and other data supporting detection of natural areas (ecosystem quality indicator theme).

Remote sensing supports the monitoring and quantitative reporting of changes in native vegetation extent, including increase, decrease or other forms of modification, cross-referenced with management and approvals for clearing across New South Wales (OEH 2014, 2016). The data derives from interpretations of satellite and aerial surveillance of land-cover change and from approvals under private native forest and property vegetation plans.

Information about changes in the extent of native vegetation can either inform development of the ecological condition indicator 3.1a or provide a basis for attributing cause to observed change in condition, depending on the method applied.

The indicator is reported as the area of native woody and non-woody vegetation cover, and can be reported for any region or in relation to vegetation (plant community) type or condition class. Using historical data, the indicator may also be reported as a trend at initial assessment.

While initial assessments based on woody and non-woody vegetation cover mapping can be reported, this indicator requires further consultation and methods design.

Indicator 3.2c: Inappropriate fire regimes

This indicator monitors the extent and impact of altered fire regimes on sensitive ecosystems. A fire regime is the prevailing intensity, seasonality, frequency (i.e. interval between burns), type of fire, severity and spatial pattern that has become established over extensive areas and through time, and that supports the maintenance of local species and ecosystems (Murphy et al. 2013; Pausas & Keeley 2009). Fire plays an important role in maintaining ecosystem integrity. It is an integral part of the Australian landscape with many terrestrial plants and animals evolving, adapting and even benefiting from their usual fire regimes. For example, many plants regenerate readily following fire, benefiting some species and enhancing regional biodiversity (Gill et al. 1999).

An inappropriate fire regime for some species may be frequent fires, whereas lack of fire, high intensity fires, or low intensity fires may be inappropriate for others. Therefore, what constitutes an inappropriate fire regime varies by environment and ecosystem type. Fire in rainforest and alpine woodland, for example, is detrimental.

Mapping of fires, including prescribed burns, is routine, but data is held across different organisations with inconsistencies in data quality for fire extent and severity. Satellite remote sensing using thermal bands is increasingly providing a basis for consistent monitoring and mapping of fire extent and intensity.

This indicator is calculated from spatial data compiled from all fires across the State, as far back in recent history as possible, and may be increasingly informed by remote sensing as methods develop. For each vegetation type, the mapped fire frequency is compared to the minimum and maximum thresholds predicted, based on scientific knowledge of its sensitivity. Departures from the expected appropriate regime signify the degree of impact on local biodiversity classed as ‘too frequently burnt’, ‘within fire thresholds’ or ‘too infrequently burnt’.

Information about inappropriate fire regimes informs development of the ecological condition indicator 3.1a or provides a basis for attributing cause to observed change in condition, depending on the method applied.

The indicator reports the area of inappropriate fires and cumulative impact (departure from an appropriate regime), with reference to fire-sensitive vegetation (plant community) types. It is in early stages of consultation and method design and is further expected to evolve as methods for detecting fire incidence and severity advance with remote sensing and with greater knowledge of fire impacts on vegetation and ecological integrity.

Indicator 3.2d: Inappropriate hydrological regimes

This indicator monitors the extent and impact of altered hydrological regimes on sensitive ecosystems. A hydrological regime is determined by the prevailing climate and its seasonality and how landform and rock types influence the redistribution of water across a landscape. It has components of seasonality, depth and duration of flooding and drying, and frequency of inundation. Estuarine systems are also dependent on tidal regimes.

The dependence of ecosystems on river flows, surface water inundation or groundwater are complex. Changes in the frequency, intensity and seasonality of water availability, for example due to extraction for irrigated land uses, can adversely affect the downstream ecosystems and the wider natural environment.

This indicator is calculated from hydrological metrics, including river flow and remotely sensed data of surface water extent and vegetation dynamics. This data quantifies the frequency and spatial extent of floodplain inundation, and it can also be used to identify vegetation response to inundation.

For each ecosystem type, the mapped hydrological regime is compared to the minimum and maximum thresholds predicted based on scientific knowledge of its requirements. Departures from the expected appropriate regime signify the degree of impact on local biodiversity.

Information about altered hydrological regimes informs development of the ecological condition indicator (3.1a) or provides a basis for attributing cause to observed change in condition.

The indicator reports the area of inappropriate hydrological regimes and cumulative impact (departure from an appropriate regime), with reference to sensitive vegetation (plant community) types. The indicator may be informed by the frequency and extent of floodplain inundation and dynamic extents of wetland vegetation. It is in early stages of consultation and methods design, and is further expected to evolve as methods for detecting hydrological regimes evolve with remote sensing and modelling of impacts on sensitive ecosystem types.

Indicator 3.2e: Invasive species (pests, weeds, disease)

This indicator monitors the extent and impact of invasive species on sensitive ecosystems. Invasive species are a significant threat to biodiversity. Many threatened species, populations and communities are likely to be impacted by alien or invasive pests, weeds and disease. Feral animals displace native species through competition and predation and affect the integrity of vegetation through grazing and trampling. Introduced plants can become invasive weeds and smother or out-compete native vegetation. Under climate change, some native species introduced from other regions of Australia may also become invasive locally and aggressively displace or disrupt the local native biota.

Data on the occurrence of invasive species, including natives in gardens and environmental plantings, is rarely collected until it becomes a problem, for example, infestations in agricultural settings. Some invasive species are regulated and data on these is routinely collected and mapped. Generally, the data is sparse and held across different organisations with inconsistencies in quality. Satellite remote sensing, for example using hyper-spectral bands, is not yet adequate in resolution for routine monitoring and mapping of invasive species. More is known about the sensitivity of particular native species and ecosystems to particular invasive species.

For sensitive species and ecosystems, the associated spatial extent and density of invasive species is determined, along with the detection of new invasive species with the potential to impact native plants and animals and the spread of emerging invasive species.

Information about invasive species' densities informs development of the ecological condition indicator 3.1a or provides a basis for attributing cause to observed change in condition, depending on the method applied.

This indicator requires consultation and design of methods. It may report initially on the level of knowledge about the extent and impact of invasive species on sensitive species and ecosystems. It will evolve as methods for collating disparate data and for monitoring and reporting on species and ecosystem impacts are developed.

Indicator 3.2f: Altered climatic regimes, variability and extremes

This indicator monitors the extent and impact of altered climatic regimes on sensitive ecosystems. A region's climate is determined from the spatial and temporal variation in rainfall, temperature, humidity, atmospheric pressure, wind and other meteorological variables over long periods of time. Climates interact with and influence the evolution of landscapes (Gutiérrez 2005) and, therefore, the fundamental environment in which species evolve. The climatic regime is explained by normal ranges of these variables, their seasonality, frequency, duration, intensity and extent of events, to which species and ecosystems have adapted locally. Species and ecosystems vary in their capacity to adapt to changes that depart significantly from their typical climatic regime (e.g. Watson et al. 2012).

Climatic average temperatures across Australia have increased by nearly 1°C since standardised records began in 1910, and native plants and animals worldwide are already adjusting to the unusual conditions (Wiens 2016). Those changes may not become evident in ecosystems until thresholds in survivability are exceeded, for example, declining bird populations following unprecedented heat waves and tree deaths after extended periods of drought. Altered fire and hydrological regimes often accompany altered climatic regimes.

Individual species will be affected in different ways. Some will be able to adapt and remain where they are. Other species will need to find new areas that have become more suitable to their requirements. Certain plants and animals will not be able to move or adapt quickly enough because they are limited by their capacity to disperse and so will be under threat of extinction (Jezkova & Wiens 2016).

Understanding how the physiology of plants and animals interacts with climate allows us to identify sensitive places that may require intervention to mitigate risks and help avoid biodiversity loss (Bellard et al. 2012). To support this understanding, information about how quickly the environment is changing can be gathered from weather station data, which is collated in meteorological databases and used in climate modelling. Knowledge of particular eco-physiological thresholds (e.g. successive days exceeding 35°C) that lead to stress or death of plants or animals provides a basis for tracking climatic trends and extreme events that also impact biodiversity more generally.

