Review of international indices of ecosystem condition

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Robbie Price, Susan Walker

Bioeconomy Science Institute Maiangi Taiao

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Prepared for: Ministry for the Environment

Reviewed by:

Peter Bellingham
Principal Researcher - Forest Ecology
Bioeconomy Science Institute

Approved for release by:

Gary Houliston
Group Portfolio Leader - Ecosystem Resilience
Bioeconomy Science Institute

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This report for the Ministry for the Environment (MfE) evaluates internationally developed indices of ecosystem condition to determine their suitability for use in New Zealand.

Objectives

The objectives of the contract are to evaluate a suite of condition indices and, for each, to determine whether it is meaningful and useful for assessing the condition of biodiversity and ecological integrity at national and regional scales in New Zealand. The indices are: the Biodiversity Habitat Index; the Biodiversity Intactness Index; the Ecosystem Intactness Index; the Ecosystem Integrity Index; the Species Habitat Index; and relevant components of the Vital Sites and Actions model that was developed for New Zealand. Three indices that are components of the above indices are also reviewed: the Human Footprint Index, the Human Modification Index and the Net Primary Productivity index. A final assessment is made to determine which of the indices are most worth pursuing.

Methods

- We reviewed each index using a literature search in Google Scholar based on the name of each index and then reading the primary references.
- We used AI-assisted Google search queries to elicit the potential connections of each index with international initiatives and data sets and then reviewed the documentation for each initiative and data set to check the material provided by the search engine.

Results

- The technical details of each index are given as well as a technical critique of the availability, reliability, and collation and collection needs in New Zealand of data required to produce the index; the suitability of the underlying assumptions and models; whether the index could be produced at different spatial scales; potential strengths and weaknesses of the assumptions, data, and models and of the index itself; whether the index is likely to detect meaningful ecological change over time; and the likely accuracy and resolution (temporal and spatial) of the index across different spatial scales and ecosystem types.
- Tables are provided showing the main features of each index, what it intends to measure, the scales of use, major inputs, key strengths and weaknesses, whether an example has been created for New Zealand, and key connections with international initiatives and data sources.

Discussion

- Global applications have demonstrated that producing the index is possible using existing data at coarse scales for most of the indices we examined. However, it is doubtful whether those outputs would be meaningful in a New Zealand context, especially if scaled down to regional levels.
- Meaningful applications of indices used for monitoring and reporting would require cycles of collecting new spatial species data and/or new spatial data on the relevant pressures on biodiversity, updating databases, and then rerunning the models.

- The selection of baselines and their defensibility and accuracy is important for some condition indices, and it is unlikely that data are available to define those baselines with confidence.

Conclusions and recommendations

- The condition indices reviewed in this report are not ready for implementation.
- Developing and implementing a robust, cross-ecosystem index of terrestrial biodiversity condition will require new investment in field data and the development of data infrastructure and workflows. This investment would be largely new and may be significant.
- A wider range of pressures than those used in global indices would be needed in any index of cross-ecosystem terrestrial biodiversity condition based on pressure alone.
- The use of a neighbourhood approach in index calculation is preferable because it considers the spatial distribution of pressures or condition around each grid cell, as well as pressures or condition at an individual grid cell.
- The most promising and feasible national, cross-ecosystem indices to represent biodiversity condition in New Zealand are (in our opinion) the Vital Sites and Actions species occupancy measure; a Native Dominance naturalness index; the Vital Sites and Actions Environmental Representation measure and a modified version of the Biodiversity Intactness Index (a more aspirational goal).

1 Introduction

Indigenous biodiversity and ecosystems are usually evaluated using metrics of extent and condition. In New Zealand some progress is being made on metrics to measure and report on natural ecosystem extent (Walker et al. 2026) and on an ecosystem typology (Sprague et al. 2026). However, metrics of extent don't capture degradation of condition due to pressures on natural ecosystems, such as invasive species, climate change, pollution, and unsympathetic land uses. Ecosystem condition is more complex and challenging to measure than ecosystem extent, but there have been international efforts to develop measures or indices of ecosystem or biodiversity condition. This report for the Ministry for the Environment (MfE) evaluates internationally developed indices of ecosystem condition to determine their suitability for use in New Zealand.

2 Background

The Department of Conservation (DOC) and regional councils currently monitor the condition of some ecosystems using field data. Coverage is patchy, although work is underway to evaluate the cost-effectiveness of field approaches and promote standardisation (e.g. Envirolink is funding the testing of a forest condition index). Advances in remote sensing and computing could potentially complement field data with scalable and consistent data with national coverage.

International agreements such as the Kunming-Montreal Global Biodiversity Framework (GBF; CBD 2022) have identified several condition-related indicators to support monitoring of progress towards the GBF’s targets and goals. Initiatives such as GEO BON[1] have developed a data pipeline for some of these condition indices, including the Biodiversity Intactness Index (BII) and the Ecosystem Intactness Index[2]. These cross-ecosystem condition metrics bring together diverse data (including remote sensing) into a single, standardised numeric measure, along with the ability to monitor over large areas using a desktop exercise. These indicators have been tested and applied in some other countries, and some come with tools (e.g. code, workflows, and guidance) intended to make them easier to implement.

If a cross-ecosystem condition index were found that is suitable for use in New Zealand, its adoption could support the practical implementation of biodiversity policy related to condition. This has the potential to save time and money for councils and resource managers, while aligning with global standards and streamlining New Zealand’s regional, national, and international reporting.

3 Objectives

This report aims to evaluate internationally developed indices of ecosystem condition to determine their suitability for use in New Zealand. The objective is to evaluate each condition index and determine whether it is meaningful and useful for assessing the condition of biodiversity and ecological integrity at national and regional scales in New Zealand, taking into consideration:

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[1] The Group on Earth Observations Biodiversity Observation Network.

[2] In this report, the Ecosystem Intactness Index is abbreviated to EII_1 to distinguish it from the Ecosystem Integrity Index (abbreviated to EII_2)

- the availability, reliability, and collation and collection needs associated with the data to produce the index in New Zealand
- the suitability of the underlying assumptions and models as indices of the condition of biodiversity and ecological integrity at national and regional scales
- whether the index could be produced at different spatial scales (national, regional, catchment, sub-catchment)
- the potential strengths and weaknesses of the assumptions, data, and models
- the potential strengths and weaknesses of applying the index in New Zealand
- whether the index is likely to detect meaningful ecological change over time
- the likely accuracy and resolution (temporal and spatial) of the index across different spatial scales and ecosystem types.

A final assessment is then to be made to determine which, of all the indices, is the one most worth pursuing.

4 Methods

4.1 Biodiversity and ecosystem condition indices reviewed in this report

The indices reviewed in this report have been informed by the list of complementary indicators provided by the GBF (CBD 2022) and by previous BSI work. They are:

- Biodiversity Habitat Index (Hoskins et al. 2018; UNEP WCMC 2024)
- Biodiversity Intactness Index (Scholes & Biggs 2005)
- Ecosystem Intactness Index (Beyer et al. 2020)
- Ecosystem Integrity Index (Blumetto et al. 2019)
- Species Habitat Index (Powers & Jetz 2019)
- relevant components of the Vital Sites and Actions model demonstrated by Overton et al. (2015).

Three indices that are components of the above indices are also reviewed:

- Human Footprint Index, which was first published by Sanderson et al. (2002) and applied to New Zealand by Burge et al. (2025)
- Human Modification Index, described by Theobald (2013)
- Net Primary Productivity index.

4.2 Review methods

The review involved a literature search in Google Scholar using the name of each index, and then reading the primary references. We used AI-assisted Google search queries to elicit the potential connections of each index with international initiatives and data sets, and then reviewed the documentation for each initiative and data set to check the material provided by the search engine.

5 Results

5.1 Biodiversity Habitat Index (BHI)

Technical details

The Biodiversity Habitat Index (BHI) is a computational index embedded in a CSIRO[3]-maintained Biogeographic modelling Infrastructure for Large-scale Biodiversity Indicators (BILBI) system (Hoskins et al. 2018; 2020; UNEP WCMC 2024). It is intended to show how well remaining habitat across an area of interest is functioning to support native species, which it does through a generalised dissimilarity model of species beta diversity (turnover in species composition between different ecosystems or habitats, using species distribution and environmental data) and a species–area relationship transformation (using land-use data as a surrogate for condition and functional connectivity of habitat).

The notes for the CSIRO BHI v2 (published April 2026) state that:

> BHI estimates the level of species diversity expected to be retained within any given spatial reporting unit (e.g., a country, a broad ecosystem type, or the entire planet) as a function of the unit's area, connectivity and integrity of natural ecosystems across it. Results for the indicator can either be expressed as 1) the 'effective proportion of habitat' remaining within the unit – adjusting for the effects of the condition and functional connectivity of habitat, and of spatial variation in the species composition of ecological communities (beta diversity); or 2) the effective proportion of habitat, which can be translated, through a species–area function, into a prediction of the proportion of species expected to persist (i.e. avoid extinction) over the long term.

CSIRO (2026) also note that:

> The BHI is used to monitor and report past-to-present trends in the expected persistence of species diversity by repeatedly recalculating the indicator using best-available mapping of ecosystem condition or integrity observed at multiple points in time, e.g., for different years.

The BHI uses generalised dissimilarity modelling (GDM, Ferrier et al. 2007) in conjunction with habitat extent and condition data from across the area of interest. GDM is a technique that models species turnover (beta diversity) as a function of environmental and geographical differences between site-pairs. It scales environmental (climate, soil) and geographical gradients to predict the compositional dissimilarity (species turnover) between any two grid cells (also called 'cells' or 'pixels'), identifying which areas are more ecologically distinctive.

