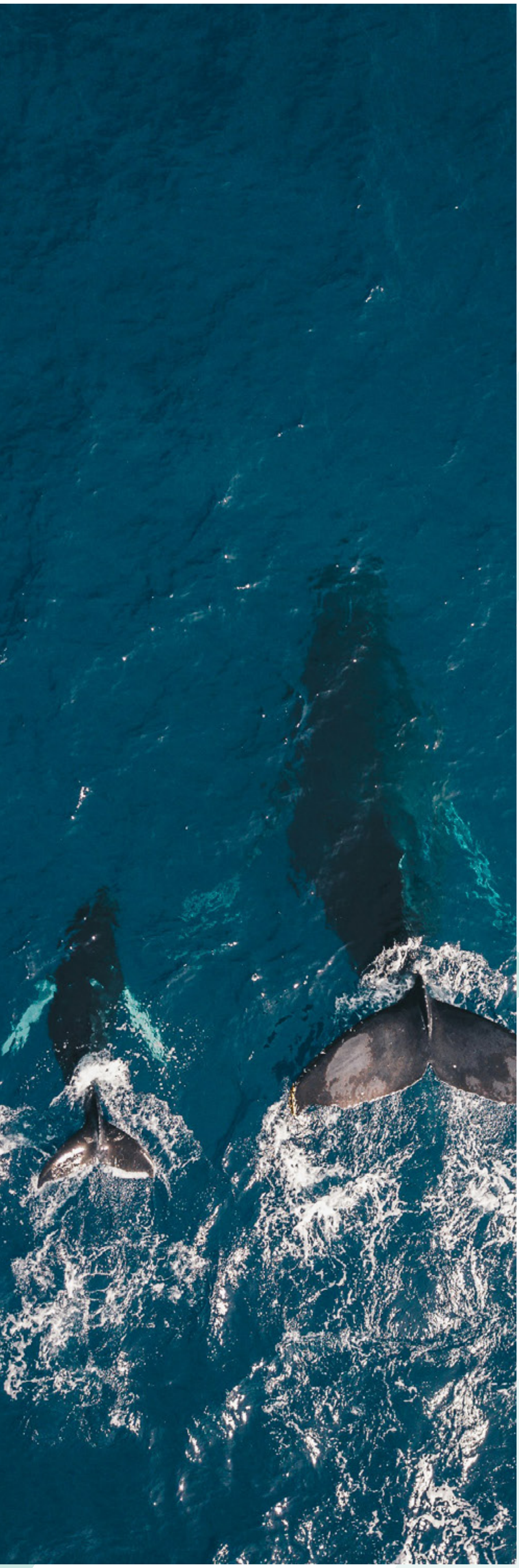
GBNAT & TNLEAD

Biodiversity Compliance in Business

Locating the interface between nature and your business
Evaluating dependencies and impacts on nature
Using spatially explicit biodiversity datasets across terrestrial and ocean

ThinkNature



EXECUTIVE SUMMARY

Biodiversity is the foundation of human society, which is referred to as natural capital. Therefore, nature positive toward 'Living in Harmony with Nature' has been set as an international goal.

In this context, business sectors are required to make a commitment to biodiversity. Individual companies have to identify the relationship between their business activities and nature, and evaluate their dependence on and impact on biodiversity ecosystem services and then disclose nature related risk and opportunity.

Think Nature takes a scientific approach to disclosure on biodiversity compliance, and provides an innovative tool "Global Biodiversity and Nature Assessment Tool (GBNAT)" and the TN LEAD service that both support businesses in their nature transformation.

GBNAT and TN LEAD are implemented by biodiversity visualisation techniques, based on macroecological studies with big data and AI and the concept and algorithm of spatial conservation prioritisation.

GBNAT as web-based service locates business activities in terms of biodiversity and ecosystem services and automatically provides a report of location-based assessment across terrestrial and marine realms.

