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Using the essential biodiversity variables framework to measure biodiversity change at national scale

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ABSTRACT

The essential biodiversity variables (EBV) framework was developed primarily to improve the detection of significant changes in global biodiversity. Its application at national level must support county-specific policy and management needs as well as allowing comparisons of estimates of biodiversity change between countries and their aggregation for reporting at regional, continental and global scales.

Here we outline a process for prioritising biodiversity variables at national scale using the EBV framework. The process involves separately identifying candidate EBVs that are useful for tracking important changes in biodiversity in each major ecological feature in each ecoregion within a country. The list is then prioritised based on the proportion of ecological feature ecoregion combinations using each variable within and across terrestrial, marine and freshwater realms.

We showcased this process in Australian state of New South Wales (NSW) using terrestrial, marine and freshwater ecoregions of the world as bioregional strata; vegetation formations as terrestrial ecological features, and broad aquatic ecosystem types as marine and freshwater ecological features. There was sufficient knowledge of ecological processes to identify useful variables for 85% of the ecological feature ecoregion combinations in NSW. Eleven candidate EBVs covering all six EBV classes, were useful in all three environmental realms.

Our structured, stepwise approach to variable selection provides a transparent process for identifying important elements of ecological theory underpinning biodiversity monitoring within countries. Worldwide adoption of a process for prioritising biodiversity variables such as the one we propose here would help ensure consistency of national contributions to global biodiversity assessments.

1. Introduction

Biodiversity is changing across the world and this change is mostly negative (Butchart et al., 2010; Tittensor et al., 2014). Documenting and quantifying global biodiversity change is still a huge challenge due to sparse or biased data and a general lack of agreed international data standards. These barriers make it difficult to consistently aggregate variables across time, space and taxa. A recent important step in this direction is the development of the Essential Biodiversity Variables (EBV) framework by the Group on Earth Biodiversity Observation Network (GEO BON) with the aim of distilling the complexity of biodiversity into a manageable list of priority measurements (Brummitt et al., 2016). This framework recognises three distinct levels of biodiversity information: primary observations; Essential Biodiversity Variables; and biodiversity indicators. EBVs are viewed as enduring entities insulated from changing technologies at the observation level and from changing approaches and information needs at the indicator level

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(Pereira et al., 2013). GEO BON's EBV framework contains two levels of hierarchy. At the higher level are EBV classes each of which represents a major dimension of biodiversity (Pereira et al., 2013). Below this are the variables or groups of variables. The six EBV classes proposed by Pereira et al. (2013) are now widely adopted as part of the EBV framework (Geijzendorffer et al., 2015; Chandler et al. 2016; Turak et al. 2016). An unofficial list of 22 EBVs was proposed in the report of the 17th meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA; UNEP/CBD/SBSTTA/17/INF/7) and a rigorous process for the development and endorsement of EBVs was proposed, using these candidate EBV as a starting point GEO BON (2015). The EBV framework will help globally consistent reporting of changes in the state of biodiversity but it is unlikely to contribute much to stemming the decline of biodiversity unless it can be effectively applied at scales of relevance to conservation decision-making (Henle et al., 2014).

Conservation programs and activities are usually guided by a jurisdiction's policy, legislation and institutional arrangements which may vary in objectives and outcomes for biodiversity, when compared globally. Managing authorities have a critical role in allocating funds for coordinating biodiversity monitoring, assessment and reporting within their jurisdiction. Shaping national and sub-national biodiversity monitoring programs around a common approach for implementing the EBV framework may enable two important processes that have remained elusive to date 1) comparison of rates of biodiversity change between jurisdictions across the world; and 2) coordination and harmonisation of biodiversity observation and measurement data across multiple jurisdictions.

If individual governments are to adopt and implement the EBV framework, they must be convinced of tangible benefits beyond meeting international obligations. In a significant departure from previous approaches to biodiversity indicator development, the EBV concept is theory-driven rather than data-driven (Geijzendorffer et al., 2015), can be applied to multiple spatial scales (Pereira et al., 2013) and is independent of measurement methods (Pettorelli et al., 2016) and environmental problems (Latombe et al., 2016). Its adoption should help to improve comprehensiveness, efficiency and usefulness of biodiversity monitoring data within and between jurisdictions by clarifying gaps and prioritising efforts towards measures capable of detecting change. No guidance has yet been provided about what steps need to be taken to apply the EBV concept at the national level although efforts are underway, e.g. in Australian State of New South Wales (NSW), Colombia, and France.