For every cell (i) the BHI calculates a metric based on the amount and condition of habitat remaining in all other cells (j), taking into consideration the ecological similarity between cells i and j (predicted by the GDM) and the condition of the habitat in cell j. The sum of the metric across all

[3] Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency.

cells in the area of interest is then transformed using a standardised species–area decay curve, represented by power z (UNEP WCMC 2024):[4]

$$BHI_i = \left(\frac{\sum_j S_{ij}\, H_j}{\sum_j S_{ij}}\right)^z$$

where Sij is the ecological similarity between cell i and each other cell j in the grid, Hj is the condition of habitat within that cell (between 0 and 1), and z is the exponent of the species–area relationship (set to 0.25 in demonstrations).

BHI scores are aggregated using a weighted geometric mean of all cells within a reporting area:

$$BHI_{reportingunit} = \exp\left(\frac{\sum_{i=1}^{n} w_i \ln(BHI_i)}{\sum_{i=1}^{n} w_i}\right)$$

A global layer of the BHI (from the year 2000 to 2020) is available (Harwood et al. 2022) with a resolution of 30 arc seconds (927m grid at the equator). The species data were:

> Global occurrence records for all terrestrial species within the following taxa, extracted from data accessible through the Global Biodiversity Information Facility (GBIF http://www.gbif.org/): vascular plants, amphibians, reptiles, birds, mammals, ants, bees, beetles, bugs, butterflies, centipedes, dragonflies, flies, grasshoppers, millipedes, snails, moths, spiders, termites, wasps'.[5] Environmental data were 'Global 30-arcsecond gridded environmental surfaces for: Min Monthly Min Temperature, Max Monthly Max Temperature, Max Diurnal Temperature Range, Annual Precipitation, Actual Evaporation, Potential Evaporation, Min Monthly Water Deficit, Max Monthly Water Deficit, Soil pH, Soil Clay Proportion, Soil Silt Proportion, Soil Bulk Density, Soil Depth, Ruggedness Index, Topographic Wetness Index (Sources: http://www.worldclim.org/, https://www.soilgrids.org/, http://www.earthenv.org/).

An estimate of habitat condition is a further data requirement. In the global application, land-use proportions were derived[6] and then in translated into an estimate of ecosystem (habitat) condition, for any given cell in any given year, using coefficients derived from global meta-analyses of land-use impacts on local retention of species diversity undertaken by the PREDICTS[7] project (led by the Natural History Museum, London). The United Nations Environment Programme (UNEP) within

[4] https://gbf-indicators.org/metadata/other/A-4-C

[5] Data for New Zealand in the GBIF presently include almost 16 million records. About half of these (7.5 million records) are bird observations from eBird, 2.4 million are 'researcher grade' observations from iNaturalist, and 1.6 million are plant occurrence data from the National Vegetation Survey database. About 12.6 million records are of vertebrates, 4.1 million are of plants, and 1.6 million are of bacteria (https://www.gbif.org/country/NZ/about)

[66] The UN WCMC factsheet (Factsheet - Indicators for the Post 2020 Global Biodiversity Framework | Indicator Repository) states that the global implementation of the BHI 'employed data on change in ecosystem (habitat) condition derived from a global time-series of land-use change generated by CSIRO using statistical downscaling of coarse-resolution land-use data using finer-resolution covariates, including remotely-sensed land cover and abiotic environmental attributes. This was achieved using the technique described by Hoskins et al. (2018), extended by employing Version 2, in place of Version 1, of the Land Use Harmonisation product (https://luh.umd.edu/), MODIS Vegetation Continuous Fields (https://modis.gsfc.nasa.gov/data/dataprod/mod44.php) as remote-sensing covariates in place of discrete land-cover classes, and constraints derived from the European Space Agency's Climate Change Initiative land-cover mapping (https://www.esa-landcover-cci.org/) (see also Di Marco et al 2019). Applying this downscaling approach across multiple years provides an effective way to translate observed changes in remotely sensed land-cover covariates into estimated changes in the proportions of 12 land-use classes occurring in each and every 30-arcsecond terrestrial grid-cell on the planet.'

[7] Projecting Responses of Ecological Diversity In Changing Terrestrial Systems.

the World Conservation Monitoring Centre (UNEP WCMC) factsheet notes that ‘the same downscaled land-use data set is also being used by the Natural History Museum to derive their Biodiversity Intactness Index (BII) globally’.

Analysis for the global layer used a focal neighbourhood of 26.5 km, which would need to be retained to make the index scalable if data resolution increased.

Technical critique

There are significant data and analysis requirements to generate the BHI. Representativeness of data across biotic groups and species (Hughes et al. 2021) and the assumptions used to map their distributions and habitats – and to infer the condition of habitats from land-use data – will have a significant bearing on the index results.

This index does not rely on species distributions directly, but uses a measure of biological dissimilarity that takes the species distributions as an input to determine the relationship between environmental distance and species turnover. This creates two difficulties.

- It makes the index more difficult to understand and communicate than an index based more directly on species distribution data (beta diversity is more difficult to conceptualise and explain).
- Because the index moves away from the underlying species distribution inputs to generalised beta diversity, it is more difficult to directly observe spatial and taxonomic biases in the species data, and to know how those in turn influence the dissimilarity estimates across the map, and ultimately the index.

Data bias will be an important limitation for all indices that rely on species data, because for much of the biota (e.g. invertebrates, fungi) New Zealand is still – and is likely to remain for some time – in a ‘discovery’ phase. In the BHI, assumptions about general beta diversity (species turnover) and distinctiveness of cells based only on native biota for which we have the strongest data (vertebrates – mostly birds – and vascular plants) will be untested. Even for the best-known groups, modelled distributions are usually based on patchy data (and even vascular plant presence/absence data are lacking from many ecological districts). This isn't a reason not to use the BHI (or any other index based on species distribution data), but data caveats should be noted in any applications.

The global example used coefficients derived from global meta-analyses of land-use impacts on local retention of species diversity to translate a map of land use into a condition layer. In New Zealand no such meta-analysis or model has been created, land-use data vary spatially in quality, and how different land uses relate to local species diversity has not been investigated.

Directly downscaling[8] from the BHI generated at the global resolution (provided by CSIRO) to the level of regional council boundaries would come at a substantial computational cost, because a change in cell resolution would require the dimensions of the neighbourhood to increase greatly.

[8] All indices examined in this report (with the exception of VSA) have global worked examples at around the 1 km grid (30 arc second for geographical projections). For the indices to be relevant and useful for reporting, and for setting limits at a regional level, downscaling to the level of regional council boundaries will be needed. High cost and variable reliability of downscaling might be a reason to recommend against use of an index.

High cost and variable reliability (which is likely to be low for some regions) could be reasons to recommend against use of the BHI.

Connections with international databases and pipelines

As noted above, the index requires land-use proportions to be derived and turned into estimates of ecosystem (habitat) condition The UNEP WCMC factsheet notes that 'the same downscaled land-use data set is also being used by the Natural History Museum (London) to derive their Biodiversity Intactness Index (BII) globally'.

5.2 Biodiversity Intactness Index (BII)

Technical details

The Biodiversity Intactness Index (BII) (Scholes & Biggs 2005) attempts to measure the current abundance of originally present species relative to their undisturbed ecosystem abundance, asking the question, 'How much of the original species assemblage remains in a given area relative to an undisturbed baseline?'. The index has been implemented using the online international PREDICTS system (Hudson et al. 2017).

In essence the BII is a weighted average of current relative to reference species abundances:

$$\text{BII}_{\text{cell}} = \frac{\sum_i \text{current abundance of taxon } i}{\sum_i \text{reference abundance of taxon } i}$$

The index was designed to enable the estimation of current distribution based on expert knowledge of the impacts of land use on species. Essentially this involves a set of impact look-up tables, which allow the index to be calculated with spatial information describing:

- the baseline reference population for each taxon representing a historical distribution
- ecosystems
- land use.

The index is then calculated by summing over taxa (i) for each ecosystem (j), and the impact of each land use (k) for each area unit:

$$\text{BII} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} R_{jk} A_{jk} I_{ijk}}{\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} R_{jk} A_{jk}}$$

Technical critique

The index requires species distribution maps (both current and potential) across a wide range of taxa. In tectonically unstable New Zealand, it would be important to be able to account for a current distribution differing from a potential distribution due to a natural disturbance, and it is not clear that the BII has developed a way to deal with this.

Typically, the BII is calculated using tree species and mammal species, which have well-known distributions and abundances and are relatively easy to map, and also have easily predicted responses to different ecosystems and land uses (or other pressures).

In New Zealand the data required for this index are probably best developed for forest tree species. For example, both Leathwick (2001) and McCarthy et al. (2019) have modelled the potential species distributions for a number of tree taxa. There are also some data available describing the present distributions of some tree species.

A paucity of native mammal species means that birds would need to feature strongly in a New Zealand application, and it should be possible to estimate the potential distributions of most forest bird species. For current distributions an atlas of bird distribution does exist at a 10 × 10 km grid scale, which could be used to create an unbiased estimate of occupancy nationally, but this is updated only infrequently (20 to 25 years, most recently in 2023). Tier 1 monitoring by DOC also produces occupancy for bird species for public conservation land, and records are potentially available for some private land through the programmes of Greater Wellington Regional Council, Auckland Council, and Waikato Regional Council.