Information about altered climatic regimes informs development of the ecological condition indicator 3.1a or provides a basis for attributing cause to observed change in condition.

This indicator requires consultation and design of methods. It may initially report on the mapped extent, frequency and intensity of eco-physiological stress predicted for plants and/or animals (using climate thresholds) as a result of climatic extremes and the cumulative impact (degree of departure from pre--industrial climatic norms). This indicator can also be forecast using modelled climate projections for the specific variables that exceed eco-physiological thresholds.

This indicator will evolve as methods for modelling and monitoring climate change impacts on biodiversity are further developed. By understanding how rates of change in climatic regimes interact with land use and habitat connections, we can design ways to help species move or adapt through targeted management interventions (Prober et al. 2017b; Prober et al. in review).

3.6 Theme 4: Ecosystem management

This theme addresses the responses (such as policies and actions) to prevent or reduce biodiversity loss, the effectiveness of these responses and the capacity to maintain or enhance ecosystem quality.

Land-use and management practices that collectively strengthen regional ecosystem quality are more likely to maintain habitats supporting retention of regional diversity (native plants and animals) and productivity through a sustained period of climate variability and change. Critical information relates to the location and boundary of lands under conservation management; the timing, duration and security of agreements; the nature of actions to maintain or enhance the capacity of habitats to support biodiversity and the effectiveness of those actions over time. Crucial to these programs are specific mechanisms for monitoring, evaluation and reporting. For example, Cook et al. (2017) used data on protected area location, extent and gazettal or degazettal dates to quantify change in conservation area networks.

Surveillance and performance monitoring to allow adaptive management responses is much more critical at present due to rapidly changing climatic regimes. All land sectors need to plan for an uncertain future and develop flexible strategies and agile decision processes responsive to change (Wise et al. 2014). This process of review and replanning can be particularly detrimental for ecological sustainability if decisions in one sector or jurisdiction are made in isolation of impacts on others (Burley et al. 2012; Jordan & Lenschow 2010; Serrao-Neumann et al. 2014). For example, the climatic regimes of New South Wales are expected to become drier and land traditionally used for dryland cropping may convert to rangeland grazing for continued sustainable production (Lavorel et al. 2015; Prober et al. 2017b).

Ensuring sustainable outcomes, while maintaining ecological mechanisms supporting adaptation and livelihoods, requires a more inclusive approach to decision-making on land-use and management practice change. Understanding the context in which decisions are made enables constraints on societal responses to change to be identified. While mapping land-use and management practices with an emphasis on area-based biodiversity conservation is necessary, a greater understanding of the security of areas in the context of changing societal values and adaptation preparedness is also needed (Gorddard et al. 2016; Wise et al. 2014; Colloff et al. 2016; Prober et al. 2017a, b; Prober & Dunlop, 2011; Paetzold et al. 2010). Thus, we need to identify shifts in societal perspectives toward natural areas more generally, as heritage to be valued and protected. Indicators for measurement of societal attitudes that are sympathetic to the conservation of biodiversity, as well as those for other types of management responses, require development.

In this indicator theme, management responses are the supporting information needed for reporting on the status and trends of biodiversity that provide context for evaluating the performance of the BC Act and enforcement mechanisms and regulations. Management effectiveness evaluates the success of these responses. Information about how biodiversity is managed or valued also influences indirectly the success of the BC Act. These interactions will need to be understood in order to evaluate the performance of the BC Act. Therefore, the integrated measure of effective ecosystem quality and management effectiveness, as foreshadowed by the ecological integrity framework (see Figure 2), is provided through family 4.3 capacity to sustain ecosystem quality.

3.6.1 Indicator family 4.1: Management responses

Many Acts in New South Wales regulate how people use or interact with the environment and so influence the outcome for biodiversity. This indicator family provides information about what policies or actions that target avoided biodiversity loss (prevent or reduce) are implemented, and where. The indicators track and monitor changes in management responses and the potential outcomes for biodiversity.

This family is under development and includes three indicators at present:

- indicator 4.1a: areas managed for biodiversity conservation in perpetuity
- indicator 4.1b: areas managed for biodiversity conservation under formal or informal agreements
- indicator 4.1c: community appreciation of biodiversity.

Indicator 4.1a: Areas managed for biodiversity conservation in perpetuity

This indicator measures the extent of areas that are designated for long-term biodiversity conservation outcomes. These areas include all categories of national park reserved under Part 4 of the *National Parks and Wildlife Act 1974*, flora reserves in state forests and other public tenures as relevant. The indicator may also be used to assess the area that each category of ecosystem represents, to ensure that all types of ecosystem are protected within these areas.

This indicator integrates area-based information about management responses. It requires the collection of spatially explicit data on: (i) what actions are proposed to be implemented and (ii) the management objectives. The objectives (e.g. aligned with IUCN conservation management category) imply a level of protection potentially afforded to biodiversity and therefore an outcome related to species persisting over time, assuming those objectives are achieved in full. The level of protection is scaled 0 (not protected) to 1 (the highest form of agreement, e.g. a strict nature reserve). The location and size of the agreement area (in hectares) determines how much biodiversity is protected. Its contribution to regional and statewide biodiversity through representation can be predicted from models. That analysis is applied through indicator family 2.2. For each area under conservation management, an index is derived by multiplying the land area by the level of protection.

This indicator is in early stages of development and requires consultation and design of methods. It can be reported as a trend using historical data on land parcels (e.g. annually) to show change over time in the amount of land gazetted under the National Parks and Wildlife Act or the area under other governance. It is complemented by iIndicator 4.1b which applies the same method to areas managed under other types of agreement aimed to benefit biodiversity.

This indicator does not directly measure the effectiveness of conservation management actions. It can only forecast 'avoided biodiversity loss'. Management effectiveness, influencing actual biodiversity outcomes, is addressed through indicator family 4.2.

Indicator 4.1b: Areas managed for biodiversity conservation under formal or informal agreements

This indicator measures the extent and tenure of areas managed for biodiversity conservation under formal or informal agreements, using data on the boundaries, purpose and duration of each agreement. Many Acts and policies provide for the protection of biodiversity and the integrity of habitats supporting biodiversity. Some areas, such as long-term voluntary agreements on private lands protect areas of very high conservation value. This indicator includes these perpetual agreements as well as shorter-term management agreements to maintain or enhance the integrity of natural areas or specific populations of threatened species. Agreements vary and well-known examples are Land for Wildlife, biodiversity stewardship agreements, wildlife refuges and conservation agreements. Each agreement contributes, at some level, to the maintenance of biodiversity across whole bioregions and statewide.

This indicator provides for the integration of disparate information about where and what biodiversity conservation management is intended and for how long. It requires the collection of spatially explicit data on what actions are proposed to be implemented where (boundary and size), for what management purpose (intent and type) and the length of the agreement (start and end dates). The agreement purpose can be aligned with an IUCN conservation management category which implies a level of protection potentially afforded to biodiversity, assuming those actions are implemented (avoided loss). Following a review of different types of agreements and conservation management objectives a more refined and comprehensive classification of partial protection levels may be developed. The level of protection is scaled 0 (not protected) to 1 (the highest form of agreement e.g. a strict nature reserve). Purposes can relate to protection, enhancement, restoration or reinstatement of biodiversity values and relate to some predicted future outcome for biodiversity (e.g. proportion of the original biodiversity expected to be retained after a specified number of years). The length of agreement (in years) specifies from when and for how long biodiversity is being protected. The location and size of the agreement area (in hectares) determines what type and how much biodiversity is potentially under management. Its contribution to bioregional and statewide biodiversity conservation through representation can be predicted from models. That analysis is applied through indicator family 2.2.

For each area under conservation management, an index can be derived, for example, by multiplying the land area by the agreement duration by the level of protection. This indicator can therefore be combined with indicator 4.1a for reporting. It can be presented as a trend using historical data on land parcels and the start/end dates of each agreement and projected forward where end dates are in the future.

