Biodiversity Assessment

Abstract
Establishing forest plantations on cleared land improves biodiversity, however due to the broad scope of biodiversity it is ambiguous how to quantify the improvement. Techniques to assess and calculate biodiversity will allow biodiversity of plantation sites to be compared, assisting with recognition of lower biodiversity plantations. This paper will firstly discuss technology available to assess biodiversity. Next, it will examine ways of quantifying biodiversity for plantations to be compared. Finally, some biodiversity offsets will be critiqued in their past success at improving biodiversity.

Corinne Sanders Feb 2017

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Introduction

The term "biodiversity" encompasses every species of bacteria, virus, plant, fungi, animal and each species' variety of genetic material. Biodiversity includes the ecosystems the species are part of as well as evolutionary processes[1].

High biodiversity is important for ecosystems[2], however planting a few resilient species take precedent over many species if they are unlikely to survive.

Part 1 - Assessment Technology

How is biodiversity measured?

There are two main ways of measuring biodiversity, which are field studies and remote sensing techniques.

Field studies, commonly referred to as *in situ* monitoring, are traditional methods of measuring biodiversity. These include vegetation assessments, fauna surveys[3], camera traps[4], and more recently, environmental DNA (eDNA) analysis[5].

Remote sensing techniques involve satellite observations of Earth. As technology develops, remote sensing will improve biodiversity assessment[6]. Remote sensing techniques directly detect characteristics of plant species or communities using NDVI spectral bands. Remote sensing techniques also indirectly measure biodiversity using environmental parameters as proxies. For instance, remote sensing can identify discrete habitats where certain species occupy[7].

	Field studies	**Remote sensing**
Spatial coverage	Sparse[8]	Synoptic view of Earth's entire surface[9].
Spatial scale	Very fine[10]	Limited[11] to widely distributed habits. Rare, small habitats[12] and dense forest canopies are difficult to recognise[13].
Temporal coverage	Mostly irregular, static "snapshots"[14]	Regular, consistent and systematic. E.g. several times a day[15].
Costs	Expensive[16]	Cost-effective and some satellite data is free[17].
Simplicity	Complicated and involves risks[18].	Simple and effective[19]. Professional forestry skills are not required[20].

Table 1. Advantages and disadvantages of biodiversity measuring methods.

Recommendation

What can Greenfleet do right now?

Combining field studies with remote sensing is essential for an accurate assessment of biodiversity[21].

In terms of field studies, camera traps are simple but can inaccurately measure species abundance. One study found that camera trap rates do not correlate with relative abundance of species, as camera trapping is affected by other factors such as animal movement rates, body size and habitat use patterns[22].

Although more complicated, eDNA is shown to be more reliable, revealing rare species that camera traps might miss[23].

Vegetation assessment and fauna surveys are somewhat successful at measuring biodiversity. One study found that although surveys on understory plants, trees, birds, butterflies, and dung beetles did not accurately correlate, most of them had a similar overall pattern of species richness variation[24]. According to another study, plots for plants and transects for birds and insects are time-efficient at assessing species richness of a group of organisms, over a large area[25].

As for remote sensing options, there are a number of satellites currently available for Earth measurement. These include Sentinel-2[26, 27] by ESA and Landsat 8[28, 29] by NASA, both of which provide free data. Worldview-3[30] by Digital Globe is another satellite, but is for a small fee[31].

What can Greenfleet do in the future?

In the near future, there will be more opportunity for remote sensing with a number of satellite launches set in the next few years that will improve remote sensing accuracy, information and accessibility[32]. These satellite launches include ICESat-2[33] by NASA in late 2017, EnMAP[34, 35] by the German Aerospace Centre (DLR) in 2018, BIOMASS 2020[36] by ESA in 2020, and HyspIRI[37] by NASA in 2022.

Part 2 - Quantifying Biodiversity

Biodiversity Indicators

Due to the broad scope of biodiversity that has no physical units, it is difficult to quantify biodiversity[38]. There are many possible biodiversity indicators and those to be used will depend on the part of biodiversity that is to be calculated and reasons for the assessment associated with value systems[39]. This lack of consistency in what variables to monitor is a contributing factor to the insufficient biodiversity monitoring and information sharing[40].

Essential Biodiversity Variables

Due to the inconsistency in biodiversity indicators, the Group on Earth Observations Biodiversity Observation Network (GEO BON) proposed Essential Biodiversity Variables (EBVs) that aim be cost-effective and efficient in representing biodiversity[41]. EBVs should quantify biodiversity in scales and dimensions, be biological, focus on "state" variables, be sensitive to change, and be measurable using field studies and remote sensing[42].

EBV class	EBV candidate	Definition
Genetic Composition	Co-Ancestry	Quantifies a species' or population's evolutionary history, calculated from measures of Allelic Diversity.
	Allelic Diversity	The number and frequency of alleles in a population or sample. It is the foundation for other genetic diversity variables.
	Population Genetic Differentiation	Measures the difference in genetic composition between individuals of a species in a population, calculated from measures of Allelic Diversity.
	Breed and Variety Diversity	The variation within a domesticated species due to human selection.
Species Populations	Species Distribution	The presence or absence of a species at certain locations and times.
	Population Abundance	The number of organisms of a given type. Calculated by counting individuals or proxied such as by biomass or cover.
	Population Structure by Age/Size Class	Categorises species population into different age classes to demonstrate whether the population is growing, declining or stable.
Species Traits	Phenology	A species' seasonal or periodic behaviour.
	Body Mass	Quantifies the size of an organism, providing information about a population's pressure such as harvesting and whether the population can adapt to the pressure.
	Natal Dispersal Distance	Mostly applicable to sessile organisms, it quantifies the dispersal distance of a propagule.
	Migratory Behaviour	Applies to non-sessile organisms, it encompasses the home range size, breeding overwintering area locations, the season pattern, and speed of movement.