There are also eBird records from the voluntary birding community (Sullivan et al. 2009), which are the largest source of New Zealand species records in the GBIF, along with standardised workflows (produced by international researchers) for species distribution modelling from eBird records (e.g. Johnston et al. 2023). However, data from eBird and other large-scale projects with volunteer observers (such as iNaturalist, which is the second-largest source of New Zealand's GBIF records) typically present several challenges that can impede robust ecological inferences, including spatial bias, variation in effort, and species reporting biases (Johnston et al. 2021), and they are generally presence-only (lacking the absence data that is required for robust spatial modelling).

Overall, substantial targeted investment in a methodology, data pipelines, and workflow would be required to produce a BII for New Zealand. Ongoing survey effort for targeted species distributions and to map the extent of ecosystems would also need to be funded. Generating reliable predictions of current species distributions would probably require targeted research, as well as new presence and (notably) absence data. There are some international tools for mapping species distributions available online,[9] but we have not evaluated their suitability.

The index itself can be calculated independently of the PREDICTS system using reference and current population models. This flexibility gives scope to use the most robust estimates of the current population abundance for chosen taxa in the index.

Scale limits to the index are largely the resolution at which the species distribution data can be provided. If the PREDICTS methodology were followed exactly, the scale would be limited to the precision at which the land-use and ecosystems components can be mapped.

5.3 Ecosystem Intactness Index (EII_1)

Technical details

The Ecosystem Intactness Index (EII_1)[10] measures the relative integrity (or intactness) of ecosystems using data sets describing anthropogenic pressures. The index is designed to be sensitive to changes in habitat area, habitat quality, and habitat fragmentation. The index was

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[9] E.g. https://support.ala.org.au/support/solutions/articles/6000212679-how-to-show-the-distribution-of-a-species-on-a-map-of-australia

[10] The Ecosystem Intactness Index is abbreviated to EII_1 to distinguish it from the Ecosystem Integrity Index (abbreviated to EII_2)

developed via a collaboration of Australian and Canadian researchers and was designed to be applicable at multiple scales (Beyer et al. 2020).

This index requires an input layer that defines relative habitat quality. In the original paper (Beyer et al. 2020) the Human Footprint Index (HFI) layer, which is strictly a measure of pressure, not condition or quality, was chosen and processed from the scored value into a continuous 0 to 1 metric. The index is calculated within the extent of the reference layer (i.e. it is essentially the mask for the analysis).

The index measures average habitat quality while accounting for spatial connectivity between habitat locations. Intactness is calculated using a reference state to ensure it operates between 0 and 1. For location (i), the current habitat state (w_i) is compared to the 'intact' ecosystem (an HFI of zero) and other locations (w_j) at distance (d_{ij}), with an exponential decay parameter (β) and scaled by z to normalise:

$$Q = \frac{\sum_{i=1}^{N} \sum_{j=i}^{N} \left(w_i w_j\right) \, z \, e^{-\beta d_{ij}}}{\sum_{i=1}^{N} \sum_{j=i}^{N} e^{-\beta d_{ij}}}$$

Low intactness occurs when habitat is fragmented, habitat quality is degraded, and human pressures are high.

Technical critique

A significant feature of this index is the use of a neighbourhood influence in the calculation,[11] which captures the spatial distribution of (assumed) habitat quality. Due to the pairwise comparisons the spatial consideration requires, the EII_1 is a computationally expensive index and might benefit from imposing maxima (limits) on distance interactions. The original paper (which used 1 km cells) refers to a distance limit of 26.5 km, but it is unclear if that was for the core calculation or the additional possible metrics the paper refers to.

Because it relies on the HFI (see section 7.1 below) or some other chosen measure of habitat quality, the EII_1 relies on the assumptions and limitations of that index. An example of an HFI has been created for New Zealand for the years 2012 and 2018 at 100 m resolution (Burge et al. 2024), so it may be feasible to produce an Ecosystem Intactness Index here.

5.4 Ecosystem Integrity Index (EII_2)

Technical details

The Ecosystem Integrity Index (EII_2) was developed by the United Nations Environment Programme World Conservation Monitoring Centre (WCMC; Blumetto et al. 2019). The essence of the initial proposal for the Ecosystem Integrity Index is a simple representation of the worst case from three indices that measure ecosystem structure, composition, and function:

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[11] In this document the type of neighbourhood analysis we refer to is a focal statistics technique, which uses a raster GIS layer and calculates statistics (e.g. average, variety) for a cell based on the values of surrounding cells in a defined neighbourhood (e.g. a 3 × 3, 5 × 5, 7 × 7 window). Larger windows (e.g. 7 × 7 or larger) increase the smoothing effect but also dilute high-precision data, increase computation time, and make downscaling computational costs higher.

$$EEI = min(\text{HMI,BII,NPP})$$

This simple metric was then modified in a second version, which weights the minimum value by the values of the remaining indices to identify differences between areas with just one low index value and those with multiple low values. The authors chose a fuzzy algebraic summing method for this refinement:

$$EII = 1 - \prod_{i=1}^{n}(1 - x_i)$$

In the described implementation (Hill et al. 2022) the index uses the following three existing indices as inputs for the calculation:

- structure – the Human Modification Index (Theobold 2013)
- composition – the Biodiversity Intactness Index
- function – the Net Primary Productivity index (see section 5.7.3 below).

Technical critique

EII_2 has a number of strengths. For example, it has a simple and extendable methodology that can be used in parallel with the UNEP-WCMC guidelines as they evolve. It can also be tailored to meet specific objectives by combining the information gained from multiple indices chosen to target specific needs.

The EII_2 calculation itself is robust and not significantly demanding computationally. In New Zealand, concerns with the EII_2 as a calculable index arise from the limitations within the sub-models.

- The BII (one of the three inputs into the EII_2) is reviewed as a standalone index in this report (section 5.2). A New Zealand EII_2 using a New Zealand BII would carry forward the limitations of the BII, either as a data-poor model or as a model requiring expert-driven model calibration.
- The Net Primary Productivity index (NPP) metric (discussed in section 5.7.3) requires monthly cloud-free imagery. Because New Zealand has a high incidence of cloud cover (Fitzharris & McAlevey 1999; Gall et al. 2022), development may be needed to devise a workflow for NPP that enables substantial data gaps (in both time and space) to be filled, especially in cloudier southern and western regions. NPP may also bring with it problems of interpretation, because elevated NPP may indicate an improvement in condition in some places and a reduction in others.

When combining a number of independent indices to a form a single metric, the fuzzy algebraic summing algorithm is an effective way of detecting multiple low values affecting a location. The EII_2 is a specific case of the generic use of this technique.

Compounded indices such as the EII_2 are not restricted to existing designs, so that it is possible to include another set of indices to create a different combined index using the fuzzy means algorithm.

5.5 Species Habitat Index (SHI)

Technical details

The Species Habitat Index (SHI) was published in 2019 (Powers & Jetz 2019) and is fully described in metadata material online (UNEP WCMC 2022). The index measures changes in the estimated size and quality of ecologically intact areas supporting species populations. The SHI takes suitability maps (ranging continuously from 0 to 1, or binary 0/1) for a set of species and calculates two metrics, habitat suitability and connectivity, which are then averaged to create a species habitat score for each species in an area, and then combined across species into an SHI.

Ideally the species suitability distributions would be quantitatively derived (e.g. from species distribution models), but the original paper relied on simple expert-derived range maps and modified the range map to an estimate of suitability by habitat. Each species distribution used in calculating the index requires a reference distribution in addition to the distribution at the time-step being reported.

In the calculation, S_{hi} is the suitability of cell h for species i, which varies from 0 to 1 or could be expressed in binary form (0 or 1). The size (i.e. area) of suitable habitat area in region j for species i (A_{ij}) is given by the summed product of the cell-level suitability of cells within region j:

$$A_{ij} = a \sum_{h} S_{hi}$$

The connectivity score (CS_{ij}) for species i in region j is calculated relative to a reference score using a neighbourhood function (with published R code[12]):

$$C_{ij} = \frac{\sum_j d_{hi}}{p}$$

The area score (AS) and connectivity score (CS) for the region in year k are then:

$$AS_{jk} = 100 \frac{(A_{j1} - A_{jk})}{A_{j1}}$$

and

$$CS_{jk} = 100 \frac{(C_P ji - C_{jk})}{C_{j1}}$$

The species habitat score for species i in region j and year k is then defined as the mean of these area and connectivity scores for that year, and the national SHI of a country is the mean of all species habitat scores across all species and regions.

The SHI is available globally via Map of Life (https://mol.org/indicators/habitat). A repository for code is available at https://github.com/GEO-BON/bon-in-a-box-pipelines.

[12] https://gist.github.com/scbrown86/7789d5e49349d37312eadb6a3e6e1742. The implementation as published requires the *Raster* package, which has been deprecated in recent R versions.

Technical critique

The SHI relies on a suite of species habitat suitability maps that are representative of the flora and fauna. Two spatially explicit maps of suitable habitat are needed for each species: one at the time-step of interest and another reference map. Representativeness of mapped species and the assumptions and data used to map suitable habitat will have a significant bearing on the index results (Hughes et al. 2021).

One of the limitations of the global metric for New Zealand is that the forest cover map makes no distinction among types of forest. It therefore fails to distinguish the quite large total areas of plantations (in New Zealand, mostly of conifers, usually subject to periodic clearcuts) from natural forests. For forest species, a New Zealand application would need to recognise that distinctions among forest (and other habitat) types and environments may be important for some species but not others.

Considerable expert input will be required to map ‘suitable habitat’ species by species in New Zealand. Many estimates will be best guesses because reliable information on habitat requirements and preferences do not presently exist for many species, even within the best-known groups (plants and birds). Maps of habitats do not exist for most species, which means that surrogates (such as land use and land cover) with low accuracy or inadequate resolution will need to be used to represent habitat extent.