In this paper, we develop a process of identifying and prioritising a set of variables for assessing and reporting on broad-scale change in the state of biodiversity that is consistent with the EBV framework. Our aim was to define a transparent, repeatable, stepwise process in which elements of ecological theory underpinning biodiversity monitoring are identified, and where understanding of biological entities and processes has been documented. Further the approach should be applicable to any jurisdiction not only to NSW as chosen as a case study here.

2. Methods

2.1. Study area

The Australian State of New South Wales (NSW) (land area: 801,428 km^2) is well suited for developing and testing this process. At a global scale of ecological classification, NSW environments can be characterised by nine terrestrial regions (TEOW Olson et al., 2001), three freshwater regions (FEOW, Abell et al., 2008) and four marine regions (MEOW, Spalding et al., 2007) (see Appendices 1 and 2 for maps showing these regions in NSW).

Over the past three decades, conservation agencies within NSW have led, or contributed to, many globally significant advances in the theory and practice of both area-based and feature-based biodiversity conservation. These include the development of new methods of spatial prioritisation for conservation (Margules and Pressey, 2000; Ferrier et al., 2000; Ferrier and Drielsma, 2010), applied to terrestrial biodiversity using individual species and plant community types as ecological features (Ferrier et al., 2002; Drielsma et al., 2014) and to freshwater biodiversity using aquatic faunal assemblages in rivers (Turak et al., 2011). NSW has a comprehensive, systematic program for conserving threatened species and ecological communities using a Project Prioritisation Protocol (Joseph et al., 2009). NSW trialled the IUCN Red Listing for threatened ecosystems (Keith et al., 2013, 2015), a new method for assessing protected area management effectiveness (Growcock et al., 2009; Hockings et al., 2009), and the IUCN Green List of Protected and Conserved Areas (IUCN, 2016). The two Australian sites chosen for Green Listing in 2014 are from NSW (IUCN, 2016). There has been substantial effort towards comprehensively measuring terrestrial, freshwater, and marine biodiversity at broad spatial scales, supported by conceptual models linking management options to biodiversity condition (e.g. Claus et al., 2011). Importantly, in September 2015 the NSW, Office of Environment and Heritage (OEH, the main government conservation agency in NSW) adopted the concept of essential variables as the corner stone of its new Environmental Monitoring, Assessment and Reporting (EMAR) Framework.

2.2. Evaluation of the EBV framework by experts and practitioners

As a first step in exploring the suitability of the EBV framework for assessing biodiversity condition in NSW, a one-day workshop was held on 25 May 2015 in Sydney. The participants were experts, practitioners and decision-makers involved in biodiversity assessments in NSW, in other parts of Australia and internationally. One of the aims of the workshop was to capture the views of the participants on the usefulness, scale of application and feasibility of each candidate EBV. Here we use the workshop outputs to do two things: 1) compare and contrast the views of the participants with the thinking behind the EBV framework; and 2) use these insights to interpret the outcomes of the stepwise process.

2.3. A stepwise process for applying ecological theory to prioritise biodiversity variables

The prospects of very slow progress towards globally agreed EBVs was our main reason for setting out to develop a scientifically rigorous process for applying the EBV framework in NSW. We sought to establish a process based on system-level knowledge of biodiversity which would meet the need for biodiversity information at local, regional and State scales. The process needed to quickly generate a reliable and relatively short list of EBVs for NSW from GEOBON's candidate variables but it also had to be repeatable and flexible allowing NSW to adopt and use globally agreed EBVs when they are finalised. The first steps in developing this process were taken by experts within OEH. We later expanded this group to include experts involved in Australia-wide and global initiatives on biodiversity monitoring especially those aiming to implement the EBV framework in broad-scale biodiversity assessments.