	Demographic Traits	Refers to mean longevity, fertility, age at first reproduction and sex ratio.
	Physiological Traits	Information about how the organism lives, physiological limits and optima, and the presence of metabolic pathways.
Community Composition	Taxonomic Diversity	A measure of ecosystem diversity, it lists species that coexist at a particular place and time, forming a community.
	Species Interactions	How species interact to form an ecosystem. Types of interactions include predator, prey, and competitor.
Ecosystem Function	Net Primary Productivity	Measures the capture of solar energy by plants that is converted into biomass to provide energy sustaining life on Earth minus the respiratory losses by the plant.
	Secondary Productivity	The growth rate of organisms living on plants.
	Nutrient Retention	Refers to an ecosystem's "leakiness". E.g. ecosystems on land leak excess nitrogen and phosphorus to freshwater systems, causing biodiversity loss.
	Disturbance Regime	The frequency and intensity of disrupting factors including fires, storms and physical disturbances.
Ecosystem Structure	Habitat Structure	The organisation of an ecosystem, measuring height, density and patchiness.
	Ecosystem Extent and Fragmentation	Refers to the area of ecosystems of different functional composition and is the most common indicator of ecosystem-level biodiversity loss.
	Ecosystem Composition by Functional Type	The basis of ecosystem classification, this is calculated by community composition intersected by species traits or by amount of coverage by stratum for plant life forms.

Table 2. Proposed EBVs[43].

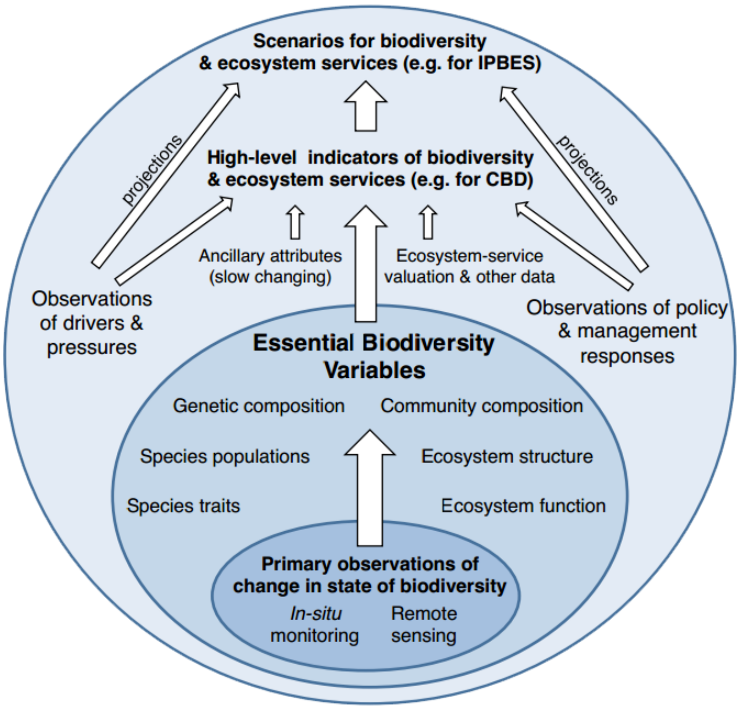

Figure 1. EBVs[44].

Common EBVs

"Ecosystem Structure" EBVs are common in Australian biodiversity measurement. Remote sensing observations of cover or biomass infer "Habitat Structure". Both field studies and remote sensing techniques measure "Ecosystem Extent and Fragmentation". "Ecosystem Composition by Functional Type" information is implicitly part of ecosystem maps[45].

"Species Distribution" is another common EBV. Field studies and remote sensing techniques can detect species. Species Distribution surveys are available for many species and there are distribution atlases of data such as GBIF, IUCN and Map of Life[46].

Habitat structure

Habitat Hectares, BioCondition and BioMetric combine "Habitat Structure", "Ecosystem Extent and Fragmentation", and "Ecosystem Composition by Functional Type" to assess biodiversity

Habitat Hectares[47]

<table>
<tr><td>State</td><td>Victoria</td></tr>
<tr><td>Benchmark</td><td>The average mature condition of the Ecological Vegetation Class pre-1750. Habitat Hectares acknowledges that this benchmark does not represent maximum possible biodiversity and some patches of native vegetation may be valued higher than the benchmark.</td></tr>
<tr><td>Method</td><td>
<table>
<tr><th></th><th>Component</th><th>Score</th></tr>
<tr><td rowspan="7">'Site Condition'</td><td>Large Trees</td><td>10</td></tr>
<tr><td>Tree Canopy Cover</td><td>5</td></tr>
<tr><td>Understorey</td><td>25</td></tr>
<tr><td>Lack of weeds</td><td>15</td></tr>
<tr><td>Recruitment</td><td>10</td></tr>
<tr><td>Organic Litter</td><td>5</td></tr>
<tr><td>Logs</td><td>5</td></tr>
<tr><td rowspan="3">'Landscape Context'</td><td>Patch Size *</td><td>10</td></tr>
<tr><td>Neighbourhood *</td><td>10</td></tr>
<tr><td>Distance to Core Area *</td><td>5</td></tr>
<tr><td></td><td>Total</td><td>100</td></tr>
</table>
* these components can be derived on-site or with the assistance of maps and other information e.g. GIS)

Table 3. Components and weightings of the habitat score.