There are also non-trivial conceptual problems. For example, where predation limits the occupancy of many species, to what extent should a habitat be considered suitable if non-native predators prevent occupancy, or, as is the case for many more common species, reduce populations? And if a continuous (non-binary) measure of habitat suitability is used, how does that affect a calculation of connectivity?

A global pipeline for producing the SHI exists and code for the neighbourhood analysis is available, though it would need updating due to package deprecation (if the code author has not done so).

The SHI can operate at the cell level, so the scale of the index is limited to or controlled by the cell resolution of the species habitat suitability layers. The SHI is therefore suitable for national use, down to the scale of species modelling.

Connections with international initiatives

The SHI is proposed as a component indicator for Goal A of the post-2020 Convention on Biological Diversity (CBD) / Kunming-Montreal Global Biodiversity Framework (GBF).

GEO BON is the institutional custodian of the SHI and houses it within its Essential Biodiversity Variable framework: specifically the ‘species populations’ and ‘ecosystem structure’ essential biodiversity variable classes. The SHI also feeds into the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystems Services (IPBES) as one of the quantitative tools used to characterise habitat and population trends. It is incorporated into the Yale/Columbia Environmental Performance Index (EPI) as a measure of the proportion of suitable habitats for a country's species that remain intact relative to a 2001 baseline.

The UNEP WCMC has produced metadata sheets and CBD webinar presentations supporting the SHI's use in national reporting.

Connections with international databases and pipelines

The primary information sources for the SHI internationally are local biodiversity observations available through the GBIF, and land-cover information available annually from Landsat and the European Space Agency Climate Change Initiative (ESA CCI, a satellite product) from the year 2001 onwards.

For forest species, the GEO BON 'Bon in a Box'[13] has an SHI pipeline that uses Global Forest Watch data to calculate area and connectivity scores by species, detecting forest loss by year and subtracting it from the initial 2000 forest layer within each species' range map.

'Sibling' indicators are the Species Protection Index, which measures how much suitable habitat is under protection, and the Species Status Information Index, hosted by the Map of Life platform.[14]

5.6 Vital Sites and Actions (VSA) naturalness indices

The Vital Sites and Actions (VSA) model demonstrated by Overton et al. (2015) was designed with the primary purpose of acting as a conservation prioritisation framework. The framework (described in detail by Overton et al. 2010) uses current state biodiversity models to predict future biodiversity, given changes in management and future pressures, to predict future biodiversity states.

The full model calculates national spatial layers of Significance and the Benefit of Management[15] that are intended to identify the places where management will make the most difference to indigenous biodiversity. However, it is the simpler *naturalness* and *representation* components of the model that potentially have the most use as condition indices. VSA was formulated with a species occupancy (SO) strand (or sub-model) and an environmental representation and native dominance (ERND) strand. A naturalness layer is created in each strand.

Species naturalness in the SO strand of the VSA model is a map of relative species richness that requires current and potential (i.e. reference) species distributions. Superficially, calculating the naturalness of a cell seems simple enough: the proportion of original species that currently remains. However, the calculation also considers the abundance of the species. This complicates

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[13] BON in a Box serves as a hub for Biodiversity Observation Networks (BONs), consolidating diverse tools and resources to enhance data analysis and collaboration

[14] https://mol.org/

[15] Significance is a marginal measure of how each location (cell) contributes to biodiversity, and the Benefit of Management is how much gain is added by preventing loss based on the overall biodiversity vulnerability. The measure of significance at the cell level is at the core of the model. The significance is the sum across species of the importance of each cell of current distribution relative to the potential distribution. This scores cells highly for species with small potential ranges or greatly reduced current distribution. This is a power function with increasing steepness as overall naturalness and specific species distributions decline:

$$V_i = \sum_{j \in \text{spp}} S_{cij} \left(\left(\frac{N_{cj}}{N_{0j}} \right)^{p_c} - \left(\frac{N_{cj} - 1}{N_{0j}} \right)^{p_c} \right)$$

where:

j = species index

S_cij = suitability / contribution of site i for species j

N_cj = number of sites currently selected for species j

N_0j = target or total required sites for species j

p_c = power parameter controlling diminishing additional value toward current equals potential.

matters because species have different abundance units, and some species that prefer disturbed or open habitats have considerably expanded their current distributions relative to their natural ranges.

In addition, it is desirable to have measures that are robust to errors in the predictions of current and natural distributions. As a result, naturalness of a cell was defined as the mean (across the species that would naturally be at the site) of the proportion of natural abundance that currently remains at the cell. To reduce sensitivity to data errors, some constraints were applied to the calculation.

The following calculation was used for naturalness:

For each cell i

> For all species j at cell i for which natural > 0
>
> Naturalness = 100 * mean {minimum(natural, current) /natural}
>
> where the mean is across all species j for which natural > 0 at cell i.

This definition has the following characteristics.

- Species that are not naturally at the cell will be ignored.
- The use of the minimum function means that naturalness cannot be greater than 100% for any species.
- Cells do not get penalised (nor rewarded) for having species in greater abundance than the natural abundance.
- The naturalness of a cell cannot exceed 100%.

Naturalness of land cover is the native dominance component of the ERND strand of VSA. Calculating this index requires spatial data on both current land cover and natural land cover, which are combined to estimate the native dominance of vegetation at each cell. The demonstration of the framework (Overton et al. 2010, 2015) used Land Cover Database classes and the Potential Natural Vegetation map (which is based largely on potential forest tree distributions Leathwick 2001)[16], respectively,[17] and made use of a potential-current naturalness look-up table, in which a percentage score was given to each unique combination of the two; for example, within a potential mataī-kahikatea-tōtara forest, Manuka and or Kanuka, Fernland, Low Producing Grassland and Built-up Area LCDB classes were assigned scores of 30, 20, 5 and 0% naturalness, respectively.

A further index (Environmental Representation, or ER) can be calculated by combining naturalness of land cover with an environmental classification. ER is the proportion of an environmental class under natural vegetation (i.e. summed naturalness of land cover at each cell, divided by the total number of cells). This metric can then be reported by environment or aggregated (e.g. by averaging) across environments.

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[16] https://lris.scinfo.org.nz/layer/123462-new-zealand-potential-vegetation-vector-version/

[17] In the full model, naturalness of land cover is combined with a spatial estimate of future loss of cover and native dominance, and an environmental surrogate for biodiversity pattern (for which the Land Environments of New Zealand was used).

Technical critique

Although the VSA framework was designed to identify priorities for conservation action, it has three intermediate outputs that are relatively simple conceptually and that measure the three aspects of ecological integrity (environmental representation, native dominance, and species occupancy), as defined for New Zealand by Lee et al. (2005).

As with all species distribution-based indices (see BHI above), the appropriate selection of species for SO naturalness is critical for sensitivity and relevance. The selection and development of species data for the demonstration in the SO strand was a non-trivial exercise, even though it was limited by the funding and resources available to a demonstration (proof-of-concept) research project. However, as far as we know this is the only attempt that has been made in New Zealand to amass the data to calculate a condition index based on species distribution data.

In the demonstration of the VSA framework two methods were used to generate the native species distributions for SO naturalness: expert-driven mapping, and modelling using boosted regression trees. Natural and current distributions were estimated and mapped for each native species. The choice of the species for the demonstration was driven largely by the availability of adequate and sufficiently comprehensive data to run the models robustly, while also covering a range of flora and fauna (albeit an incomplete range for the reasons of scope discussed above) (Overton et al. 2010).

The limitations of both PNV and LCDB were the main weaknesses of the demonstration runs of the naturalness of land cover. However, there is work in progress under contract to MfE that may improve on PNV. Furthermore, estimates of the current distribution of native dominance could be derived from plot data (e.g. spatial estimates of proportion of species or proportion of biomass that is native, as demonstrated by Cieraad 2007), combined with up-to-date mapping of converted land. This would circumvent the use of LCDB (used in the potential current naturalness look-up table in the demonstration), which has known thematic and scale limitations (Walker 2026).

The finest resolution at which the model has been run nationally is 500 m (which is probably suitable for regional-scale reporting but not for districts), but this was to make the more complex computations of the model (i.e. computations beyond SO and ERND naturalness) tractable at the time. Both of the naturalness components involve quite simple calculations (and computing power has increased greatly in the last two decades), and a finer-scale grid is possible for them.

5.7 Component indices or models

This section describes indices that are used as a component of one of the six indices described above.

5.7.1 Human Footprint Index

Technical details

The Human Footprint Index was first published in 2002 (Sanderson et al. 2002) as an attempt to use proxies to represent human influence on the environment. Multiple instances of the index have been implemented (e.g. Mu et al. 2022; Venter et al. 2016). Burge et al. (2025) used New Zealand data layers to create the index for New Zealand in 2012 and 2018 at a 100 m resolution.

The index uses four types of data as proxies for human influence: population density, land transformation, accessibility, and electrical power infrastructure. The original paper (Sanderson et al. 2002) used a total of nine layers to describe influence across globally meaningful aspects of human activity. In implementing the HFI for New Zealand, Burge et al. used as inputs Roads, Rail, Navigable Waterways, Visible Night Lights, Population Density, Built Environment, Cropland – Land Cover Database (LCDB), and Pasture – Land Cover Database (LCDB).

Within the index each input layer is scored from 0 (no influence) to a maximum value for that layer, then the layers are summed to calculate the sum at each location, and could be converted from the raw score to a 0–1 index by dividing by the maximum potential sum

For *n* layers the index is calculated as:

$$\text{Index} = \sum_{i=1}^{n} L_i \,, L_1 \in [0, R_1],\; L_2 \in [0, R_2], \dots,\; L_n \in [0, R_n].$$

The authors of the index were careful to note that the index highlights areas where humans have more, or less, direct responsibility for biological outcomes rather than necessarily identifying all areas with negative outcomes for ecosystems, so it will downplay indirect outcomes such as those caused by introduced and invasive species.