The approach by Hayes et al. (2015) for selecting essential variables for assessing the condition of Australian marine ecosystems provided a good foundation for developing a stepwise process for applying the EBV framework at national scale. Central to that approach (Hayes et al., 2015) was the use of qualitative models that show how implementing specified management actions may reduce pressures and improve biodiversity condition across key ecological features (KEFs)—parts of the marine ecosystems that are considered to be important for a region's biodiversity or ecosystem function and integrity. They defined KEFs as having regionally or nationally important species, group of species, communities, areas or habitats because of their ecological role, high biodiversity or endemism, high aggregation of marine life, enhanced biological productivity or unique sea-floor features (Hayes et al., 2015).

We extended this approach to help identify indicators for measuring change in biodiversity across an entire jurisdiction (Fig. 1). Instead of being confined to KEFs, our approach potentially allows development of qualitative models for all ecological features in the land and sea. We define ecological features as ecosystems or parts thereof, which have a defined contribution to the biodiversity character or ecological integrity of a region, inclusive of the processes and drivers involved. The qualitative models hereafter referred to as conceptual models use a Response-Pressure-State-Benefit (RPSB) framework (Butchart et al., 2010; Sparks et al., 2011). The RPSB approach is useful to apply to jurisdictions because it starts from management actions (responses), shows how this flows on to pressures, then onto biodiversity condition (state) and then finally demonstrates how effective actions improve values to society (benefits).

The first step in the process we propose is the identification of ecological features for terrestrial, marine and freshwater environments (Fig. 1). We used bioregional boundaries to help stratify, organise and test for completeness of ecological system knowledge, and to guide the scale and classification hierarchy expected for ecological feature conceptual models. Bioregions are a familiar concept for most jurisdictions for reporting on biodiversity conservation outcomes. For global consistency, we used the Terrestrial Ecoregions of the World (TEOW, Olson et al., 2001) and its equivalents in freshwater and marine environments (FEOW, Abell et al., 2008; MEOW, Spalding et al., 2007). (see online appendices for these maps).

2.3.1. Identifying ecological features

Using existing and widely applied ecological typologies, we grouped ecosystems supporting similar ecological communities, sharing common ecological processes, or faced with common anthropogenic pressures. We also took particular care to identify ecosystems, or groups of ecosystems, exhibiting centres of species richness or endemism, and or distinct intrinsic biodiversity values (Ghilarov, 2000). These features may often be matched to distinct management strategies and actions (responses), represent a socio-ecological icon (benefit) and are subject to programs involving large investments, and are of particular importance to a jurisdiction. We defined ecological features as specific to an environmental realm (terrestrial, marine, and freshwater) and used their bioregional context (TEOW, FEOW or MEOW) to test for additional geographic uniqueness. For terrestrial ecological features, we used NSW vegetation formations (Keith, 2004, Table 2). For freshwater ecological features, we used broad classes under the Australian National Aquatic Ecosystem Classification (Aquatic Ecosystems Task Group, 2012) and a wetland classification used for reporting on wetland condition in NSW (Claus et al., 2011) (see online Appendices). The five freshwater ecological features were riverine floodplains, river channels, groundwater-fed wetlands, rain-fed wetlands, and subterranean aquatic ecosystems. For marine ecological features, we selected the five major habitat features that are commonly used and agreed on: rocky shores, beaches, rocky reefs, estuaries (MEMA, 2016) and offshore islands (see online Appendices).

2.3.2. Identifying biodiversity state variables from conceptual models

We identified variables potentially useful to measure using either existing conceptual models or tacit knowledge of ecological processes available for development of conceptual models. We attempted to match this knowledge to each ecological feature ecoregion combination (Fig. 1). We assigned each ecological feature ecoregion combination to one of the following three categories: A) suitable models already exist; B) such models have not been developed yet but ecological processes, threats and management options are understood well enough to develop these models; and C) knowledge of ecological processes, threats and management options needed to develop models is not readily available. This assessment was based on evidence from peer-reviewed scientific literature and government reports. We then classified all state variables derived from conceptual models in categories A and B, and matched these to the list of candidate EBVs (GEO BON, 2015).