This indicator is in early stages of development and requires consultation and design of methods. The component measures can be summarised in hectares, for example, by categories of land tenure, IUCN management type (or other adopted level of protection classification) and length of agreement. They may include changes in the location and size of places designated for conservation; new, varied and terminated conservation agreements; agreement length; and changes in purpose and level of protection afforded to biodiversity. The indicator can also be expressed as a proportion of any geographic domain using spatial allocation rules to account for overlapping boundaries. Its application depends on routine collection, attribution and management of spatially explicit boundary data (like a geospatial conservation actions inventory).

This indicator can only forecast ‘avoided biodiversity loss’. Management effectiveness, influencing actual biodiversity outcomes, is addressed through indicator family 4.2.

Indicator 4.1c: Community appreciation of biodiversity

This indicator monitors the level of community understanding and support for biodiversity conservation and biodiversity values.

The BC Act exists because the community of New South Wales appreciates their native plants and animals, like to visit natural places, and support their conservation for future generations. In this context, community is defined as both the general public, as well as landholders and communities subject to particular legal regulation.

Knowledge and understanding, by society in general and landholders, of the importance of biodiversity and the requirements of management to conserve and restore habitats and mitigate pressures that threaten biodiversity can directly and indirectly influence environmental decision-making.

This indicator measures community attitudes and understanding of biodiversity, and engagement in and level of support for biodiversity conservation measures, including climate-adapted management and the programs implemented under the BC Act. Data are systematically collected through structured surveys of the general population, such as the OEH Who Cares about the Environment? survey and through landholder surveys.

Explanatory data linked to changes in community attitudes (such as demography, relationship to environment and education levels) may also need to be collected in order to diagnose change over time.

This indicator is in early stages of development and requires consultation and design of methods. Data requirements and measurement methods will follow a review of past surveys.

3.6.2 Indicator family 4.2: Management effectiveness

This indicator family measures the effectiveness of implemented policies or actions to reduce the rate of biodiversity loss, including societal attitudes leading to actions (e.g. volunteer engagement in on-ground programs) and planning for adaptation under climate change that is being implemented to facilitate ecosystem change.

Data derived from direct (on-ground) observations of the effectiveness of management actions on outcomes for biodiversity and ecological integrity is relevant to this indicator. Predicted outcomes that are inferred from management objectives are reported under management responses indicator family 4.1.

While more work is needed to shape these indicators, three have been identified for initial review and development (others may be identified subsequently):

- indicator 4.2a: effectiveness of on-ground biodiversity conservation programs
- indicator 4.2b: community-based maintenance of biodiversity values
- indicator 4.2c: implemented climate-adapted conservation planning and management.

Indicator 4.2a: Effectiveness of on-ground biodiversity conservation programs

This indicator monitors the individual and collective effectiveness of conservation outcomes on the ground. Legislation regulating use of the environment, such as the BC Act, the National Parks and Wildlife Act, and the *Local Land Services Act 2013* (and its 2016 amendment) also supports programs implementing conservation actions on the ground. Each program is responsible for monitoring, evaluation and reporting on conservation-related outcomes against objectives.

Examples of programs under the BC Act supporting on-ground actions are:

- *Saving our Species* (the effectiveness of threat mitigation actions in reversing declining threatened species populations or ecological communities)
- private land conservation (the effectiveness of ecosystem-based management that is maintaining or enhancing ecological integrity)
- declaration and protection of areas of outstanding biodiversity value.

Under amendments to the Local Land Services Act, areas set aside in rural lands can be nominated as clearing offsets.

Under the National Parks and Wildlife Act, the state of the parks reports (prepared every three years) use the IUCN's best-practice framework for measuring management effectiveness.

This indicator compiles and harmonises management effectiveness information across programs to enable statewide and regional reporting on outcomes for biodiversity and ecological integrity from direct (on-ground) observations. Change in the value of the indicator may be attributed to actual increases in the area of effective conservation actions or to increased reporting on outcomes.

This indicator is in early stages of development and requires consultation and design of methods. Data requirements and measurement methods will follow a review of individual program monitoring, evaluation and reporting methods.

Indicator 4.2b: Community-based maintenance of biodiversity values

This indicator monitors the collective effectiveness of voluntary community-based management of biodiversity in maintaining or enhancing natural values. Examples of community engagement on biodiversity conservation include:

- volunteers in on-ground programs including stewardships
- environmental plantings supporting habitat restoration and connectivity
- citizen contributions to monitoring, evaluation and reporting (i.e. citizen science)
- local government, Landcare and nature-based collectives and community groups.

This indicator identifies, compiles and harmonises management effectiveness information across volunteer networks and stewardships to enable statewide and regional reporting on outcomes for biodiversity and ecological integrity from direct (on-ground) observations.

Increased outcomes for biodiversity, achieved through community-based collectives that take responsibility for managing their local biodiversity values, improves the longer-term outlook for sustaining biodiversity regionally and statewide. Change in the value of the indicator may be attributed to actual increases in the area of effective volunteer conservation actions or to increased reporting on outcomes and voluntary activities.

This indicator is in early stages of development and requires consultation and design of methods. Data requirements and measurement methods will follow a reviews of community engagement activities and how on-ground outcomes are monitored, evaluated and reported.

Indicator 4.2c: Implemented climate-adapted conservation planning and management

The indicator monitors the potential effectiveness of conservation management actions in facilitating biodiversity adaptation to climate change.

Climatic average temperatures across Australia have increased by nearly 1°C since standardised records began in 1910. The associated increase in seasonal variability and extremes of weather require management responses to be more adaptive. Past management of natural areas focussed on resisting change in order to protect values. More flexible management principles are needed to facilitate biodiversity adaptation to changing climates and to be responsive during extreme events (Prober et al. 2017a, b; Prober et al. in review).

This indicator tracks the adoption and implementation of conservation management principles and actions and their perceived effectiveness for facilitating biodiversity adaptation to climate change. Increased outcomes for biodiversity are expected from on-ground management actions that are adaptive to climate and so improve the longer-term outlook for sustaining biodiversity locally.

Change in the value of the indicator may be attributed to, for example, increased uptake of climate adaptation principles in conservation planning and implemented actions, or increased area under conservation management adopting and implementing climate adaptation principles.

This indicator is in early stages of development and requires consultation and design of methods. Data requirements and measurement methods will follow a review of climate-adapted options included in existing conservation management plans and agreements across the private and public sector (e.g. applying the framework and typology developed by Prober et al. in review).

3.6.3 Indicator family 4.3: Capacity to sustain ecosystem quality

This indicator family measures the change in adaptive management capacity to maintain or enhance ecosystem quality and so improve the longer-term outlook for sustaining biodiversity. It does this by integrating specific measures of ecosystem quality and ecosystem management. All types of information influencing biodiversity outcomes are potentially incorporated, including land management that moves toward ecological sustainability (i.e. responses in the RPSB framework, see Figure 4).

This indicator family presently includes one indicator:

- indicator 4.3a: capacity to maintain or enhance ecosystem quality (through local system resilience).

The indicator family will be developed following the design of methods for integrated reporting of ecosystem quality, management responses and effectiveness. More indicators or indicator components may be identified.

Indicator 4.3a: Capacity to maintain or enhance ecosystem quality (through local system resilience)

This indicator measures the degree to which the ecological carrying capacity of habitats is maintained or enhanced by forecasting the ‘avoided loss’ scenario implied by the overall effectiveness of adaptive management responses (theme 4) on ecosystem quality (theme 3). It develops a measure of local system resilience, derived from knowledge of the effectiveness of local-scale management, to mitigate or halt processes that threaten the maintenance of ecosystem quality. Local system resilience is one of two elements of resilience defined by Cumming (2011). It is here equated with the capacity of adaptive management to maintain and enhance the quality of ecosystems.