The HFI is an input for the Ecosystem Intactness Index (EII_1) of Beyer et al. (2020).

Technical critique

Choice of input layers is probably key for developing an index that is fit for the purpose. This index was initially developed for reporting at a global level, some of the layers (e.g. navigable waterways) have little known direct relevance to effects on indigenous biodiversity in New Zealand, and some are spatially highly correlated (roads, visible night lights, built environment, human population) but treated as additive, creating undue emphasis on modification in particular places. Other layers (e.g. distributions of animal pests and weeds, application of agricultural fertilisers, abstraction from waterways and altering of river flows below dams) are not included in the HFI, although they are highly relevant to ecosystem condition.

The scale of the input data layers may also be inadequate: for example, some layers not included in the national HFI may be small in scale but can have very high and enduring local impact (e.g. toxic sites at Māpua and Dow Paritūtū at New Plymouth). Others missing, but with widespread effects on ecosystems, are agricultural fertilisers and pesticides, which have additional complications in that their effects occur beyond the site of their application. The definition of ‘pasture’ using LCDB in the New Zealand application conflated anthropogenic and semi-natural ecosystems[18] under quite different pressures (and with different outcomes for indigenous biota), and will also have carried forward known data inaccuracies (Walker 2026; Walker et al. 2026).

The index is capable of being used at national, regional or district scales provided the data can be obtained at high enough spatial resolution.

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[18] LCDB Classes 2 (Urban Parkland/Open Space), 40 (High Producing Exotic Grassland), 41 (Low Producing Grassland), and 44 (Depleted Grassland) were all included in this definition.

This equation is the equivalent of a weighted sum if all inputs were scored continuously as 0–1. The scoring method fits between a minimum value only and a fuzzy algebraic way of dealing with multiple low scores.

5.7.2 Human Modification Index

Technical details

This index was described by Theobald (2013) and was developed as a quantitative measure of ecological integrity suitable for landscape-level assessments. The model uses stressors, defined as a factor with both spatial extent and a magnitude of impact scaled from 0.0 to 1.0. Multiple stressors are combined using fuzzy means. While the approach is quantitative, stressor layers were assembled using a mix of empirical data, where possible, and expert knowledge elsewhere to define the spatial impacts of each stressor within ecoregional (USA) areas.

In the example paper (Theobold 2013) the following layers were used as inputs to the index: croplands, pasturelands, rangelands, plantations, built-up areas, human population density, roads, rails, quarries and mining, wind turbines, electrical infrastructure and powerlines. As with the HFI, many pressures relevant in New Zealand are missing from the index (e.g. biological invasions, agricultural inputs, local intense pressures such as toxic sites, and abstraction from and dewatering of rivers below dams).

The individual stressor layers are rasterised and used to calculate cell-level products of impact and extent:

$$HM_s = H_e \times H_i$$

The product formula enables the analysis to be run at different resolutions (with downscaled data layers) and retain global sums. The index is assembled using a fuzzy algebraic sum across multiple HM_s layers:

$$HM_c = 1 - \prod_{i=1}^{n} (1 - HM_s)$$

This index is an input into the Ecosystem Integrity Index (EII_2) of Blumetto et al. (2019).

Technical critique

The merits of the approach are traceability and being able to assess how each stressor helps drive the overall score. However, choosing stressors that are relevant and calibrating the impact reliably at a national scale across multiple environmental domains is problematic

Choice, and systematic development, of the spatial data for individual stressors would be key for success in using this index in New Zealand.

5.7.3 Net Primary Productivity index (NPP)

Technical details

This index is the ratio between potential productivity and realised productivity. There is a wide range of methods for estimating NPP at a national scale. While accurate determinations require the measurement of plant traits, it is possible to calibrate these with remote-sensing data to estimate NPP at a local or national level. Coarse-grained NPP data are available and used to generate global NPP data sets (Rodal et al. 2025).

The standard NPP index is the ratio of current NPP to potential NPP (usually with a limit of 1 applied to ensure the index retains values in the 0 to 1 range):

$$I_{NPP} = min\left(1, \frac{NPP_a}{NPP_p}\right)$$

The index may be modified by using an absolute difference of the actual and potential values to ensure that component systems that might be negatively affected by productivity increases are flagged. However, this would again have to be limited to 1 using the minimum function as above:

$$I_{NPP} = 1 - \frac{|NPP_{actual} - NPP_{potential}|}{NPP_{potential}}$$

In the New Zealand context only a marine NNP is currently available as a continuous spatial data set. No systematic approach to developing a routine workflow for terrestrial environments has been undertaken.

A national assessment by Tate et al. (2000) was able to estimate a total NNP value for New Zealand, but this was an aspatial analysis focused on the total carbon budget, not the bioactive component of the carbon cycle.

A pasture-specific productivity analysis (Amies et al. 2021) has been undertaken using Sentinel-2 data. The analysis generated a Normalised Difference Vegetation Index (NDVI) to estimate NPP using a model to estimate NPP from NDVI[19] based on field data.

Technical critique

New Zealand does not have a ready means of producing an NPP data layer or the NPP index across all land-cover or ecosystem types.

Estimating Actual NPP requires monthly cloud-free imagery, which may not be reliably accessible across New Zealand because of the cloudy climate. The requirement for frequent (monthly at minimum) cloud-free satellite imagery may make routine NPP calculations especially difficult, because a gap-filling process may be required for most months for most years across much of the country. Even more substantial research effort would probably be required for the development of an 'NPP potential' layer for an index.

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[19] Outside of NPP calculations, NDVI has been successfully used to detect changes in ecosystem health due to kauri dieback in New Zealand (Meiforth et al. 2020).

A secondary concern in developing the NPP index is interpretation. Elevated NPP in New Zealand may indicate an improvement in condition in some places (e.g. kelp forests; Qu et al. 2023) but a reduction in condition in others (e.g. the conversion of indigenous and semi-natural non-forest vegetation, such as tussock grasslands to high-intensity exotic pasture, which is likely to increase NPP). Callaway et al. (2026) note that 'One of the more striking ecological consequences of plant invasions is that they are commonly associated with an approximate doubling of NPP'.

6 Comparison of indices

All of the indices reviewed were designed to enable reporting to be undertaken at whole-data-set scales, and at multiple other scales down to a minimum largely determined by data resolution and accuracy. All indices (with the exception of VSA, which was developed in and for New Zealand) also have global worked examples at around the 1 km grid (30 arc seconds for geographical projections).

The following tables show what each index intends to measure:

- intended audiences or users
- the type of index (is it an index of condition or of pressure?)
- the potential scales of use (global, national, and/or regional)
- whether there is neighbourhood analysis (i.e. a moving window/focal metrics method, which takes into account condition not only at the individual cell but also at those around it)
- how significant the downscaling computational cost is likely to be.

The inputs to each index are then listed and key strengths and weaknesses tabulated. Final rows document whether a New Zealand example exists, link to code repositories (if found), and provide connections with international initiatives and existing international data sets.

The six principal indices can be categorised based on spatial data inputs.

- *Species distributions (current and natural/potential):* the only index based entirely on species distribution data and models is Vital Sites and Actions (VSA) species occupancy (SO) naturalness.
- *Distributions of species' habitats:* the Species Habitat Index (SHI) uses habitat suitability maps (maps of the current suitable habitat and a potential range map for each species), which also require species-by-species information and expert understanding of limiting factors for each (both present limiting factors, and those in the past or potentially, if human-induced pressures were absent).
- *Species distributions (current and natural/potential), environmental and land-use (pressure) data:* the Biodiversity Habitat Index (BHI) is based on data describing both species distributions and the environment (climate, soil, and other geographical gradients), linked through a generalised dissimilarity model, and an estimate of habitat condition (estimated as the inverse of a surrogate for pressure, which is represented by different land uses).
- *Species distributions (current and natural/potential), ecosystems, and land-use (pressure) data:* the Biodiversity Intactness Index (BII) uses weighted averages of current relative to reference species abundances, an ecosystem map, and land-use data. Impact tables must also be created based on expert knowledge of the impacts of different land uses on species in each ecosystem. The Ecosystem Integrity Index (EII_2) uses component indices requiring

species distribution data (the BII), pressure data (the HMI), and a surrogate for habitat condition, Net Primary Productivity (NPP).

- *Environmental classification and potential and current land cover data:* the VSA Native Dominance (ND) naturalness index is based on potential and current land cover. The VSA Environmental Representation (ER) index combined just three national data layers (LENZ, PNV, and LCDB) but could incorporate an improved VSA Native Dominance (ND) naturalness index (see Discussion).
- *Pressure data alone:* The Ecosystem Intactness Index (EII_1) is based purely on pressure data, combined in the Human Footprint Index (HFI), which is inverted to provide a surrogate for habitat condition and connectivity.

Table 1. The main indices investigated in the report, showing the main features of each index, including what it intends to measure, the scales of use, major inputs (including subsidiary indices – see also Table 2 – and data types), some key strengths and weaknesses, whether an example has been created for New Zealand, and key connections with international initiatives and data sources. All indices can be used across all terrestrial ecosystems.