A major source of information on conceptual models in the terrestrial realm was recent publications exploring the application of IUCN Red Lists of Threatened Ecosystems (Keith et al., 2013). This work was underpinned by two key concepts: "ecosystem types" and "ecosystem collapse" (Keith, 2015). Metcalfe and Lawson (2015) developed a conceptual model of rainforests that is applicable to NSW rainforests. Past and ongoing habitat loss/decline, degradation by exotic species, changes

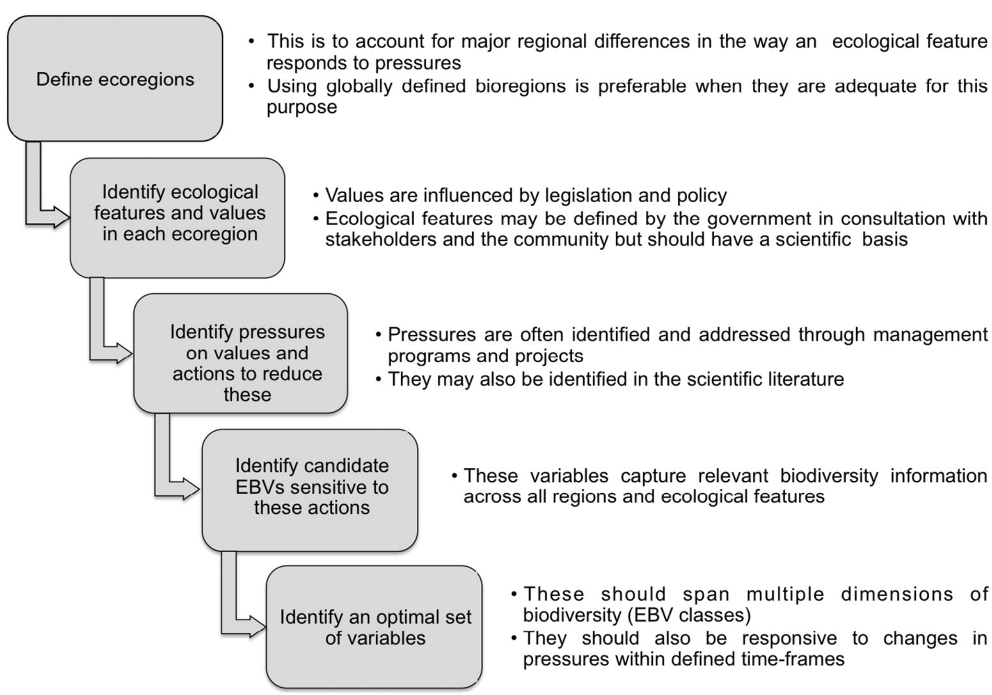

Fig. 1. A variable selection process to help determine what information is needed to determine how biodiversity is changing. The boxes linked with arrows describe major steps in the process. The text beside each box gives the context of these steps. In this process ecological features are the main landscape units for which 1) values and pressures are identified, 2) management actions aimed at reducing these pressures are planned and implemented; and 3) biodiversity state variables used in monitoring assessment and reporting are selected.

to fire regimes and climate impacts (changes to storms and rainfall, heat stress, new pathogens) are all major factors driving reduced species occupancy, simplified structure, and species composition in rainforests (Metcalfe and Lawson, 2015). Keith et al. (2013) provide a model for upland wet heathlands that can be readily applied to dry heathlands. Keith and Tozer (2012) provide specific details for heaths in Sydney Basin. When combined across these domains, key elements are fire regimes, competition, moisture availability, weeds, soil depth, and topography. Tozer et al. (2015) developed a conceptual model for Cumberland Plain Woodland that could be applied broadly to Dry Sclerophyll forests. This model identifies the key pressures on dry sclerophyll forests as clearing, fragmentation, weeds, fire, grazing, and competition. Williams et al. (2015) identified key elements for maintenance of High Alpine Herbfields that could be used to derive a model. Key pressures that drive change in alpine environments are feral animals (livestock grazing, horses, deer, rabbits), weeds, fire regimes, snow cover duration, competition (expansion of heathland at the expense of grasslands and herb fields) and climate change (Williams et al., 2015). Another source of information for terrestrial biodiversity was White (2012) containing ecosystem conceptual models for the Australian State of Victoria focus on protected area management.