Each habitat zone is given a score out of 100 by summing the individual scores from site condition and landscape context components. This score is divided by 100 to give a value out of 1.00, which is multiplied by the area of the habitat zone for the final score.

<table>
<tr><th>Habitat Zone</th><th>EVC</th><th>Area (ha)</th><th>Habitat Score</th><th>Calculation</th><th>Habitat Hectares</th></tr>
<tr><td>1</td><td>1</td><td>5.9</td><td>0.83</td><td>5.9 x 0.83</td><td>4.9</td></tr>
<tr><td>2</td><td>1</td><td>6.8</td><td>0.43</td><td>6.8 x 0.43</td><td>2.9</td></tr>
<tr><td>3</td><td>2</td><td>4.3</td><td>0.27</td><td>4.3 x 0.27</td><td>1.2</td></tr>
<tr><td></td><td></td><td>17</td><td></td><td>Total Patch habitat hectares</td><td>9.0</td></tr>
</table>

Table 4. Calculation of overall Habitat Hectares score with three habitat zones.
</td></tr>
</table>

BioCondition[48]

State	Queensland
Benchmark	Sites least impacted by local threats.
Method	For each assessment unit, two to five sites are selected. Sites are at least 50 m from disturbances like roads and dams, and are at least 1 km apart. Assessment occurs during maximum plant diversity, at the end of the summer rainfall growing season.

	Attribute	Weighting (%)
Site-based condition attributes	Large trees Tree canopy height Recruitment of canopy species Tree canopy cover (%) Shrub layer cover (%) Coarse woody debris Native plant species richness for four lifeforms Non-native plant cover Native perennial grass cover (%) Litter cover	15 5 5 5 5 5 20 10 5 5
Landscape attributes (fragmented subregions[3])	Size of patch Context Connectivity	10 5 5
OR Landscape attributes (intact subregions)	Distance to permanent water	20
TOTAL		100

Table 5. Assessable attributes and weightings to calculate the BioCondition score.

Attribute	Wooded ecosystems Weighting (%)	Grassland ecosystems Weighting (%)	Shrubland ecosystems Weighting (%)	Mangrove* ecosystems Weighting (%)
Site-based Large trees	15	0	0	15
Tree canopy height	5	0	0	5
Recruitment of dominant canopy species	5	0	5	5
Tree canopy cover (%)	5	0	0	5
Shrub layer cover (%)	5	0	5	5
Coarse woody debris	5	0	0	5
Native plant species richness - Trees - Shrubs - Grasses - Other	5 5 5 5	0 0 5 5	0 5 5 5	5 5 0 5
Non-native plant cover	10	10	10	10
Native perennial grass cover (%)	5	5	5	0
Litter cover	5	5	5	0
Total site score	**80**	**30**	**45**	**65**
Landscape Size of patch	10	10	10	10
Context	5	5	5	5*
Connectivity	5	5	5	5
OR Distance to artificial water	20	20	20	N/A
Total landscape score	20	20	20	20
TOTAL BioCondition SCORE	100	50	65	85

* ocean may be included as 'remnant'

Table 6. Assessable attributes and weightings in ecosystems that naturally lack certain attributes.

BioMetric[49]

State	New South Wales
Benchmark	The average mature condition of the Ecological Vegetation Class pre-1750.
Method	BioMetric calculates clearing effects by considering a Regional Value, Landscape Value and Site Value.

Regional Value considers the percentage of cleared vegetation.

$$\textit{Regional Value} = \sum_{i=1}^{n}\left(\left(1-\left(1-\left(\frac{\%cleared}{100}\right)\right)^{0.25}\right)\times\left(\frac{ZoneArea}{TotalArea}\right)\times 100\right)_i$$

Where:
i is the *n*th vegetation zone (of either the clearing or offset site);
%cleared is the percent of the vegetation type in the *i*th vegetation zone that is cleared;
ZoneArea is the area of the *i*th zone in hectares; and
TotalArea on the clearing site is the sum of the area of all clearing zones in hectares, where a site includes more than one zone.
TotalArea on the offset site is the sum of the area of all offset zones hectares.

Landscape Value quantifies the spatial configuration of vegetation.

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

where:
s_v is the score for the *v*th variable (*a*-*d*) as defined below
w_v is the weighting for the *v*th variable (*a*-*d*) as defined below
a = percent cover of native vegetation within a 1.79 km radius of the site (1000 ha)
b = percent cover of native vegetation within a 0.55 km radius of the site (100 ha)
c = connectivity value
d = total adjacent remnant area

Site Value is the quality and quantity of vegetation, based on ten variables. Each variable is scored from zero to three, relative to the benchmark.

benchmark, where 100% is within benchmark range.