	Biodiversity Habitat Index (BHI)	Biodiversity Intactness Index (BII)	Ecosystem Intactness Index (EII_1)	Ecosystem Integrity Index (EII_2)	Species Habitat Index (SHI)	Vital Sites and Actions (VSA) Naturalness components
What it intends to measure	Level of species diversity expected to be retained long term	How much of the original species assemblage remains in a given area, relative to an undisturbed (by humans) baseline	Average habitat quality, while accounting for spatial connectivity between habitat locations	Areas of concern for ecosystems, highlighted by combination of other indices	Size and quality of ecologically intact areas supporting species populations (how much habitat area and connectivity has a species of interest lost or gained through restoration?)	Remaining natural value, based on reference and present species distributions: SO naturalness, ND naturalness, and ER

What spatial data are needed	• Species current distributions
	• Environment
	• Land use (as a surrogate for habitat condition)
		• Current and reference (potential/ natural) species abundances
		• Ecosystems
		• Land use
			• Pressure data sets (see HFI)	• Current and reference species abundances
				• Ecosystems
				• Land use
				• Pressure data sets
				• NPP (as a surrogate for habitat condition)
					• Habitat suitability maps
					• Reference (potential/ natural) species distributions
						• SO naturalness: current and reference (potential/natural) species distributions (presence-absence) or abundances
						• ND naturalness: current and reference land cover
						• ER:
						  ○ current and reference land cover
						  ○ an environmental classification

Intended Audience/ Users	Governmental	Governmental	Governmental	Governmental and private sector nature disclosure	Governmental	Governmental
Type	Species occupancy and habitat condition	Species (assemblage) occupancy relative to a reference	Habitat condition	Mixed (species occupancy, habitat condition, pressures)	Amount of habitat and connectivity remaining for given species	Naturalness of species occupancy, naturalness of land cover (relative to reference states) and

	Biodiversity Habitat Index (BHI)	Biodiversity Intactness Index (BII)	Ecosystem Intactness Index (EII_1)	Ecosystem Integrity Index (EII_2)	Species Habitat Index (SHI)	Vital Sites and Actions (VSA) Naturalness components
						environmental representation
Scales	Global, national, regional	Global, national, regional	Global, national, regional	Global, national, regional	Global, national, regional	National, regional
Neighbourhood Analysis (Moving Window/ Focal Window)	Y. Very large window (26.5 km) in global model (but could be scaled down for NZ)	N	Y (26.5 km for global model)	Indirect	Y	N
Downscaling Computational Cost)	Very high (large focal window)	High cost (species modelling)	Very high (large focal window)	High–very high	High (species modelling & small focal window)	Low
Input: Index			HFI	BII		
Input: Index				HMI		
Input: Index				NPP		
Input: Current Land Use/Cover	Y	Y	Y	Y (indirect through HMI)	N	Y
Input: Reference Land Use/Cover	Y	Y	Y	Y (indirect through HMI)	N	Y
Input: Habitats	Y	Y	N	N	Y	N
Input: Current Species Distributions	Y (into underpinning GDMs)	Y	No	Y (indirect through BII)	Y	Y (for SO naturalness)
Input: Reference or 'Potential' Species Distributions	N	Y	No	Y (indirect through BII)	Y	Y (for SO naturalness)
Strength	Generalises biodiversity patterns from species, environment data and condition surrogates to create a continuous map which highlights the most valuable places	Reflects actual biodiversity loss rather than proxy measures like land cover Statistically models species responses to a set of pressure covariates	Focal window allows influence of local conditions Includes multiple types of pressures allowing for more relevant inputs	Numerical approach to combining indices Could be applied to other inputs of ecosystem surrogates The generalised method may be	Useful for threatened species, indicator species, or management priorities Incorporates connectivity using focal methods	Has been demonstrated using NZ data; can be based on existing national data sets, and can be improved on over time Able to incorporate different data formulations (e.g.

	Biodiversity Habitat Index (BHI)	Biodiversity Intactness Index (BII)	Ecosystem Intactness Index (EII_1)	Ecosystem Integrity Index (EII_2)	Species Habitat Index (SHI)	Vital Sites and Actions (VSA) Naturalness components
	Focal-based metrics consider surrounding environment Input data potentially available for NZ, including data developed for VSA	Is complementary to pressure indices and can be used alongside to validate or flag areas of uncertainty or complexity		extended with additional input indices		species occurrence *or* abundance data, different current and potential land-cover data sources, or naturalness estimates from plot data, an updated environmental classification) Strong conceptual logic, and scalable Simplicity of calculations for all three indices
Weakness	By generalising from the underlying species distribution inputs to beta diversity, biases in the underlying species data are hidden May be difficult to understand and communicate Would be computationally expensive to downscale due to large focal window with fine-scale data	Requires detailed current and reference abundance data of many taxa Prone to index bias based on species selections where data across taxa are limited Model parameters and data selection critical in value of the output as policy or monitoring tool	Original paper used the HFI, which may not be entirely relevant for the function of NZ ecosystems Large focal window becomes computationally expensive at higher resolution Requires a reference condition and a relative condition	Substantial investment required for underpinning data Relies on sub-models that may be either computationally expensive or difficult to obtain (e.g. NPP) in the NZ context	Requires substantial understanding of individual species–habitat interactions Raises questions about what constitutes suitable habitat. For NZ, would forest habitat be considered suitable habitat for a forest bird species if predators prevented occupancy or reduced populations? Will rely on expert knowledge to determine what constitutes suitable habitat Rare or cryptic species may be poorly represented by adequate data, or if only some are included will create index bias.	Framework not used globally SO naturalness is prone to bias if species selections are biased or have limited taxonomic breadth (i.e. prominent species and groups may not be good surrogates for others) Potential/current naturalness tables (for ND naturalness and ER indices) may not be easily validated.
NZ example	N	N	N	N	N	Yes at 500 m resolution.

	Biodiversity Habitat Index (BHI)	Biodiversity Intactness Index (BII)	Ecosystem Intactness Index (EII_1)	Ecosystem Integrity Index (EII_2)	Species Habitat Index (SHI)	Vital Sites and Actions (VSA) Naturalness components
Code Repository (if found)	CSIRO (in house)	https://github.com/mapme-initiative/mapme.biodiversity?utm_source=chatgpt.com (code and embedded global data pipeline)	No codebase found	https://ecosystemintegrityindex.org/?utm_source=chatgpt.com (code and embedded global data pipeline)	https://github.com/GEO-BON/bon-in-a-box-pipelines/tree/main/pipelines/SHI (requires additional code to run, https://github.com/GEO-BON/bon-in-a-box-pipelines)	BSI (in house)
Connections with International initiatives	Developed by CSIRO working in partnership with GEO BON, GBIF, Map of Life and the PREDICTS project (led by the Natural History Museum). Designed pre-2020 as an indicator for measuring and reporting progress in relation to the CBD's Aichi Target 5. An IPBES core indicator, used in the IPBES Global Assessment (Chapters 2 and 3) and regional assessments. Hosted on the Biodiversity Indicators Partnership (BIP) Dashboard (providing downloadable country-level results). Contributes to the Yale/Columbia Environmental Performance Index. Data sets, models and analytical techniques also used in deriving	Headline indicator used to track progress on Global Biodiversity Framework (GBF) Goal A and Target 2 (CBD/GBF). Lead indicator for the Biosphere Integrity boundary within the Planetary Boundaries framework. An evidence base for the 2019 IPBES Global Assessment. Incorporated as a measure of ecosystem-level biodiversity change into WWF's Living Planet Report (alongside the Living Planet Index, which captures species population trends). One of the five habitat health indicators in NatureMetrics' Portfolio Assessment and Taskforce on Nature-related Financial Disclosures (TNFD) risk assessments.	None found	Developed to help national governments measure and report on CBD/GBF Goal A. Listed in the adopted GBF Monitoring Framework so has official standing. Developed or co-developed through UNEP-WCMC, which hosts the Secretariat of the Biodiversity Indicators Partnership. Embedded in UNEP-WCMC's advisory role in the creation of the TNFD framework.	Primary designated purpose is as a component indicator for GBF Goal A (CBD/GBF). Peer-reviewed and approved as a core indicator of IPBES and was used in the IPBES global assessment and IPBES national assessments	None

	Biodiversity Habitat Index (BHI)	Biodiversity Intactness Index (BII)	Ecosystem Intactness Index (EII_1)	Ecosystem Integrity Index (EII_2)	Species Habitat Index (SHI)	Vital Sites and Actions (VSA) Naturalness components
	two other indicators developed by CSIRO: the Bioclimatic Ecosystem Resilience Index and the Protected Area Representativeness and Connectedness indices.					
Connections with existing international data sets	Global occurrence records for all terrestrial species are extracted from GBIF to underpin the generalised dissimilarity modelling that maps ecological similarity. Utilises the full temporal coverage of Hansen et al.'s Global Forest Change data set from 2000 onwards (derived from the entire Landsat archive, provides annual forest loss data). Also uses NASA's MODIS Land Cover Change data set from 2001 onwards, enabling annual reporting. MODIS Vegetation Continuous Fields data are used as remote-sensing covariates within CSIRO's land-use downscaling procedure. Incorporates constraints derived from European Space Agency Climate	Scientific foundation is the PREDICTS database (Natural History Museum). In statistical models that turn field observations into maps, BII uses ESA Copernicus (high-resolution satellite imagery from the Copernicus programme), Harmonized Land Use (LUH) data and a variety of human pressure data. Sources of human pressure data include the Gridded Population of the World (GPW) from CIESIN and WorldPop. Road data are typically derived from OpenStreetMap or global road data sets. Travel time to cities (Weiss et al. 2018) is used as a proxy for human accessibility and diffuse human pressure		See table entries for BII, HMI, and NPP. The functional integrity component of the EII_2 uses the International Union for Conservation of Nature (IUCN)-designated strictly managed protected areas (IUCN Categories I and II) as the reference state against which current ecosystem productivity is benchmarked.	Global occurrence records for all terrestrial species are extracted from the GBIF. The international index builds on land-cover information available annually from Landsat and ESA CCI from 2001 onwards	None

	Biodiversity Habitat Index (BHI)	Biodiversity Intactness Index (BII)	Ecosystem Intactness Index (EII_1)	Ecosystem Integrity Index (EII_2)	Species Habitat Index (SHI)	Vital Sites and Actions (VSA) Naturalness components
	Change Initiative (ESA CCI) land-cover mapping, MODIS Vegetation Continuous Fields, and Version 2 of the Land Use Harmonisation product (LUH2) into downscaling of coarse-resolution land-use data. The same downscaled land-use data set is also being used by the Natural History Museum to derive their BII.	in areas between roads and settlements.				