The overall objective of conservation management is to maintain or enhance the resilience and capacity of ecosystems and their component species to adapt to change. The longer-term outlook for sustaining biodiversity depends on the quality of ecosystems at initial assessment and how land management practices plan to continue supporting the retention of those ecosystems, either by maintaining or enhancing their quality into the future.

While acknowledging uncertainty, this indicator forecasts the short-term outlook for ecosystem quality, and therefore biodiversity, based on the present situation. Locations where ecosystems are presently managed for conservation are predicted to be sustained, based on their present quality and the effectiveness of present management. The present management may be forecast for the duration of each agreement, all else being equal. That is, other locations and conditions not managed for conservation outcomes are assumed to be maintained or degrading at a rate consistent with historical trends. There is potential to apply the method developed for this indicator to scenarios that take into account new regulations supporting ecological sustainability across land sectors by assuming the effectiveness of proposed ecosystem management.

This indicator is in preliminary stages of development and requires consultation and design of methods. It requires development of data integration methods consistent with an understanding of management interactions. The results inform theme 5 indicators.

3.7 Theme 5: Ecosystem integrity

This indicator theme addresses the capacity of ecosystems to retain biodiversity and ecological functions in the face of ongoing, yet uncertain, environmental change, including climate change and land-use change (and so provide for the needs of future generations). It aims for the integration and synthesis across other themes of biodiversity and ecological integrity and introduces the concept of ecosystem resilience toward an overall measure of ecological integrity. Indicators developed under this theme will enable estimation and reporting of past-to-present changes in adaptive capacity. They test the adaptive capacity and resilience of the present state of the system using plausible future scenarios to report on a key component of ecological integrity.

The indicator theme will be developed following the design of methods for reporting ecosystem quality (theme 3) and ecosystem management (theme 4). While more work is needed to shape this theme, four indicators within two families have been identified for initial review and development (others may be identified subsequently). They are classed by the type of state that is being assessed (biodiversity or ecological functions), and by pervasive threat (climate change or land-use change).

3.7.1 Indicator family 5.1: Capacity to retain biological diversity

This indicator family measures the capacity of ecosystems to adapt and retain their biodiversity in the face of ongoing, yet uncertain, environmental change, including climate change and land-use change.

While more work is needed to shape these indiactors, two have been identified for initial review and development (others may be identified subsequently):

- indicator 5.1a: ecosystem capacity to adapt to change and retain biological diversity under climate change
- indicator 5.1b: ecosystem capacity to adapt to change and retain biological diversity under land-use change.

Indicator 5.1a: Ecosystem capacity to adapt to change and retain biological diversity under climate change

This indicator measures the ability of ecosystems to adapt and retain their biodiversity in the face of ongoing, and uncertain, environmental change, particularly climate change. It uses the present quality (condition) and spatial-environmental connectedness of ecosystems, through time, under plausible climate change scenarios to report on a key component of ecological integrity.

Two dimensions of resilience (following Cumming 2011) are integrated: (i) local system resilience, derived from local-scale management of processes that threaten the maintenance of integrity (from indicator 4.3a), and (ii) spatial resilience, derived from the spatial and environmental connectedness of ecosystems exhibiting high local resilience. Initial development of the indicator will focus largely on the spatial-resilience dimension, using ecological carrying capacity (from indicator 3.1c) as a proxy for local system resilience, while the more comprehensive approach using indicator 4.3a is in development.

The indicator dimension of spatial resilience will be generated by assessing the spatial and environmental connectedness of ecosystems under a plausible range of climate projections. This assessment will be undertaken using the observed (existing) spatial configuration of natural habitats, from the ecological carrying capacity indicator 3.1c, and will assume no future change in that capacity under the climate projections evaluated (the comprehensive assessment uses indicator 4.3). A generalised dissimilarity model (from indicator 2.2b) is projected under climate change to inform the environmental connectedness of ecosystems.

The proposed indicator would use space-for-time substitution to project expected turnover in biological composition over time as a function of GDM-modelled turnover across space. The connectedness, relative to each focal cell, of good-quality habitat within ecosystems, projected to have a similar composition in the future to that of the focal cell in the present, would be calculated for a given observed spatial configuration of ecosystem quality under a given climate scenario. Repeating this calculation for a set of plausible climate scenarios would yield an indicator of the capacity of the ecosystem centred on this focal cell to retain biological diversity in the face of uncertain climate change. This could then be mapped for all cells across New South Wales and/or summarised to report change in relation to any desired spatial reporting unit. The method may be extended be identify places likely to remain sufficiently connected through time and space to support adaptation of the local biodiversity (including dispersal and migration dynamics), or places where the change may exceed capacity to adapt and potentially require intervention (e.g. see Drielsma et al. 2017).

This indicator is in preliminary stages of development and requires consultation and design of methods. A review of and development of data integration methods consistent with an understanding of ecological system interactions are needed. The design of the indicator should allow for future incorporation of data, once available, on changes in the effectiveness of adaptive management of these ecosystems (i.e. indicator 4.3).

Indicator 5.1b: Ecosystem capacity to adapt to change and retain biological diversity under land-use change

This indicator measures the ability of ecosystems to adapt and retain their biodiversity in the face of ongoing and uncertain environmental change, particularly land-use change. It uses the present quality (condition) and spatial-environmental connectedness of ecosystems, through time, under plausible climate change scenarios to report on a key component of ecological integrity. This indicator extends indicator 5.1a by including plausible land-use change scenarios.

This indicator is in preliminary stages of development and requires consultation and design of methods. A review and development of data integration methods consistent with an understanding of ecological system interactions are needed. The design of the indicator should allow for future incorporation of data, once available, on changes in the effectiveness of adaptive management of these ecosystems (i.e. indicator 4.3).

3.7.2 Indicator family 5.2: Capacity to retain ecological functions

This indicator family measures the capacity of ecosystems to adapt and retain their ecological functions in the face of ongoing, yet uncertain, environmental change, including climate change and land-use change.

While more work is needed to shape these indicators, two have been identified for initial review and development (others may be identified subsequently):

- indicator 5.2a: ecosystem capacity to adapt to change and maintain ecological functions under climate change
- indicator 5.2b: ecosystem capacity to adapt to change and maintain ecological functions under land-use change

Indicator 5.2a: Ecosystem capacity to adapt to change and maintain ecological functions under climate change

This indicator measures the ability of ecosystems to adapt and retain the natural dynamics of ecological functions in the face of ongoing and uncertain environmental change, particularly climate change. It draws on information about the capacity to maintain or enhance ecosystem quality (from indicator 4.3a) which, in turn, incorporates information about climate-adapted conservation management (from indicator 4.2c), and applies an assessment of the natural state of ecological functions (from indicator 3.1d) to report on a key component of ecological integrity.

Eco-hydrological models are coupled with a plausible range of climate projections to assess the local resilience of ecological functions, taking into account current capacities of management (from indicator 4.3a) and system status (from indicator 3.1d).

This indicator requires research and development. It is in preliminary stages of development and requires consultation and design of methods. Data integration should be consistent with an understanding of socio-ecological system interactions.

Indicator 5.2b: Ecosystem capacity to adapt to change and maintain ecological functions under land-use change

This indicator measures the ability of ecosystems to adapt and retain the natural dynamics of ecological functions in the face of ongoing and uncertain environmental change, particularly land-use change. This indicator extends indicator 5.2a by including plausible land-use change scenarios.

Eco-hydrological models are coupled with a plausible range of climate projections and of land-use change scenarios to assess the local resilience of ecological functions, taking into account current capacities of management (from indicator 4.3a) and system status (from indicator 3.1d).

This indicator requires research and development. It is in preliminary stages of development and requires consultation and design of methods. Data integration should be consistent with an understanding of socio-ecological system interactions.

3.8 Development of indicator workflows

3.8.1 How indicators may be presented

An indicator may be expressed in multiple ways, depending on the context in which it is used or the scale at which it is aggregated for application. An index (indices plural) is a summary measure of the indicator designed to capture some property of the phenomena being assessed in a single number. An index can also be a way to scale a measure against an initial assessment or can be derived from a composite of measures to facilitate reporting and communication of results.