Variable	Score in *BioMetric*			
	0	1	2	3
a. Native plant species richness	0	>0-<50% of benchmark	50-<100% of benchmark	≥ benchmark
b. Native over-storey cover	0-10% or >200% of benchmark	>10-<50% or >150-200% of benchmark	50-<100% or >100-150% of benchmark	within benchmark range
c. Native mid-storey cover	0-10% or >200% of benchmark	>10-<50% or >150-200% of benchmark	50-<100% or >100-150% of benchmark	within benchmark range
d. Native ground stratum cover (grasses)	0-10% or >200% of benchmark	>10-<50% or >150-200% of benchmark	50-<100% or >100-150% of benchmark	within benchmark range
e. Native ground stratum cover (shrubs)	0-10% or >200% of benchmark	>10-<50% or >150-200% of benchmark	50-<100% or >100-150% of benchmark	within benchmark range
f. Native ground stratum cover (other)	0-10% or >200% of benchmark	>10-<50% or >150-200% of benchmark	50-<100% or >100-150% of benchmark	within benchmark range
g. Exotic plant cover (calculated in *BioMetric* as percent of total ground stratum and mid-storey cover)	>66%	>33-66%	>5-33%	0-5%
h. Number of trees with hollows	0 (unless benchmark includes 0)	>0-<50% of benchmark	50-<100% of benchmark	≥ benchmark
i. Proportion of over-storey species occurring as regeneration	0%	>0-<50%	50-<100%	≥100%
j. Total length of fallen logs	0-10% of benchmark	>10-50% of benchmark	>50-<100% of benchmark	≥ benchmark

$$\textit{Site Value} = \sum_{z=1}^{n}\left(\left(\frac{\left(\sum_{v=a}^{j}(s_v w_v)+5\left((s_a s_g)+(s_b s_i)+(s_k s_j)+(s_c s_k)\right)\right)\times 100}{c}\right)\times(ZoneArea)\right)_z$$

where:
z is the *n*th vegetation zone
s_v is the score for the *v*th variable (*a*-*j*) as defined in Table 8
w_v is the weighting for the *v*th variable (*a*-*j*) as defined in Table 8
$k = (s_d + s_e + s_f)/3$

c is the maximum score that can be obtained given the variables *a*-*j* that have a benchmark greater than zero for the vegetation type (i.e. this varies depending on which variables are in the vegetation type)
ZoneArea is the total area of the *n*th vegetation zone in hectares

Species Distribution

Species Richness and Species Evenness

Species Distribution geographically maps species abundance. The two main factors to consider for deriving species abundance are species richness and species evenness.

Species richness is the number of species of a specific taxon (e.g. birds or grasses) or life form (e.g. trees or plankton) located in a certain biological community, habitat, or ecosystem type[50]. However as more individuals are observed, new species are discovered less often with only the rare species left to be found[51]. This prevents accurately comparing species abundance of plantations.

Species evenness is a measure of the homogeneity of abundances in a sample or a community[52].

Diversity Indices

Diversity indices combine species richness and evenness into a mathematical function to represent species abundance as a single number. Common diversity indices are the Shannon-Wiener diversity index, Simpson's diversity index, Berger-Park diversity index and Fisher's alpha.

Table 7. Comparison of four common diversity indices.

	Shannon-Wiener[53-56]	**Simpson**[57-60]	**Berger-Parker**[61,62]	**Fisher's alpha**[63-66]
Formula	**$H = -sum(P_i ln[P_i])$,** where species i comprises proportion P_i of the total individuals in a community of S species.	**$D = 1 – sum(P_i^2)$,** where species i comprises proportion P_i of the total individuals in a community of S species.	**$B = N_{max}/N_T$,** where N_{max} is the maximum number of individuals of a species and N_T is the total number of individuals observed.	Simultaneous equations **$\alpha * x/(1-x)=N$** and **$- \alpha * ln(1-x)=S$** can be solved to find a, Fisher's alpha. N is the total counts and S is number of species. Assumes species abundance is distributed by the log series: **$\alpha x, \alpha x^2/2, \alpha x^3/3, \alpha x^4/4, \ldots \alpha x^n/n$,** where successive terms represent the number of species with 1, 2, 3,…n individuals.
Number scale	Logarithmic. Higher values of H indicate higher biodiversity.	D is between 0 (no diversity) and 1 (infinite diversity).	Lower values of B indicate a less dominant species in the community, corresponding to greater diversity.	Higher values of α indicate higher biodiversity.
Species richness	✓✓	✓	✗	✓✓✓
Species evenness	✓	✓✓	✓✓✓	✗

✓ = factor changes index value. Number of ticks indicates relative amount of impact.   ✗ = factor makes no change to index value.

Recommendation

With Habitat Hectares, BioCondition and BioMetric already in use in Australia, "Ecosystem Structure" EBVs would be easiest to adopt.

A limitation of these EBVs is that they do not consider fauna. However, BioCondition claims that vegetative structural elements are more reliable and cost-effective for assessing biodiversity than species abundance, arguing that relationships between species and biodiversity are uncertain and species detection and identification methods are imperfect[67].

Another advantage of the vegetation assessment tools is that they apply to various habitat types. In contrast, diversity indices have limited use due to their different weightings placed on species density and evenness.

Of the three vegetation assessment tools discussed, BioCondition is likely to be more useful in the context of climate change[i]. Unlike Habitat Hectares and BioMetric which compare sites to pre-1750, BioCondition compares sites to those least impacted by local threats, a more realistic vegetation state for comparisons.

If Greenfleet chooses to adjust the assessment tool and use a different benchmark for biodiversity comparison, such as cleared forest where biodiversity is the lowest, then Habitat Hectares may be preferable since it considers both site quality and quantity in multiplying site value by land area.

BioMetric involves complicated mathematical equations that can be difficult to articulate.

[i] On the 17th May 2016, Greenfleet Revegetation Committee agreed to aim for plantation restoration to improve species/provenance abundance to approach "the southern extent of their range" instead of "pre-1750 ecosystems".