Table 2. The subsidiary indices investigated in the report, showing the main features of each index, including what it intends to measure, the scales of use, major inputs (indices and data types), some key strengths and weaknesses, whether an example has been created for New Zealand, and key connections with international initiatives and data sources. All indices can be used across all terrestrial ecosystems.

INDEX	HUMAN FOOTPRINT INDEX (HFI)	HUMAN MODIFICATION INDEX (HMI)	NET PRIMARY PRODUCTIVITY (NPP)
What it intends to measure	Human influence on the environment	Cumulative modification or pressure as a product of multiple stressors	The ratio of current to potential NPP as a surrogate for habitat condition or ecosystem health
Intended Audience / Users	Governmental	Governmental and private sector nature disclosure	Governmental and private sector nature disclosure
Type of Index	Pressure	Pressure	Habitat condition
Scales	Global, national, regional	Global, national, regional	Global, national, regional
Neighbourhood Analysis (Moving Window/ Focal Window)	N	N	N
Downscaling Computational Cost)	Low	Low	Low
Input: Index			Normalised Difference Vegetation Index (NDVI), which is a remote-sensing metric of greenness based on the ratio between red (absorbed by chlorophyll) and near-infrared (reflected by plant cellular structure) light
Input: Current Land Use/Cover	Y	Y	Y
Input: Reference Land Use/Cover	Y	Y	Y
Input: Habitats	N	N	Y
Input: Current Species Distributions	N	N	Can be used
Input: Reference Species Distributions	N	N	N
Strength	A version has been developed for NZ using nationally available data sources (Burge et al. 2025) Combines multiple human pressures	Very simple implementation Inputs can be tailored to meet objectives	A robust quantitative method exists Can be improved with each implementation as better data are acquired

INDEX	HUMAN FOOTPRINT INDEX (HFI)	HUMAN MODIFICATION INDEX (HMI)	NET PRIMARY PRODUCTIVITY (NPP)
	Flexible and potentially extendable for specific purposes		A marine NNP is currently available for NZ as a continuous spatial data set (from NIWA, now Earth Sciences NZ)
Weakness	Relevance of global and NZ inputs not fully evaluated May not be consistent with other countries if formulated locally Measures human pressure, not actual ecological condition or species outcomes Doesn't consider activities that reduce pressures	Inputs may not be relevant to NZ context; no NZ version attempted Measures human pressure, not actual ecological condition or species outcomes Simplistic approach to interactions	Requires NDVI for minimum of monthly time-steps, which is problematic for NZ land The meaning of the index is likely to vary among ecosystems (i.e. low productivity may mean good or bad condition in different contexts) Likely to require supplementary science to determine potential NPP and to understand the meaning of the index in different terrestrial contexts Likely to require supplementary science and data collection to convert NDVI to NPP across complex environments
NZ Example	Y	N	In part
Code Repository (if found)	https://github.com/HaoweiGis/humanFootprint Mapping	No code found	Multiple global examples
Connections with international initiatives	Underpins the structural component of the UNEP-WCMC EII, a listed GBF component indicator. Provides the pressure data on which the Forest Landscape Integrity Index partly depends. Used in the IPBES Global Assessment on Biodiversity and Ecosystem Services (2019). Also appears in IPBES regional assessments.	EII_2 incorporates HMI methodology in combination with HFI to serve as a GBF-compatible annual biodiversity tracking indicator (see Table 1 for EII_2 international initiative connections). HMI is produced by a team of scientists working with or in The Nature Conservancy (TNC) and Conservation Science Partners, producing a series of data sets. These start with an original 2019 TNC map and are now up to GHM v3 (for temporal trend analysis). GHM v3 (2025) was developed to support monitoring of the GBF targets, particularly the 30 × 30 target. The 'Managing the middle' concept, that moderately modified landscapes (roughly HMI 0.10–0.40) represent the most critical and overlooked conservation opportunity, has been adopted in spatial planning by organisations	An indicator for UN Sustainable Development Goal (SDG) 15 (Life on Land) to track land degradation and forest quality, and SDG 14 (Life Below Water) for marine ecosystem health. Used to assess nature-related risks and dependencies in corporate and financial reporting under TNFD and the Corporate Sustainability Reporting Directive (CSRD). IPCC climate monitoring uses NPP to assess the terrestrial carbon cycle and the effectiveness of vegetation as a carbon sink. The Global Terrestrial Observing System (GT-Net), and the Food and Agriculture Organization (FAO) use NPP to track global trends in biospheric productivity, such as desertification and land degradation. An input for composite measures like EII_2.

INDEX	HUMAN FOOTPRINT INDEX (HFI)	HUMAN MODIFICATION INDEX (HMI)	NET PRIMARY PRODUCTIVITY (NPP)
		including The Nature Conservancy[20] and Conservation Science Partners[21].	
Connections with existing international data sets	Composite of 8 pressure variables, each sourced from a distinct international data set. International data set connections include NASA/NOAA remote sensing (Defense Meteorological Satellite Program [DMSP], Visible Infrared Imaging Radiometer Suite [VIIRS], Landsat), global land-use databases (Ramankutty pastures, ESA CCI, GlobCover), transport infrastructure (gROADS, OpenStreetMap), hydrology (HydroSHEDS), and population (Gridded Population of the World [GPW], WorldPop). Burge et al. (2025) used nationally available data sources for the global pressures (built environment, cropland, navigable waterways, pasture, population density, rail, road, visible nightlights).	*Human settlement:* GPW; Global Human Settlement Layer (GHSL) from the European Commission Joint Research Centre; DMSP Operational Linescan System for night-time lights; and VIIRS night-time lights. *Agriculture:* MODIS land cover; cropland and pasture layers from global land-use data sets, including products derived from Ramankutty et al. and related global agricultural mapping efforts; Global Forest Watch (Hansen et al. 2013) forest loss data. *Transportation:* OpenStreetMap (OSM) supplemented by Digital Chart of the World (DCW) vMap0. *Mining and energy production:* OSM polygons and global oil and gas infrastructure data sets. *Electrical infrastructure:* OSM; DCW supplementary powerline data; DMSP/VIIRS night-time lights. *Biological resource use / forestry:* Hansen et al. Global Forest Change data set produced by the University of Maryland. *Pollution:* Sentinel-5P TROPOMI (tropospheric nitrogen dioxide (NO_2) concentration), and OSM solid waste. *Water and land surface:* ESA CCI land cover; Global Surface Water (GSW) data set. The stressor categories used to build HMI are purposely drawn from the IUCN Threats Classification Scheme (Salafsky et al. 2008) so that the same standardised vocabulary is used as that in IUCN Red List assessments to record what is threatening species.	Different versions use MODIS NPP (NASA); Copernicus Global Land Service (CGLS) Sentinel-3 observations (monitoring every 10 days); the Global Primary Production Data Initiative (GPPDI) database of field-based NPP estimates from over 2,500 sites worldwide; the Ocean Colour Climate Change Initiative (OC-CCI) long-term record; and the Global Ecosystems Monitoring (GEM) Network (a ground-based network for the tropics that provides standardised protocols for measuring NPP components (wood, roots, litterfall) to benchmark satellite data).

[20] https://www.nature.org/en-us/

[21] https://csp-inc.org/

7 Discussion

7.1 Ecosystem condition indices

Would outputs based on existing data be meaningful?

The goal of reporting on biodiversity condition runs into the well-known problem of environmental data inadequacy across New Zealand. As the PCE (2019) noted: ‘Ours has been a passive [environmental reporting] system that has harvested whatever data is there and done the best it can to navigate what’s missing. … A conscious choice was made to make do with what there was. In my judgment, what there is, is clearly inadequate’.

The attraction of an internationally demonstrated, off-the-shelf biodiversity condition index is the promise that such an index could ‘make do with what there is’ (in the way of data) as well as having ready-made or easily adapted workflows and production scripts. Global applications have demonstrated that this is possible at coarse scales for most of the indices we examined in this report (apart from those in Vital Sites and Actions).

However, it is doubtful whether those outputs would be meaningful in a New Zealand context, especially if scaled down to regional levels, because the data underlying the global models will be too coarse, too partial, and/or too biased to produce meaningful outputs. Furthermore, many of the assumptions about the relationships between biodiversity and habitat condition or pressure surrogates used in the global indices are unlikely to be fit for New Zealand conditions.

Indices using species-level data

Any of the condition indices informed by models of species distributions (Vital Sites and Actions species occupancy naturalness) or the distributions of species habitats (Species Habitat Index, Biodiversity Intactness Index, and Ecosystem Integrity Index) must contend with the limitations of the best species-level data we have to work with (those for vascular plants and vertebrates), which have large geographical gaps, leading to biases and probably inaccurate models. This problem can only be rectified by a structured programme of field data collection to fill data gaps (and for some vertebrates, historical reconstruction). Even then, a caveat will be needed that the biota we know very little about (many invertebrate groups, other kingdoms) may not follow the same patterns of richness and diversity as vertebrates and vascular plants. Local evaluations to test that assumption across environmental gradients is the best we can do.