The process for the production of indicators can be broadly divided into scientific workflow (comprising the data and processes that produce indicator data products), and business workflows (which take the data products, and apply appropriate presentation and interpretation) to produce the final indicator information products (see Figure 8). The scientific workflow is concerned with developing and testing scientifically sound data products for indicators. The business workflow is concerned with developing indicator information products, comprising data visualisations and interpretative information for stakeholders. The business workflow will also need to ensure compliance with appropriate NSW corporate data and web standards and policies.

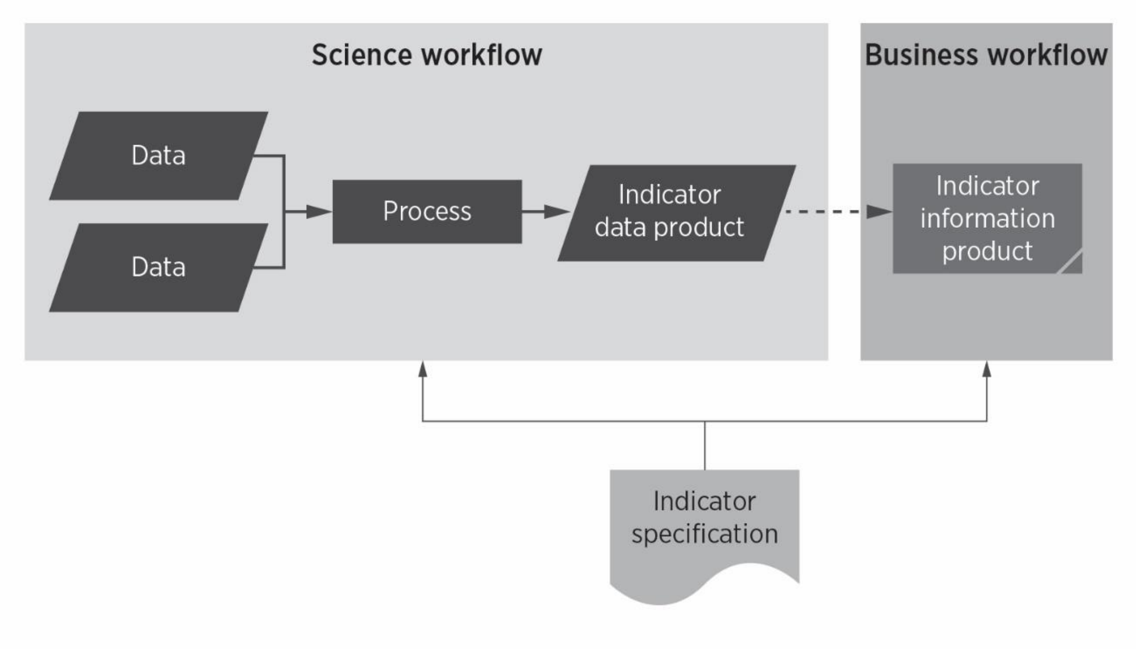

Figure 8 Scientific and business workflows and the role of indicator specifications for presenting data products as information products

For any given indicator there are likely to be a number of options for presentation based on the target audience and nature of the indicator, the nature of the data and process used, and the potential requirement to present the indicator together with supporting information. As part of the specification that will be used to document and communicate the indicator, guidelines and suggestions for appropriate data presentation will be provided.

It is anticipated that indicator data visualisation will comprise:

- indices for each indicator for all of New South Wales and spatial subdivisions of it (where it is relevant to do so), for example, conservation areas, landscapes or bioregions
- spatial information products, that is, maps showing indicator values as surfaces or indicator values aggregated and reported against spatial reporting units such as bioregions, landscapes or administrative reporting boundaries
- tabular and chart data.

We anticipate a variety of map, tabular, chart and index data visualisations will be needed to suit different presentation modalities such as printable A4 PDFs and interactive web-based platforms. Given the interrelated nature of indicators, layered indicator presentations may work best to communicate results. For example, a high level view of indicators in the form of a statewide number and increasingly more detailed data to explore particular aspects of biodiversity, ecological integrity, and supporting information and to indicate uncertainty.

3.8.2 An example indicator workflow

Workflows are being developed as supporting information for communicating the design of each indicator, including the source and derived datasets, analytical or other processes. They are a schematic set of instructions for the recreation of the indicator. Each workflow diagram is designed to stand alone while reflecting links with other indicator components. In order to maintain a minimum level of consistency between the diagrams, a set of workflow design rules are being implemented, as follows:

1. Individual components in each workflow are refered to as data objects. Workflows should contain only the following data objects:
    a. source datasets (SD)
    b. derived datasets (DD)
    c. processes (P) incorporating software/scripts, instructions
    d. synthesis of outputs for report card (RC).
2. Data objects can contain just one or mutiple individual datasets or processes depending on suitability, ease of understanding and flow.
    a. It is possible for multiple processes (P) to be wrapped up into one set of instructions, script or code. Where this occurs, each process must be clearly identified in the documentation.
    b. Multiple datasets may be assigned to a single dataset object (SD or DD) in the workflow.
3. A workflow can start with any available dataset object (SD or DD) but cannot start with a process (P).
    a. Workflow can only start with a DD if that derived dataset has been created in a separate workflow. Otherwise each DD must be preceded by a process (P).
4. A process can contain a simple list of instructions, or comprise a set of processes and datasets within component processes.
    a. The detail of the workflow should be a balance between the need for ease of communication with suitable transparency.
    b. Workflows should be sufficiently simple for technical users to grasp the process, with sufficient detail to enable the process to be repeated.
    c. To assist communication, the detail can be simplified using subprocesses, which expand on the simple list of instructions, or the set of processes with datasets within component processes.
5. The identifiers need to be unique across all workflows. Further details about each uniquely identified item will be provided separately in a master list.
    a. Processes and datasets are reusable in other workflows and will retain their unique ID.
    b. The numbering of identifiers is therefore not necessarily contiguous within a workflow.
    c. As workflows grow/change over time, new data objects can be added anywhere in the workflow using the next available identifier.
6. Colouring:
    a. blue for datasets at time *t* (initial assessment or reference time)
    b. orange for datasets at time *t* plus Δt (initial assessment or reference time plus change in time)
    c. white for datasets that are time-independent
    d. grey for processes.
7. Every dataset has a unique connection to a process.
    a. Arrows connecting should not connect objects (SD or DD) prior to connecting to a process.
    b. If a join is implied, revise the workflow because a missing process and DD is implied.

An example workflow for indicator 1.1a is presented in Figure 9.