Part 3 - Biodiversity Offsets

Biodiversity offsets create a biodiversity gain that compensates for an equivalent biodiversity loss somewhere else. To classify as a biodiversity offset, the action must not only compensate for ecological damage and be quantifiable, but also generate "additionality"[68, 69]. According to DELWP, acceptable biodiversity offsets are revegetation of a site and improvement in the condition of vegetation, both of which also require management and protection[70].

Site Revegetation

Revegetation, including forest restoration, rehabilitation, and threat management, is limited in its success by time delays. One study analysed 108 biodiversity offset studies and revealed that when revegetation occurs, the best scenario takes almost 100 years for species richness to reach old-growth reference values, 200 years for species similarity to reach the reference value, and thousands of years for assemblage composition to reach the reference value. The study acknowledged that forest restoration improves biodiversity, however the benefits are hindered by large time lags, uncertainty, and potential restoration failure[71]. Another study had similar results, observing slow biodiversity recovery after the discontinuation of forest management, specifically anthropogenic pressures from direct forest resources[72].

In terms of specific habitat types, one study revealed that revegetation of cleared land or improving the habitat of degraded woodland increased habitat biodiversity for shrub-dependent species, which feed and nest in low vegetation, ground litter and in grassy areas. The simulations showed that higher canopy initially declined, then towards the end of certain simulations higher canopy increased. Old tree-habitat declined throughout all simulations[73]. A different study investigated how restoration areas of eucalypt woodland in Western Sydney differed to untreated pasture and remnant vegetation. More than 1000 hectares of abandoned pasture were restored through weed reduction treatment. Less than ten years ago, areas were planted with seedlings of 26 plant species, native to similar soil and topographic positions. Restored vegetation and untreated pasture had the same composition, which differed significantly to that of remnant vegetation. The study concluded that either restoration treatments failed or restoration requires more than ten years to detect[74].

Birds surveys indicated low biodiversity in plantations due to poor native vegetation. One study monitored replanted forests less than 18 hectares in area and less than 30 years old, located at the Murray River, Victoria. Birds present in major forest floodplain remnants were underrepresented in plantations, most likely due to insufficient native vegetation at plantations[75]. Bird surveys highlighted that many small and medium trees cannot substitute for large trees. One study identified that in reserves and urban built-up areas, the same number of individuals and species occupied several small and medium trees as a single large tree. However, in pasture and urban parklands, a single large tree attracted more species than many small and medium trees. Notably, 29% of bird species only occupied large trees.[76]

Vegetation Improvement

Installation and enhancement of ecological features is a way to improve vegetation of forest conditions. A nest box is one ecological feature that increases biodiversity. One study observed that nest boxes were mainly occupied by a few common native and exotic species and hence this nest box strategy may not effectively increase biodiversity of rare and threatened species. Moreover, this study revealed that entrance size strongly influences the overall occupancy of nest boxes. Larger entrance nest boxes (115, 95, 75 and 55 mm) had higher occupancy than smaller entrance size nest boxes (35 and 20 mm). Overall occupancy did not vary much with tree size and landscape context. Nevertheless, multinomial analysis revealed that occupancy by common fauna were impacted by landscape context as well as entrance size[77].

Another way of improving species habitat is to place dead wood and rock piles randomly throughout plantations. The habitat feature of dead wood takes many years to occur naturally. It has been shown that habitat for invertebrates is improved when large single logs and log piles are placed before planting. Vertebrates were released and observed to locate these logs for cover[78].

The establishment of landscape corridors, which connect isolated patches of forests, have mixed results in their effect on biodiversity. One study analysed a 95 km long forest corridor in Madagascar, which connects two large national parks (416 and 311 km^2). The corridor and national parks were observed to share the same communities of 300 species in 5 taxonomic groups, indicating that corridors are effective biodiversity offsets[79]. Some studies claim that corridors hinder biodiversity, suggesting that the edge effects of corridors increase nest predation rates[80-82]. In contrast, other studies reported lower nest predation rates in corridors than other habitats[83-85]. Between 1995 and 1998, a corridor of dimensions 1.2 km and 100 m was established along Toohey Creek, Queensland. This corridor connected Crater Lakes National Park and the Wooronooran National Park, which had been isolated since the 1930s when forest was cleared for agriculture. This corridor succeeded in improving biodiversity for certain species. Pipes and pumps were installed to provide an off-stream watering system. A three-row windbreak of Hoop Pine along both sides of the corridor decreased edge effects[86]. Plant reproductive timing and seasonality of bird movement may impact long-distance seed dispersal along corridors. One study reported that corridors at the Savannah River Site in South Carolina promote long-distance seed dispersal by birds moving between patches during winter, but not during summer[87].

Recommendation

Overall, “Site Revegetation” benefits are limited by long time delays and “Habitat Improvement” seems to be the better biodiversity offset. With large entrance sizes, nest boxes can successfully increase biodiversity, but not of rare and threatened taxa. Landscape corridors can be successful, provided that careful measures are undertaken. For instance, the corridor along Toohey Creek took measures to reduce edge effects, which have been associated with increased nest predation rates in other studies. While biodiversity offsets can be beneficial, it is preferable to protect remnant forests from being cleared[88].

Conclusion

Considering the advantages and disadvantages of field studies and remote sensing for assessing biodiversity, these two techniques are best combined to accurately observe biodiversity. Field studies have not changed much, whereas remote sensing techniques will become more prevalent in the future as technology advances.