In the marine realm there is a long history of using conceptual models to guide the selection of variables for monitoring (MEMA, 2016). For riverine ecosystems, and some wetland types, we relied on generalised models of ecosystem function (e.g. Vannote et al., 1980; Junk et al., 1989; Poff et al., 1997; Acreman et al., 2009). For most wetland types we used the models developed for the NSW Wetlands Monitoring Evaluation and Reporting Programs (Claus et al., 2011).

2.3.3. Prioritising variables

Once the ecological features were matched to the biodiversity state variables used by the models, it was possible to determine which of these could be used for the same features in different ecoregions or for multiple features within one ecoregion (Appendices S5 to S7). The variables that would be useful to measure in a large proportion of the ecological feature ecoregion combinations could be prioritised as candidate essential variables for NSW, especially if they were generally well spread across ecoregions and features, and across realms.

3. Results

3.1. Expert and practitioner evaluation of candidate EBVs

Six of the 22 candidate EBVs (Table 1) were assessed as high priority at the workshop based on their usefulness for measuring biodiversity change at different spatial scales (local, regional and State) and the estimated magnitude of additional resources needed to measure these. Ten variables were considered as medium priority including the four candidate EBVs in the genetic composition EBV class which the workshop treated as one variable (genetic differentiation within species). Assessments were not made of the remaining six variables for a variety of reasons, such as, the variable was not considered important, it needed to be included as part of another variable, or the views in the workshop were too divergent to arrive at an agreed assessment.

3.2. Conceptual models for ecological features of NSW

By applying the stepwise process (Fig. 1.) in NSW we concluded that there was currently sufficient knowledge of ecological processes to develop conceptual models for 68 of the 80 ecological feature ecoregion combinations and that suitable models already existed for 19 of these (Table 2, Appendices S3, S4).

The results of the application of the process (Table1) are based on an analysis that includes 10 Terrestrial ecological feature ecoregion combinations that were marginal i.e. only a very small part of the ecological feature was present in that region (Table 2). We included four of these in the analyses because these fragments may be unlike the much larger representatives if the same ecological feature in other ecoregions.

3.3. Use of candidate EBVs in conceptual models

Nineteen of the 22 candidate EBVs were identified as biodiversity state variables that are useful for assessing the condition of biodiversity in one or more ecological feature ecoregion combination (Table 1). Large differences among chosen candidate EBVs were attributed to environmental realm (terrestrial, marine or freshwater, within a given ecoregion but there was very little variation among ecoregions in the identified variables for a given ecological feature.

4. Discussion

We here developed a scientific basis for prioritising observations and measurement of variables for routine and broad-scale assessment of biodiversity for jurisdictions (Fig. 1). We then demonstrated how this process may be applied in NSW. For jurisdictions and conservation administrations, an approach like ours would help to prioritise and improve biodiversity monitoring. Our process relies on the availability of knowledge of ecological processes to develop conceptual models of ecological features. For the purposes of our case study we identified that to a large degree adequate knowledge already exists. While NSW is relatively rich in biodiversity data compared with many other jurisdictions around the world, it is probably data-poor compared with many European countries and North America. Regardless of whether more, or less work is needed to build knowledge of ecological processes, the method we propose here is still applicable in other jurisdictions and scales across the world. Our analysis, however, shows that even in regions where little is known about ecological processes, the method we propose here can provide a transparent and rigorous basis for selecting biodiversity condition variables.

By applying this process in NSW we concluded that there was currently sufficient knowledge of ecological processes to develop conceptual models for a very large proportion (85%) of ecological feature ecoregion combinations and that suitable models already existed for a quarter. However, the accuracy of this conclusion is likely to vary greatly among ecoregions and ecological features. The information available on conceptual models relevant to an ecological feature in any given ecoregion was not synthesised or even compiled in a single publication and some of this information was difficult to obtain. Hence investing a greater amount of effort into obtaining this information is likely to alter the results. It is possible that there is enough knowledge to develop conceptual models for some of the ecological feature ecoregion combinations where we concluded that there was not enough information e.g. offshore islands and semi-arid woodlands. We relied on experts to decide on whether a conceptual model developed somewhere else was applicable to a given ecological feature ecoregion combination, but the level of expertise available was uneven across ecological features and ecoregions. Hence it is likely that some important differences in ecosystem processes between ecoregions are missed, especially for arid and semi-arid regions of NSW.