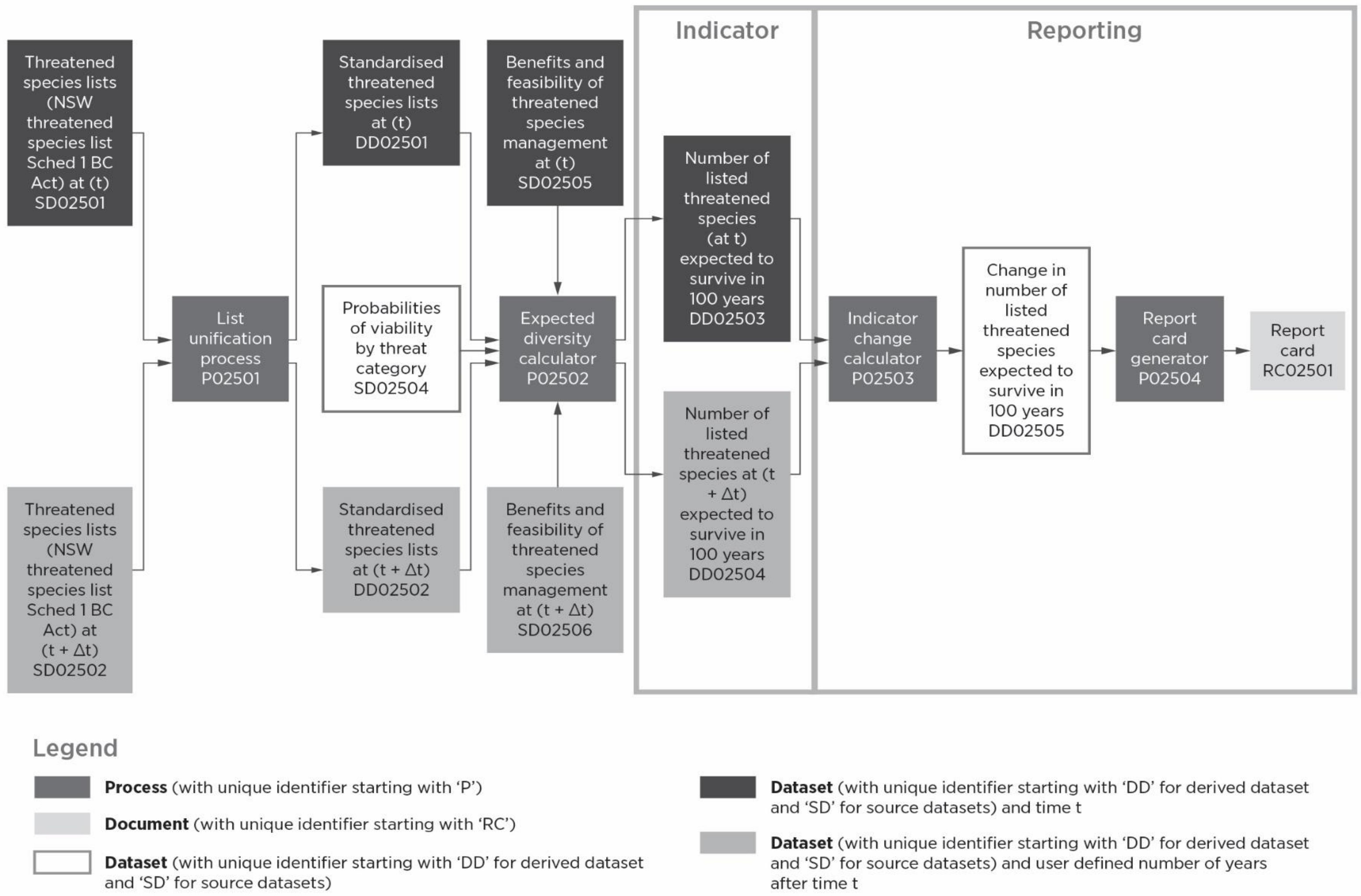

Figure 9 An example workflow for indicator 1.1a: Expected survival of listed threatened species

Each data object (DD = derived dataset; SD = source dataset; P = process; RC = report card) is described as part of the technical methods for the indicator

Glossary of key terms and definitions

Adaptation: responses that decrease the negative effects of change and capitalise on positive opportunities associated with impacts. In relation to biodiversity responses, whether natural or assisted by humans, adaption enables species and ecological processes to adjust and evolve in response to a changed environment.

Adaptive genetic diversity: see genetic diversity.

Adaptive management: involves learning from management actions and using those lessons to improve future management.

Alpha diversity: the diversity at each site (local species pool).

Animal: any animal, whether vertebrate or invertebrate, and in any stage of biological development, but does not include: (a) humans, or (b) fish within the meaning of the *Fisheries Management Act 1994*. Note: some types of fish may be included in the definition of animal and some types of animal may be included in the definition of fish. See s. 14.6 of the *Biodiversity Conservation Act 2016* (BC Act).

Anthropogenic: produced or caused by human activity.

Area of occupancy (AOO): as defined by the NSW Scientific Committee, is the area within the total range (and hence within the extent of occurrence, or EOO) that is currently occupied by the species. It excludes unsuitable and unoccupied habitat. In some cases, (e.g. irreplaceable colonial nesting sites, crucial feeding sites for migratory taxa) the area of occupancy is the smallest area essential at any stage to the survival of existing populations of a taxon.

Area of outstanding biodiversity value: an area declared under Part 3 of the BC Act as being important at a state, national or global level by being irreplaceable or with outstanding value and in need of special protection.

Assessment: use of biophysical data collected through monitoring, combined with other inputs such as benchmarks, to make judgements about environmental condition and trends.

Benchmark: the quantitative measures that represent the ‘best-attainable’ condition, which acknowledges that native vegetation within the contemporary landscape has been subject to both natural and human-induced disturbance. Benchmarks are defined for specified variables for each plant community type. Vegetation with relatively little evidence of modification generally has minimal timber harvesting (few stumps, coppicing, cut logs), minimal firewood collection, minimal exotic weed cover, minimal grazing and trampling by introduced or overabundant native herbivores, minimal soil disturbance, minimal canopy dieback, no evidence of recent fire or flood, is not subject to high frequency burning and has evidence of recruitment of native species.

Beta diversity: the ratio between regional and local species diversity.

Biodiversity (biological diversity): is defined by the BC Act as the ‘variety of living animal and plant life from all sources and includes diversity within and between species and diversity of ecosystems’. It encompasses all the variability among living organisms from all sources, including genetic, species and ecosystem diversity across terrestrial and land-based aquatic realms and certain coastal and marine species. Biodiversity includes both species and ecosystems that are currently known, as well as those that are yet to be discovered.

Biodiversity Assessment Method: this method was established under s. 6.7 of the BC Act for the purpose of assessing certain impacts on threatened species and threatened ecological communities and their habitats, and the impact on biodiversity values, where required under the BC Act, *Local Land Services Act 2013* or the *State Environmental Planning Policy (Vegetation in Non-Rural Areas) 2017*.

Biodiversity conservation: protection of the variety of all life forms including genetic, species and ecosystem diversity from harm or destruction to safeguard the biological support systems on earth.

Biodiversity information program: program/s that can be established by the Environment Agency Head for the collection, monitoring and assessment of information on biodiversity under the BC Act (see s. 14.3) and Regulation (see clause 14.2).

Biodiversity values: include the composition, structure and function of ecosystems, and (but not limited to) threatened species, populations and ecological communities and their habitats.

Bioregion: relatively large land areas characterised by broad, landscape-scale natural features and environmental processes that influence the functions of entire ecosystems and capture large-scale biophysical patterns. These patterns in the landscape are linked to fauna and flora assemblages and processes at the ecosystem scale. There are 17 bioregions represented in New South Wales.

Camera traps: cameras set-up to remotely photograph ('trap') wildlife. Usually equipped with a motion detector to trigger the shot.

Citizen science: the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists.

Climate change: change in the climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is, in addition to natural climate variability, observed over comparable time periods. The Intergovernmental Panel on Climate Change definition refers to a statistically significant variation in either the mean state of the climate or in its variability persisting for an extended period (typically decades or longer). Climate change can be due to natural internal processes or external forces, or due to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate variability: long-term changes in the patterns of average weather of a region or the Earth as a whole.

Community composition: an assemblage or association of populations of two or more different species occupying the same geographical area and in a particular time.

Complementarity: is the marginal gain in biodiversity provided by a location, place or region relative to other locations, places or regions. For example, the complementarity value of an area (for example, National Park A) is given by the number of so-far-unrepresented features of biodiversity that it contributes, relative to other areas (for example, National Parks B to Z). The principle of (biodiversity) complementarity, applied to conservation planning, ensures that places chosen for inclusion in a network of conservation areas complement those already selected in order to increase the overall representation of different features of biodiversity within the network.

Connectivity: the degree to which the landscape facilitates animal or plant movement or spread and ecological flows.

Conservation: in relation to biodiversity, conservation is the protection, maintenance, management, sustainable use, restoration and improvement of the natural environment. In relation to natural and cultural heritage, conservation generally refers to the safekeeping or preservation of the existing state of a heritage resource from destruction or change.