Many Essential Biodiversity Variables (EBVs) are available. Two commonly used are "Ecosystem Structure" and "Species Distribution". Australian vegetation assessments like Habitat Hectares, BioCondition and BioMetric are based on "Ecosystem Structure". Diversity indices including Shannon-Wiener diversity index, Simpson's diversity index, Berger-Park diversity index and Fisher's alpha calculate "Species Distribution". With the thorough methods and broad applications of vegetation assessments, the "Ecosystem Structure" EBVs are recommended.

Studies of "Site Revegetation" and "Vegetation Improvement", the biodiversity offsets endorsed by DELWP, were analysed in how they have improved biodiversity. Biodiversity improvement from "Site Revegetation" is limited by time delays. "Vegetation Improvement" has been more successful, particularly nest boxes and landscape corridors, provided their implementation adheres to specifications.

Bibliography

[1] Morton, S., Sheppard, A. & Lonsdale, M. (2012). Explainer: what is biodiversity and why does it matter? Web. 30 Jan 2016. < http://theconversation.com/explainer-what-is-biodiversity-and-why-does-it-matter-9798>.

[2] Hajkowicz, S., Cook, H. & Littelboy, A. (2012). Our Future World: global megatrends report. *CSIRO Futures,* 1(1), 8-10. *CSIRO Research Publications Repository.* Web. 30 Jan 2016.

[3] Duelli, P. & Obrist, M. (2003). Biodiversity indicators: The choice of values and measures. *Agriculture Ecosystems & Environment,* 98(1-3), 87-98. *Research Gate.* Web. 24 Jan 2017.

[4] Rowcliffe, J.M. & Carbone, R. (2014). Surveys using camera traps: Are we looking to a brighter future? *Animal Conservation,* 1(1), 185-186. *Research Gate.* Web. 24 Jan 2017.

[5] Bohmann, K. et al. (2014). Environmental DNA for wildlife biology and biodiversity monitoring. *Trends in Ecology & Evolution,* 29(6), 358-367. *Science Direct.* Web. 2 Feb 2017.

[6] Walters, M. & Scholes, R.J. (2017). *The GEO Handbook on Biodiversity Observation,* 30-32. Switzerland: Springer Nature. Print.

[7] Turner, W. et al. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution,* 18(6), 306-314. *ScienceDirect.* Web. 14 Feb 2017.

[8] Walters & Scholes, op. cit, 240.

[9] O'Connor, B. et al. (2015). Earth observation as a tool for tracking progress towards the Aichi Biodiversity Targets. *Remote Sensing in Ecology and Conservation,* 1(1),19-28. *Wiley Online Library.* Web. 24 Jan 2017.

[10] Walters & Scholes, op. cit, 20.

[11] Laurin G. V. et al. (2016). Discrimination of tropical forest types, dominant species, and mapping of functional guilds by hyperspectral and simulated multispectral Sentinel-2 data. *Remote Sensing of Environment,* 176(1), 163-176. *ScienceDirect.* Web. 26 Jan 2017.

[12] Walters & Scholes, op. cit, 31.

[13] Meng, Y.S. et al. (2009). Empirical near ground path loss modeling in a forest at VHF and UHF bands. *IEEE Transactions on Antennas and Propagation,* 57(5), 1461-1468. *IEEE Xplore Digital Library.* Web. 26 Feb 2017.

[14] Walters & Scholes, op. cit, 190.

[15] O'Connor, et al., op. cit.

[16] Mairota, P. et al. (2015). Very high resolution Earth observation features for monitoring plant and animal community structure across multiple spatial scales in protected areas. *International Journal of Applied Earth Observation and Geoinformation,* 37(1), 100-105. *ScienceDirect.* Web. 25 Jan 2017.

[17] O'Connor, et al., op. cit.

[18] Hill, D. et al. (2005). *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring,* 1(1), 17-35, 47-48. United Kingdom: Cambridge University Press. Print.

[19] Walters & Scholes, op. cit, 30.

[20] Liu, J. et al. (2016). Can global navigation satellite system signals reveal the ecological attributes of forests? *International Journal of Applied Earth Observation and Geoinformation,* 50(1), 74-79. *ScienceDirect.* Web. 25 Feb 2017.

[21] Walters & Scholes, op. cit, 31, 190.

[22] Rowcliffe & Carbone, op. cit.

[23] Bohmann, et al., op. cit.

[24] Schulze, C.H. et al. (2004). Biodiversity Indicator Groups of Tropical Land-use Systems: Comparing plants, birds, and insects. *Ecological Applications,* 14(5),1330. *Wiley Online Library.* Web. 9 Feb 2017.

[25] Duelli & Obrist, op. cit.

[26] Skidmore, A.K. et al. (2015). Agree on biodiversity metrics to track from space. *Nature,* 523(7561), 404. *GEO BON.* Web. 7 Feb 2017.

[27] ESA. (2017). Sentinel-2 Operations. Web. 2 Jan 2017. <http://m.esa.int/Our_Activities/Operations/Sentinel-2_operations>.

[28] USGS. (2016). Landsat 8. Web. 9 Feb 2017. <https://landsat.usgs.gov/landsat-8>.

[29] NASA. (2017). Where to Get Data. Web. 9 Feb 2017. <https://landsat.gsfc.nasa.gov/data/where-to-get-data/>.

[30] DigitalGlobe. (2017). WorldView-3. Web. 9 Feb 2017. <http://worldview3.digitalglobe.com/>.