The ecosystem-based approach we have developed presents some challenges regarding individual species programs such as threatened or flagship species that are locally iconic, which we have not addressed here. The EBV framework generally does not consider threatened or flagship species individually, rather, the framework focuses on a comprehensive documentation of biodiversity change. However, some organisations or jurisdictions may have a statutory requirement to evaluate and report on outcomes for such species. In such instances, methods for identifying target species to monitor are manifold (Schmeller et al., 2008), and can be e.g. topical (Henle et al., 2013) or based on national responsibilities (Schmeller et al., 2012). To properly represent threatened species under the EBV framework, they should be treated as a distinct stratification across the ecoregion EF matrix,

Table 1
Usefulness of candidate EBVs for biodiversity assessments NSW. The third column captures agreed outputs from a workshop attended by experts, stakeholders and decision makers. The figures in the last four columns were derived by applying the stepwise process we developed here. The grey shaded rows show the 11 candidate EBVs that correspond to variables identified in all three environmental realms.

EBV Class	Candidate EBV	Assessment at expert/stakeholder/ decision maker workshop	% of ecological features for which the variable is useful			
			All	Terrestrial	Marine	Freshwater
Species populations	Species distribution	Very useful at regional and State scales; can be measured with existing resources; high priority.	100	100	100	100
	Population abundance	Very useful at all spatial scales; additional resources are needed; high priority	72	100	–	71
	Population structure	Very useful at local and regional scales; substantial resources are needed; medium priority	47	28	100	43
Genetic composition	Co–ancestry	The four variables in this EBV class were regarded as one variable: genetic differentiation within species.	9	5	–	29
	Allelic diversity	As above; very useful at all spatial scales; substantial additional resources are needed; medium priority	–	–	–	–
	Population genetic differentiation	As above	31	3	100	36
	Breed & variety diversity	As above	–	–	–	–
Species traits	Phenology	Very useful at all spatial scales; additional resources are needed; medium to high priority.	31	41	–	33
	Body mass	An agreed assessment was not achieved.	–	–	–	–
	Natal dispersal distance	(dispersal); very useful at regional to State scales; additional resources needed; medium priority	4	–	–	20
	Migratory behaviour	Very useful at regional to State scales; additional resources are needed; high priority.	43	8	100	80
	Demographic traits	Very useful at all spatial scales; additional resources are needed; high priority.	23	31	–	20
	Physiological traits	Very useful at local to regional scales; additional resources are needed; medium priority.	74	100	–	73
Community composition	Taxonomic diversity	Useful at all spatial scales; additional resources are needed; medium priority.	94	100	100	73
	Species interactions	It was recommended that this be named “interaction” and regarded as part of ecosystem function.	62	100	–	20
Ecosystem function	Net primary productivity	Useful at all spatial scales; may be measured with existing resources; high priority.	69	59	100	67
	Secondary productivity	An agreed assessment was not achieved.	35	–	100	67
	Nutrient retention	An agreed assessment was not achieved.	57	67	47	47
	Disturbance regime	An agreed assessment was not achieved.	91	100	73	87
Ecosystem structure	Habitat structure	Useful at local to regional scales; additional resources are needed; medium priority.	84	92	73	73
	Ecosystem extent & fragmentation	(community); Very useful at all spatial scales; may be measured with existing resources; high priority.	84	90	100	53
	Ecosystem composition by functional type	An agreed assessment was not achieved	50	26	100	67

Table 2
Availability of bioregional conceptual models in NSW that link biodiversity condition within terrestrial key ecological features (vegetation formations, Keith, 2004) to management action. Dark grey cells are where there is clearly large enough area covered by this vegetation type to include it in the ecoregion, medium grey shading indicates that this vegetation type may be marginal, and light grey shading shows where only very small fragments are present. The three categories of feasibility are: A) Suitable models already exist; B) Such models have not been developed yet but ecological processes, threats and management options are understood well enough to develop these models C) Knowledge of ecological processes, threats and management options needed to develop models is not readily available.