Crown land: Crown land within the meaning of the *Crown Lands Act 1989*, including Crown land dedicated for a public purpose under that Act.

Demand points: used in location-allocation analysis, to be the uniformly distributed set of locations that most efficiently service demands (like the location of fire stations). In ecology, demand points are uniformly distributed locations in continuous environmental space used in the environmental diversity (ED) method to calculate biodiversity complementarity.

Development: has the same meaning it has in the *Environmental Planning and Assessment Act 1979* which includes the use and subdivision of land or the erection or demolition of a building or any other act controlled by an environmental planning instrument.

Dispersal: the spread of animals and plants into new areas.

Disturbance: in relation to ecology, any process or event which disrupts ecosystem structure and resource availability.

Divergence: see genetic divergence.

Ecological carrying capacity: the ability of an area to maintain self-sustaining and interacting populations of all species naturally expected to occur there, given the habitat resources, such as food and water, and connections to other habitat needed for persistence.

Ecological community: an assemblage of species occupying a particular area at a particular time.

Ecological condition: the intactness and naturalness of habitat to support biodiversity, without considering the indirect effects of fragmentation or connections with surrounding suitable habitat.

Ecological connectivity: accounts for the generalised quality of habitats supporting biodiversity at each location, the fragmentation of habitat within its neighbourhood and its position in the landscape (e.g. as part of a habitat corridor or as a stepping stone).

Ecological integrity: is about maintaining the diversity and quality of ecosystems and enhancing their capacity to adapt to change and provide for the needs of future generations.

Ecologically sustainable development: in this case, to maintain or enhance values related to biodiversity and ecological integrity, allowing development without risking greater numbers of threatened species and collapsed ecological communities.

Eco-physiological processes: Ecophysiology is the study of how the environment, both physical and biological, interacts with the physiology of an organism. It includes the effects of climate and nutrients on physiological processes in both plants and animals and has a particular focus on how physiological processes scale with organism size. Examples of eco-physiological processes in plants are respiration, photosynthesis and nutrient uptake. The growth response of plants to climate differs between species, depending on their ecophysiology and life history characteristics.

Ecosystem: a dynamic complex of plant, animal and microorganism communities and their non-living environment that interact as a functional unit. Ecosystems may be small and simple, like an isolated pond, or large and complex, like a specific tropical rainforest or a coral reef.

Ecosystem function: a general term that includes stocks of materials and rates of processes, for example, photosynthesis, respiration, carbon and nutrient cycles.

Ecosystem integrity: supporting and maintaining a balanced, integrated adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of a natural habitat of the region.

EDGE: the EDGE of Existence program is a global conservation program that focuses on evolutionarily distinct and globally endangered (EDGE) species that represent a significant amount of unique evolutionary history. It is a conservation program of the Zoological Society of London.

Effective habitat area: the proportion of residual habitat quality at a site following the impacts of clearing, degradation and fragmentation at the site and in its neighbourhood.

Environment Agency Head: the Chief Executive of the New South Wales Office of Environment and Heritage.

Environmental diversity (ED): is a specific surrogates-based approach to measuring biodiversity complementarity, see section 1.5.6.

Essential biodiversity variables (EBVs): the minimum information needed to quantify significant biodiversity change at a range of geographic scales. They sit as an intermediate layer between primary observations (including remotely sensed data) and indicators and indices. For more information, see essential variables in section 1.5.4.

Essential variables (EVs): the minimum information needed to quantify significant environmental change at a range of geographic scales. They sit as an intermediate layer between primary observations (including remotely sensed data) and indicators and indices. See section 1.5.4.

Expected diversity: the number of features (species, genes, ecosystems) that are expected to be extant in 100 years' time, see section 1.5.5.

Extant: currently existing.

Extent: the area covered by something.

Extent of occurrence (EOO): as defined by the NSW Scientific Committee, the area of the total geographic range that includes all extant populations of the species.

Extinction debt/lag: the future extinction of species due to events in the past, such as clearing of habitat. Generally refers to the *number of species* in an area likely to become extinct, rather than the prospects of any one species, but colloquially it refers to any occurrence of delayed extinction.

Extinction risk: a measure of the actual or potential decline and extinction over time of a species or other defined ecological unit (e.g. ecological communities).

Forb: an herbaceous flowering plant other than a grass.

Fragmentation: the division of continuous habitat by vegetation clearance for human land-use activities, which isolates the remnant patches of vegetation and the species within them and limits genetic flow between populations.

FRAGSTATS: is a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns, developed originally by Oregon State University.

Fungi: a diverse group of microorganisms in the taxonomic kingdom of Fungi, including mushrooms, moulds, mildews, smuts, rusts and yeasts.

Generalised dissimilarity modelling (GDM): a statistical technique for analysing and predicting spatial patterns of change in community composition across large regions. See section 1.5.1.

Generalised linear model (GLM): a flexible generalisation of ordinary linear regression that allows for response variables that have error distribution models other than a normal distribution.

Genetic composition: also 'population genetics'. The distribution in frequency of alleles (make-up of gene variations) that occurs within species or populations.

Genetic divergence: the process in which two or more populations of an ancestral species accumulate independent **genetic** changes (mutations) through time, often after the populations have become reproductively isolated for some period of time.

Genetic diversity: the range of intrinsic differences in genes among individual organisms within a species, or among different species within a taxonomic group. There are several hypotheses to account for the emergence of genetic diversity. The two considered here are neutral and adaptive genetic diversity. Neutral genetic diversity results from the accumulation of neutral substitutions (i.e. processes such as gene flow, migration or dispersal which are influence by the spatial configuration of habitats and their relative connectivity across whole landscapes). Adaptive genetic diversity results from subpopulations of a species living in different environments that select for different alleles at a particular locus.

Geographic scale: the ratio of a distance on a map to the corresponding distance on the ground. Here, used to indicate how much area we are looking at, such as locally (based on a small site or area, able to be defined as a unit, such as a town or a forest), regionally (for example, the Murray–Darling Basin) or nationally (across Australia).

Habitat: an area or areas occupied, or periodically or occasionally occupied, by a species, population or ecological community, including any biotic or abiotic component.

Habitat condition: the capacity of an area to provide the structures and functions necessary for the persistence of all species naturally expected to occur there in an intact state.

Habitat corridor: an area of habitat connecting wildlife populations separated by human activities or structures (such as roads, development or logging).

Habitat fragmentation: the emergence of discontinuities (fragmentation) in an organism's preferred environment (habitat), causing population fragmentation and ecosystem decay.

HCAS: the habitat condition assessment system method (Harwood et al. 2016), a novel approach to environmental modelling designed to work with sparse site data to calibrate remote sensing applied across large areas.

Heuristic: in a mathematical sense, a method to solve a problem, one for which no algorithm exists and which therefore depends on inductive reasoning from past experience of similar problems

Index (plural indices): a metric used to quantify the information represented by an indicator.

Indicators: specific, measurable characteristics that show trends or changes in the status of something — in this report, changes in the status of biodiversity and ecological integrity. See section 1.2.1.

Invasive species: a plant or animal that has been introduced into a region in which it does not naturally occur and that becomes established and spreads, displacing naturally occurring species.

Invertebrates: animals without backbones, such as insects, worms, snails, mussels, prawns and cuttlefish.

Irreplaceability: an inability of a species or ecosystem to be replaced, often because of uniqueness. In conservation planning, irreplaceability reflects how important a specific area is for the efficient achievement of conservation objectives (e.g. retention of species and ecosystems). A completely irreplaceable area is considered essential for meeting conservation objectives, whereas an area with low irreplaceability can be substituted by other sites.

IUCN: International Union for the Conservation of Nature, a union of government and non-government organisations that provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together.

Kernel regression: a non-parametric technique in statistics to estimate the conditional expectation of a random variable. The objective is to find a non-linear relation between a pair of random variables, X and Y.

Keystone species: a species that is vital, due to its fundamental role in an ecosystem.