Also, populating species distribution models with data for a condition index could not be a one-off exercise: if the index is to be used for monitoring and reporting, species distribution models will need to be updated at appropriate intervals. This would entail a cycle of collecting new data, updating databases, and then rerunning the models.

Indices using pressure data

Indices that measure spatial arrangements of pressures alone are superficially attractive because they don’t rely on the collection of species distribution data. However, the condition indices that rely on pressure data and have been demonstrated globally (i.e. the Biodiversity Habitat Index, Biodiversity Intactness Index, and Ecosystem Integrity Index) do not include some of the main drivers of biodiversity degradation and loss in New Zealand (e.g. fertilisers, pesticides, biological invasion pressure) that are most relevant to resource managers.

For example, currently the Biodiversity Habitat Index and Biodiversity Intactness Index rely in part on land-use patterns and assume a relationship between a land-use class and remaining biodiversity. This approach will not capture most of the relevant pressures on biodiversity in New Zealand. The pressure-based Human Footprint Index and Human Modification Index are also insufficient because they presently emphasise the pressures most relevant – or those that are simply the easiest to gather data on – in their countries of origin.

In the New Zealand context predator and browser populations are major drivers of ecosystem condition and species declines. The pressures and (inversely) the condition estimates that contribute to the international indices we examined here are therefore less valuable. For example, the Species Habitat Index relies on a concept of habitat connectivity, which assumes that habitat is a binary state (either present or absent). This concept of connectivity is not useful in the common New Zealand situation where invasive species compromise animal and plant populations within habitat that is otherwise connected and suitable.

An aggregate pressure index of some (but not all) biological invasions has been devised for public conservation land (Bellingham et al. 2020) and could be applied more widely and expanded in scope.

Net Primary Productivity index

The use of the Net Primary Productivity index as a surrogate for condition in the Ecosystem Integrity Index is problematic in New Zealand for two reasons. First, the fundamental assumption that 'higher productivity is better' is unlikely to be appropriate for many New Zealand ecosystems, which have inherently low productivity and raising productivity is a symptom of degradation, not of good condition or health. Second, it may not be possible to reliably acquire cloud-free satellite imagery at the required frequency to generate the spatial layer: while the Net Primary Productivity index can be calculated with data collected on longer than monthly intervals, the more frequent the images, the more robust the calculations.

Baselines

The selection of baselines and their defensibility and accuracy is important for some condition indices, especially those that rely on natural or potential distributions of species (i.e. the Biodiversity Intactness Index, Species Habitat Index, Vital Sites and Actions species occupancy naturalness, and the Ecosystem Integrity Index). Options include baselines set at 1750 AD (serving in IUCN assessments as the pre-industrial benchmark for evaluating long-term historical losses in ecosystem extent) and 1250 AD (e.g. approximating the date of human settlement in New Zealand; Ausseil et al. 2011). Both raise issues of how confident we can be in defining the baseline and at what scale. To capture the rapid pace of environmental disruption over recent history, the IUCN also evaluates ecosystem changes (such as reduction in distribution or degradation) across moving 50-year time windows to evaluate past, present, and projected future collapse risk. Again, it is unlikely that data are available to make those evaluations with confidence.

The consequences of New Zealand's natural disturbance regime (cyclones, tectonic events) on condition indices needs thought and appraisal, including how these natural disturbances might influence the setting of baselines for the potential (or 'natural') distributions of species. Thought will also be needed on how to account for climate change in setting baselines, because many ecosystems are unlikely to revert to prehuman states under the new emerging climatic regime, while novel ecosystems may be those with the species adaptations that are essential for future persistence.

New Zealand's diversity of terrain and climate impose limitations on the spatial and temporal resolution of climate products required for developing finer-resolution productivity models consistently. This may be partially offset by the relatively condensed footprints for agricultural productive lands within some regions.

7.2 What are the most promising and feasible national, cross-ecosystem indices to pursue in New Zealand?

In our opinion, the most promising and feasible national, cross-ecosystem indices to represent biodiversity condition in New Zealand are:

- the Vital Sites and Actions Species Occupancy measure
- a Native Dominance naturalness index modified from the Vital Sites and Actions species occupancy measure
- the Vital Sites and Actions Environmental Representation measure
- (as a more aspirational goal) a modified version of the Biodiversity Intactness Index.

The Vital Sites and Actions indices have the disadvantage of not being used internationally (and therefore cannot be picked up in New Zealand and used for global CBD reporting under the GBF), and none of the three indices involve a neighbourhood approach. However, all are conceptually simple and have been demonstrated at a national level using existing data sources (land cover and environmental pattern for Environmental Representation and Native Dominance) and with species data (for Species Occupancy), to the extent that those species data could be feasibly compiled within the scope of demonstrating (but not fully implementing) the model at a national scale. These indices offer demonstrated workflows that use more of 'what there is' in the way of existing data (compared to the global models), within a flexible framework requiring comparatively few assumptions. Importantly Vital Sites and Actions is non-prescriptive and envisages new and improved data on species distributions, and new potential and current land cover and environmental pattern datasets to be substituted as they are updated and become available.

Operationalising a Species Occupancy condition index in practice would require new presence-absence data for a relevant and representative range of species, to be collected on an ongoing basis. A set of species could be selected, and a collaborative effort across the agencies and organisations would then be needed to collect and curate the data.

Operationalising a data-derived Native Dominance naturalness index (for vegetation) could be achieved using vegetation plot data to model and spatially predict indigenous dominance of vegetation (either cover or composition, or both) and then masking the spatial predictions using maps of fully converted land (Walker 2026) or natural ecosystem extent (Walker et al. 2026). An appropriate and representative plot network outside public conservation land would need to be designed and integrated with existing networks (e.g. DOC's Tier 1), where possible[22]. For reporting and monitoring with this index, periodic remeasurement of vegetation plots would be needed, and a collaborative effort across agencies might be used to collect and curate the data.

An Environmental Representation measure (for vegetation) could be operationalised as an index by combining the Native Dominance naturalness condition index with an environmental

[22] Three large Regional Councils already are collecting these data, but it would almost certainly require central government investment to extend the network to more thinly populated regions with lower rating bases.

classification (such as LENZ; Leathwick et al. 2003). This would highlight how ecosystem condition (i.e. native dominance naturalness) is distributed across the full range of terrestrial environments.

Adopting and building the data and systems to implement the indices from VSA may not provide all of the data required for New Zealand to produce a different (international) condition index for GBF reporting, should one such index become a standard. If agencies decide to go ahead and implement a condition index, it would be important to assess opportunities to assemble data in such a way that they could also be used to inform international indices.

The development of a modified Biodiversity Intactness Index would be a more aspirational goal. It would require the same, new, presence-absence data for a relevant and representative range of species as a Species Occupancy index. Further requirements for a Biodiversity Intactness Index are a map of ecosystems (which is in progress; Sprague et al. 2026) and a map of the impacts of New Zealand-relevant pressures on biodiversity.

The map of pressure impacts for a New Zealand Biodiversity Intactness Index would require the same new and relevant pressure data layers as any other biodiversity condition index based on pressure data alone (i.e. the Human Footprint Index, Human Modification Index, and/or Environmental Intactness Index). However, there is an additional requirement in the Biodiversity Intactness Index to explicitly model the impacts of those pressures on indigenous biodiversity. Such pressure-impact modelling is feasible and has been demonstrated for New Zealand in the Vital Sites and Actions model.

8 Conclusions and recommendations

1. The condition indices reviewed in this report are not ready for implementation.
2. Developing and deploying (implementing) a robust, cross-ecosystem index of terrestrial biodiversity condition will require new investment in field data across private, Crown, and public land, along with the development of data infrastructure (e.g. appropriate data repositories) and workflows. This investment would be new for New Zealand (although it may employ existing methods) and may be significant.
3. If an index of cross-ecosystem terrestrial biodiversity condition based on pressure alone is to be developed, it will require new spatial information describing a wider range of pressures than those used in global indices (especially pressures most relevant to New Zealand biota and ecosystems, such as invasive and introduced species).
4. If the development of any cross-ecosystem index of terrestrial biodiversity condition is pursued, we recommend the use of a neighbourhood approach in the calculation (e.g. as in the Ecosystem Intactness Index). A neighbourhood approach is preferable because it takes into account not only pressures or condition at an individual cell, but also the spatial distribution of pressures or condition around each cell.
5. In our opinion, the most promising and feasible national, cross-ecosystem indices to represent biodiversity condition in New Zealand are:
   - the Vital Sites and Actions species occupancy measure
   - a Native Dominance naturalness index
   - the Vital Sites and Actions Environmental Representation measure
   - a modified version of the Biodiversity Intactness Index (a more aspirational goal).

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Declaration of the use of generative AI / AI-assisted technologies

This research work included the use of AI-assisted Google searches to provide information on the connections of each index with international initiatives and existing international data sets. For each index we used the query 'What are the connections with international initiatives and connections with existing international datasets of the … Index?'. After using this tool/service, the content was reviewed and edited as needed by the authors.

We used ChatGPT 4.0 to help prepare some, but not all, of the formulae in this report by generating LaTeX encoding from manually identified PDF and website content (both embed formula and plain text descriptions), then generated a MS Word compatible OMML (Office Math Markup Language) used for OfficeMath objects from both this LaTeX and manually created LaTeX code using the R programming language. Manual corrections were made to the generated LaTeX code where necessary.

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