[31] LANDinfo. (2017). Buying Satellite Imagery: Pricing Information for High Resolution Satellite Imagery. Web. 9 Feb 2017. <http://www.landinfo.com/satellite-imagery-pricing.html>.

[32] Skidmore, et al, op. cit.

[33] Markus, T. et al. (2017). The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2): Science requirements, concept, and implementation. *Remote Sensing of Environment,* 190(1), 260-273. *ScienceDirect*. Web. 9 Feb 2017.

[34] EnMAP Hyperspectral Imager. (2017). Welcome to EnMAP. Web. 9 Feb 2017. <http://www.enmap.org/>.

[35] O'Connor, et al, op. cit.

[36] ESA. (2015). BIOMASS. Web. 9 Feb 2017. <http://m.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Future_missions/Biomass>.

[37] NASA. (2012). HyspIRI Mission Concept Overview. <https://hyspiri.jpl.nasa.gov/downloads/2012_Workshop/day1/16_HyspIRI_Mission_Concept_Overview-Workshop_FY12_ULR.pdf>.

[38] Skidmore, et al, op. cit.

[39] Duelli, P. & Obrist, M.K. (2003). Biodiversity indicators: the choice of values and measures. *Agriculture, Ecosystems & Environment,* 98(1-3), 87-98. Web. 19 Jan 2017.

[40] Pereira, H. M. et al. (2013). Essential Biodiversity Variables. *Science,* 339(6117), 277-278. *Science Magazine.* Web. 19 Jan 2017.

[41] Paganini, M. et al. (2016). The role of space agencies in remotely sensed essential biodiversity variables. *Remote Sensing in Ecology and Conservation,* 2(3),132-140. *Wiley Online Library.* Web. 2 Feb 2017.

[42] GEO BON. (2017). What are EBVs? Web. 2 Feb 2017. <http://geobon.org/essential-biodiversity-variables/criteria-to-adopt-an-ebv/>.

[43] Convention on Biological Diversity. (2013). Essential Biodiversity Variables. Web. 2 Feb 2017. <https://www.cbd.int/doc/meetings/sbstta/sbstta-17/information/sbstta-17-inf-07-en.pdf>.

[44] GEO BON. What are EBVs?, op. cit.

[45] GEO BON. (2017). EBV class - Ecosystem structure. Web. 9 Feb 2017. <http://geobon.org/essential-biodiversity-variables/ebv-classes-2/>.

[46] GEO BON. (2017). EBV class - Species populations. Web. 9 Feb 2017. <http://geobon.org/essential-biodiversity-variables/ebv-classes-2/>.

[47] State Government of Victoria Department of Sustainability and Environment Biodiversity and Natural Resources Division. (2004). Native vegetation: sustaining a living landscape. Web. 9 Feb 2017. <http://www.depi.vic.gov.au/__data/assets/pdf_file/0009/228771/VQAM-V1_3-Chapters-1-11.pdf>.

[48] State Government of Queensland Department of Science, Information Technology, Innovation and the Arts, op. cit.

[49] State Government of NSW Department of Environment, Climate Change and Water. (2011). Operational Manual for BioMetric 3.1. Web. 9 Feb 2017. <http://www.environment.nsw.gov.au/papers/BioMetricOpManualV3-1.pdf>.

[50] Colwell, R.K. (2009). Biodiversity: Concepts, Patterns, and Measurement. *The Princeton Guide to Ecology,* 257-263. Simon, L. A. et al. Print.

[51] Gotelli, N.J. & Colwell, R.K. (2001). Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters,* 4(4), 379–391. *Wiley Online Library.* Web. 9 Feb 2017.

[52] Colwell, op. cit.

[53] Maryland Sea Grant. (2017). How to calculate biodiversity? Web. 24 Jan 2017. <http://ww2.mdsg.umd.edu/interactive_lessons/biofilm/diverse.htm>.

[54] Colwell, op. cit.

[55] Pisces Conservation Ltd. (2017). Shannon-Wiener Index. Web. 24 Jan 2017. <http://www.pisces-conservation.com/sdrhelp/index.html?fishers.htm>.

[56] Ingram, J.C. (2016). Berger-Parker Index. *Reference Module in Earth Systems and Environmental Sciences.* 332-334. Print.

[57] Maryland Sea Grant, op. cit.

[58] Colwell, op. cit.

[59] Pisces Conservation Ltd. (2017). Simpson's Index. Web. 24 Jan 2017. <http://www.pisces-conservation.com/sdrhelp/index.html?fishers.htm>.

[60] Ingram, op. cit.

[61] Pisces Conservation Ltd. (2017). Berger-Parker Dominance. Web. 14 Feb 2017. <http://www.pisces-conservation.com/sdrhelp/index.html?fishers.htm>.

[62] Ingram, op. cit.

[63] Colwell, op. cit.

[64] Pisces Conservation Ltd. (2017). Fisher's alpha. Web. 24 Jan 2017. <http://www.pisces-conservation.com/sdrhelp/index.html?fishers.htm>.

[65] Balestrini, M. (2017). Diversity index - Fisher's alpha parameter. Web. 24 Jan 2017. <http://groundvegetationdb-web.com/ground_veg/home/diversity_index>.

[66] Rice, C.G. & Demarais, S. (1996). A table of values for Fisher's [alpha] log series diversity index. *The Texas Journal of Science,* 48(2). *Free Patents Online.* Web. 24 Jan 2017.