Key threatening process: a threatening process listed in Schedule 4 of the BC Act. Processes are listed by the NSW Scientific Committee if they adversely affect threatened species or ecological communities or could cause species or ecological communities that are not threatened to become threatened.

Land cover: the biophysical cover on the Earth's surface, including native vegetation (woody and non-woody vegetation), soils, exposed rocks and waterbodies as well as man-made elements such as plantations, crops and built-up areas.

Landscape: a heterogeneous area of local ecosystems and land uses that is of sufficient size to achieve long-term outcomes in the maintenance and recovery of species or ecological communities, or in the protection and enhancement of ecological and evolutionary processes.

Listed threatened ecological communities: ecological communities listed as threatened in the BC Act.

Listed threatened species: species listed as threatened in the BC Act.

Living Planet Index: the Living Planet Index is a measure of the state of the world's biological diversity based on population trends of vertebrate species from terrestrial, freshwater and marine habitats. It is managed by the Zoological Society of London in a collaborative partnership with WWF.

Long-term datasets: repeated measurements that are collected continuously and then analysed for at least 10 years.

Modelling: computational simulation of a process, concept or the operation of a system.

Models: an abstract, usually mathematical, representation of a system which is studied to gain understanding of the real system. See section 3.2.1.

Monitoring: in this context, activities to collect new biophysical data.

Neutral genetic diversity: see genetic diversity.

New South Wales Threatened Species List: refers to all threatened species listed in Schedules 1 and 3 of the BC Act.

New South Wales Threatened Ecological Communities List: refers to all threatened ecological communities listed in Schedules 2 and 3 of the BC Act.

Non-woody vegetation: for vegetation monitoring using Landsat MSS satellite sensors, vegetation formations that are less than 2 metres high or with less than 20% canopy cover (mainly grasslands, arid shrublands and woodlands).

Phenology: the science dealing with the influence of climate on the recurrence of annual phenomena of animal and plant life, such as flower budding and bird migration.

Phylogenetic diversity (PD): a measure of biodiversity which incorporates phylogenetic difference between species, often within a taxonomic group. For more information, see section 1.5.7.

Plant: any plant, whether vascular or non-vascular and in any stage of biological development in the taxonomic kingdom of Plantae. Note that under the NSW biodiversity legislation, 'plant' includes fungi and lichens (but not marine vegetation which is under fisheries legislation).

Power curve: in ecology, a power curve describes the non-linear relationship between an increasing number of biodiversity features (genes, species or ecosystems) and increasing area sampled (or number of locations).

PREDICTS: Projecting responses of ecological diversity in changing terrestrial systems is a collaborative project aiming to use a meta-analytic approach to investigate how local biodiversity typically responds to human pressures such as land-use change, pollution, invasive species and infrastructure and ultimately improve our ability to predict future biodiversity changes. The project is a collaboration between the Natural History Museum (London UK), the UN Environment World Conservation Monitoring Centre and several British universities.

Pressures: threats in the landscape that cause biodiversity loss or threaten the quality of ecosystems, including key threatening processes listed under Schedule 4 of the BC Act as well as other threats not listed on the BC Act.

Private land conservation agreements: a biodiversity stewardship agreement, a conservation agreement or a wildlife refuge agreement under Part 5 of the BC Act.

Proxy: in this context, a species or group of taxa used as substitutes for other taxa. See also ‘representative’ and ‘surrogate’ species.

Rarefaction methods: techniques to assess species richness from the results of sampling. Rarefaction allows the calculation of species richness for a given number of individual samples, based on the construction of so-called rarefaction curves. This curve is a plot of the number of species as a function of the number of samples. Rarefaction curves generally grow rapidly at first, as the most common species are found, but the curves plateau as only the rarest species remain to be sampled.

Red List of Ecosystems: a global standard for how to assess the risk of extinction status of ecosystems, applicable at local, national, regional and global levels. Under the auspices of the IUCN.

Red List of Species: a global standard for how to assess the risk of extinction status of species, applicable at local, national, regional and global levels. Under the auspices of the IUCN.

Reference sites: sites used to establish benchmarks of environmental condition.

Remnant: in relation to ecology, is a small, fragmented portion of vegetation that once covered an area before being cleared.

Remote sensing: a means of acquiring information using airborne or satellite equipment and techniques to determine the characteristics of an area; most commonly using imagery from aircraft and images from satellites.

Representative species: a species (or subset of species) that represents or is typical of that group of species. For more information, see section 1.5.2.

Sensitivity analysis: a technique used to determine how different values of an independent variable impact a particular dependent variable under a given set of assumptions. Enables ordering, by importance, of the strength and relevance of the inputs in determining the variation in the output from a model.

Spatial resilience: an ecological integrity indicator that aims to measure the capacity of terrestrial ecosystems to retain their biological diversity in the face of climate change, as a function of the quality (condition) and spatial-environmental connectedness of these ecosystems, through time.

Species: a taxon comprising one or more populations of individuals capable of interbreeding to produce fertile offspring.

Species–area relationship: the relationship between the area of a habitat, or of part of a habitat and the number of species found within that area (see power curve).

Species distribution: the geographic extent and range of environments in which a species is found.

Species richness (SR): the number of species within an area.

Species richness response: the response of SR to changes in or to the area in which the species inhabit.

Status: the condition or 'health' of a species, population, community, habitat or ecosystem.

Stepping stone: patches of habitat that help reduce the effects of fragmentation by facilitating dispersal of species or their propagules among otherwise isolated habitat areas.

Suitable habitat: suitable habitat is predicted by identifying where each species lived originally and its associated environment.

Surrogate, biodiversity: a species, group of species or ecosystem that can be used as a substitute for wider biological groups, see section 1.5.3.

Sustainability: environmentally sound resource use; use that does not degrade ecosystems or affect the quality of the resource.

Taxonomic diversity: the variety of plant or animal groups at various taxonomic levels (e.g. species, genus, family) that are found to live in a defined area.

Trends: directions of significant change in the environment, as shown by the changing values of measures (like essential variables, indicators or indices).

Vascular plant: plants containing vascular tissue (i.e. tissue specialised for the conduction of fluids); the more highly evolved plants above mosses and liverworts.

Vegetation condition: the health of native vegetation communities which reflects the level of naturalness and is commonly assessed against a benchmark, considering factors such as structural integrity, species composition, presence or absence of weeds and diseases and reproduction of species.

Vegetation integrity: being the degree to which the composition, structure and function of vegetation at a particular site and the surrounding landscape has been altered from a near-natural state.

Vegetation structure: the organisation of plants within a plant stand or assemblage consisting of one or more layers or strata.

Vertebrates: animals with backbones and spinal columns, including fishes, sharks and rays, amphibians, reptiles, mammals and birds.

Woody vegetation: for vegetation monitoring using Landsat MSS satellite sensors, vegetation formations (mainly woodlands and forests) that are over 2 metres high and with more than 20% canopy cover; also known as 'detectable native forest'.

Acronyms and abbreviations

Abbreviation	Meaning
AOO	Area of occupancy
BC Act	*Biodiversity Conservation Act 2016*
BC Regulation	Biodiversity Conservation Regulation 2017
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DD	Derived dataset
DI	Disturbance Index
ED	Environmental diversity
ED–SGA	Environmental diversity – survey gap analysis
EDGE	Evolutionarily Distinct and Globally Endangered
EHA	Effective habitat area
EOO	Extent of occurrence
eMAR	Environmental monitoring assessment and reporting
EV	Essential variables
GDM	Generalised dissimilarity modelling
GLM	Generalised linear model
HCAS	Habitat condition assessment system
IUCN	International Union for the Conservation of Nature
LUE	Light-use efficiency
OEH	Office of Environment and Heritage
PD	Phylogenetic diversity
PREDICTS	Projecting responses of ecological diversity in changing terrestrial systems
RC	Report card
RPSB	Response–pressure–state–benefit
RUE	Rain-use efficiency
s.	section of Act
SD	Source datasets
SR	Species richness

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