Ecoregion	Arid shrublands	Semi–arid woodland	Grassy woodands	Grassland	Rainforest	Dry sclerophyll forests	Wet sclerophyll forests	Alpine complex	Heathand
Eastern Australian Temperate Forests		C	A	B	A	A	B		A
Southeast Australia Temperate Forests		C	B	B	B	B	B	C	A
Brigalow Tropical Savanna	B	C	B	B	B	B	C		B
Eastern Australia Mulga Shrublands	B	B		B					
Southeast Australia Temperate Savanna	B	B	B	B		B			
Australian Alps Montane Grasslands			A	A	C	B	B	A	
Murray–Darling Woodlands & Mallee	B	B	B	C		B			
Simpson Desert	B	B		C					
Tirari–Sturt Stony Desert	B	B		C					

given their response to pressures and management will often differ from other more common species within the same system. While a systematic framework for allocating resources at the species level is also needed, differences will always exist because jurisdictions must respond to local socio-ecological values requiring uneven monitoring of some elements of their biodiversity.

A major strength of the approach we propose here is the strong link between monitoring and management applicable to an adaptive management framework. Appropriately-scaled and detailed conceptual models of ecosystem processes and feedbacks are critical to adaptive management. Our approach to the identification and priority ranking of EBVs is consistent in requiring conceptual models be developed for each key ecological feature, using regions to guide the search and test for gaps. A similar process was employed in the development of the Arctic Council's Circumpolar Biodiversity Monitoring Program, where the selection of key ecological features (described as 'Focal Ecosystem Components') and state (biodiversity) variables and pressure variables was guided by the development of conceptual models that described the current understanding of the relationships between key ecological elements, functions and processes and various drivers (Gill et al., 2011). While this process was employed prior to the introduction of the EBV concept, the resulting biodiversity variables chosen as the priority focus for the CBMP map closely to most of the proposed EBV classes and variables. In NSW, there are existing theory driven environmental monitoring programs for which biodiversity is a minor focus. For example the Estuary Health Monitoring Program measures variables that have clear relevance to conceptual (Kilminster et al., 2015) and mechanistic (Sanderson and Coade, 2010) models that guide management of pressures (Roper et al., 2011). The long-term program was designed to monitor a small subset of the candidate EBVs as indicators, with the intention that if the indicator showed poor performance, then a more comprehensive set of EBVs would be assessed. This represents a practical adaptation of the EBV approach to accommodate limited resources. The adoption of an EBV framework for State-wide monitoring across all environmental realms based on the stepwise process described here may allow the current Estuary Health Monitoring Program to readily evolve into an effective biodiversity monitoring program for estuaries.

Our approach could contribute to, and be strengthened by a range of tools and initiatives aimed at improving biodiversity observations across the world. One of these is GEO BON's 'Bon in a Box' initiative (http://geobon.org/bon-in-a-box/what-is-bon-in-a-box/) which is a capacity building and technology transfer tool, based upon and organised by the EBV classes, and designed to facilitate the start-up or enhancement of interoperable sub-national, national and regional biodiversity observation systems. Such an approach offers an opportunity for the modular and replicated development of biodiversity observation systems from local to regional scales (Latombe et al., this Issue) that can be connected to facilitate data aggregation (Kissling et al., 2015). Through the use of state-of-the-art biodiversity data collection tools and the enhanced ability to aggregate data across scales, statistical power to detect and understand important biodiversity trends would be improved. Using the approach outlined for NSW and applying the EBV concept via Bon-in-a-Box would allow biodiversity observations to be easily connected across Australia and globally.

5. Conclusions

The list of eleven variables that we identified as useful for assessing biodiversity change in NSW across terrestrial, freshwater and marine realms may be regarded an immediately applicable list of interim essential variables for assessing biodiversity change in NSW. In prioritising variables to add to this list, the proportion of ecological feature ecoregion combinations using each variable within and across realms is useful supporting information along with other logistical, social and political factors.

Our structured, stepwise approach to variable selection provides a transparent process for identifying important elements of ecological theory underpinning biodiversity monitoring in a jurisdiction and documenting understanding of biological processes and entities.

In addition to meeting information needs of individual countries, such a process would also contribute to global biodiversity assessments.

It would enable countries to participate and strategically build their contribution to a global information set over time. Worldwide adoption of a transparent, stepwise process for prioritising variables such as the one we propose here would help ensure consistency of national contributions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2016.08.019.

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