[67] State Government of Queensland Department of Science, Information Technology, Innovation and the Arts. (2015). BioCondition: A Condition Assessment Framework for Terrestrial Biodiversity in Queensland. Web. 2 Feb 2017. <https://www.qld.gov.au/environment/assets/documents/plants-animals/biodiversity/biocondition-assessment-manual.pdf>.

[68] Marton, M. et al. (2016). Interactions Between Biodiversity Offsets and Protected Area Commitments: Avoiding Perverse Outcomes. *Conservation Letters,* 9(5), 1-2. *ResearchGate.* Web. 7 Feb 2017.

[69] Greenfleet. (2016). Paper 5.6 Carbon on Crown Land. *Greenfleet Board Meeting 13 December 2016.* Print.

[70] State Government of Victoria Department of Environment, Land, Water and Planning. (2017). Native vegetation offsets. Web. 7 Feb 2017. < http://www.delwp.vic.gov.au/environment-and-wildlife/biodiversity/native-vegetation-offsets>.

[71] Curran, M., Hellweg, S. & Beck, J. (2014). Is there any empirical support for biodiversity offset policy? *Ecological Applications,* 24(4), 617-632. *JSTOR.* Web. 9 Feb 2017.

[72] Paillet, Y. et al. (2010). Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. *Conservation Biology,* 24(1). *Wiley Online Library.* Web. 7 Feb 2017.

[73] Bedward, M., Ellis, M.V. & Simpson, C.C. (2009). Simple modelling to assess if offsets schemes can prevent biodiversity loss, using examples from Australian woodlands. *Biological Conservation,* 142(11), 2732-2742. *ScienceDirect.* Web. 9 Feb 2017.

[74] Wilkins, S., Keith, D.A. & Adam, P. (2003). Measuring Success: Evaluating the Restoration of a Grassy Eucalypt Woodland on the Cumberland Plain, Sydney, Australia. *Restoration Ecology,* 11(4), 489–503. *Wiley Online Library.* Web. 7 Feb 2017.

[75] Nally, R.M., De Vries, L. & Thomson, J.R. (2010). Are Replanted Floodplain Forests in Southeastern Australia Providing Bird Biodiversity Benefits? *Restoration Ecology,* 18(1), 85-94. *Wiley Online Library.* Web. 7 Feb 2017.

[76] Le Roux, D.S. et al. (2015). Single large or several small? Applying biogeographic principles to tree-level conservation and biodiversity offsets. *Biological Conservation,* 191(1), 558-566. *ScienceDirect.* Web. 9 Feb 2017.

[77] Le Roux, D.S. et al. (2016). Effects of entrance size, tree size and landscape context on nest box occupancy: Considerations for management and biodiversity offsets. *Forest Ecology and Management,* 366(1), 135-142. *ScienceDirect.* Web. 9 Feb 2017.

[78] Tucker, N.I.J. & Simmons, T. (2009). Restoring a rainforest habitat linkage in north Queensland: Donaghy's Corridor. *Ecological Management & Restoration,* 10(2), 98-112. *ResearchGate*. Web. 9 Feb 2017.

[79] Ramiadantsoa, T. et al. (2015). Large-Scale Habitat Corridors for Biodiversity Conservation: A Forest Corridor in Madagascar. *PLoS ONE,* 10(7), 1-13. Web. 9 Feb 2017.

[80] Erikson, L.M. et al. (2001). Nestpredation at the edge: an experimental study contrasting two types of edges in the dry Chaco, Paraguay. *Ecography,* 24(6), 742-750. *ResearchGate.* Web. 16 Feb 2017.

[81] Estrada, A., Rivera, A. & Coates-Estrada, R. (2002). Predation of artificial nests in a fragmented landscapes in the tropical region of Los Tuxtlas, Mexico. *Biological Conservation,* 106(2), 199-209. *ResearchGate.* Web. 16 Feb 2017.

[82] Weldon, A.J. (2006). How corridors reduce Indigo Bunting nest success. *Conservation Biology,* 20(4), 1300-1305. *ResearchGate.* Web. 16 Feb 2017.

[83] Yahner, R.H. & Mahan, C.G. (1999). Potential for predator learning of artificial arboreal nest locations. *Wilson Bulletin,* 111(1), 536-540. *ResearchGate.* Web. 16 Feb 2017.

[84] Hazler, K.R. et al. (2006). Factors influencing Acadian flycatcher nesting success in an intensively managed forest landscape. *Journal of Wildlife Management*, 70(1), 532-538. *ResearchGate.* Web. 16 Feb 2017.

[85] Huhta, E., Eramo, M. & Jokimäki, J. (2015). Predation risk of artificial ground nests in forest stands, edges, clear-cuts, and forested corridors as an ecological indicator. *Old-Growth Forests and Coniferous Forests: Ecology, Habitat and Conservation,* 1(1), 37-53. Weber, R.P. Nova Publishers. Print.

[86] Tucker & Simmons, op. cit.

[87] Evans, D.M., Levey, D.J. & Tewksbury, J.J. (2013). Landscape Corridors Promote Long-Distance Seed Dispersal by Birds During Winter but Not During Summer at an Experimentally Fragmented Restoration Site. *Ecological Restoration,* 31(1), 23-30. Web. 9 Feb 2017.

[88] Gonçalves, B. et al. (2015). Biodiversity offsets: from current challenges to harmonized metrics. *Current Opinion in Environmental Sustainability,* 14(1), 61-67. *ScienceDirect*. Web. 7 Feb 2017.