GBNAT' s output includes measures of biodiversity importance and intactness, and a number of metrics of ecosystem condition (e.g., forest area change, human footprint increase, flood probability, water shortage etc.).

The TN LEAD service by biodiversity intelligence analysts is tailored to the business activities of various industry sectors, which enables individual companies to quantitatively assess the impact and dependency of their business activities on nature in order to disclose information on nature-related risks and opportunities in accordance with the Taskforce on Nature-related Financial Disclosures (TNFD).

TN LEAD implements scenario analysis, including land/marine use and climate changes, to develop effective actions to reduce negative impact on biodiversity and ecosystem services.

GBNAT and TN LEAD covers all areas of terrestrial, freshwater and ocean, which promote nature positive business, by visualising the natural capital that companies and financial institutions are involved with.

This paper argues the concept of GBNAT and TN LEAD and their methodologies involving algorithms, data layers and nature-related indices.

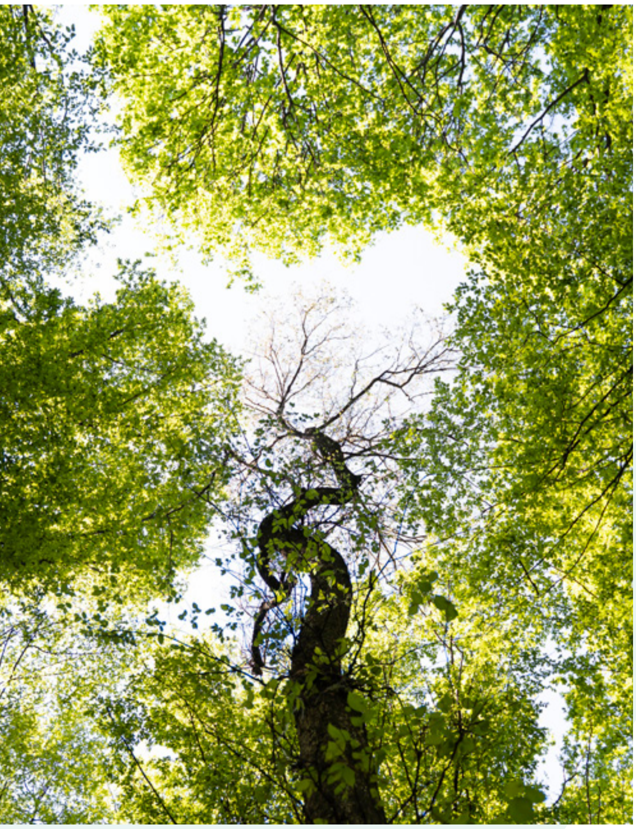
INTRODUCTION

Our society is structured on the basis of the biosphere (Keith et al. 2022). Biodiversity is the foundation of natural capital, supporting the global economy (Carola Paul et al. 2020; Dasgupta 2021). Anthropogenic impacts on the terrestrial and ocean ecosystems affects the extinction risk of one million wildlife species (IPBES 2019), causing unprecedented rapid biodiversity loss (Tollefson 2019).

Biodiversity conservation is a key component of the Convention on Biological Diversity (CBD) underpinned by strategic targets of the recently adopted Kunming-Montreal Global Biodiversity Framework (KM-GBF) that promoting protection, restoration and sustainable use (Milner-Gulland et al. 2021), and effective actions are urgently required to achieve visions of the 2030 "Nature Positive" and 2050 "Living in Harmony with Nature" (Nicholson et al. 2021). For the business sector, the conservation of biodiversity is therefore a critical issue for ensuring the sustainability of business activities.

Biodiversity-based natural capital provides a range of commodities, and those international trade supports the livelihoods of people around the world (Lenzen et al. 2012). Supply chains from commodity production to its consumption have geographically disproportionate environmental impacts across regions, accelerating region-specific degradation of biodiversity and ecosystem services through telecoupled supply chains (Liu et al. 2013; Carmenta et al. 2023).

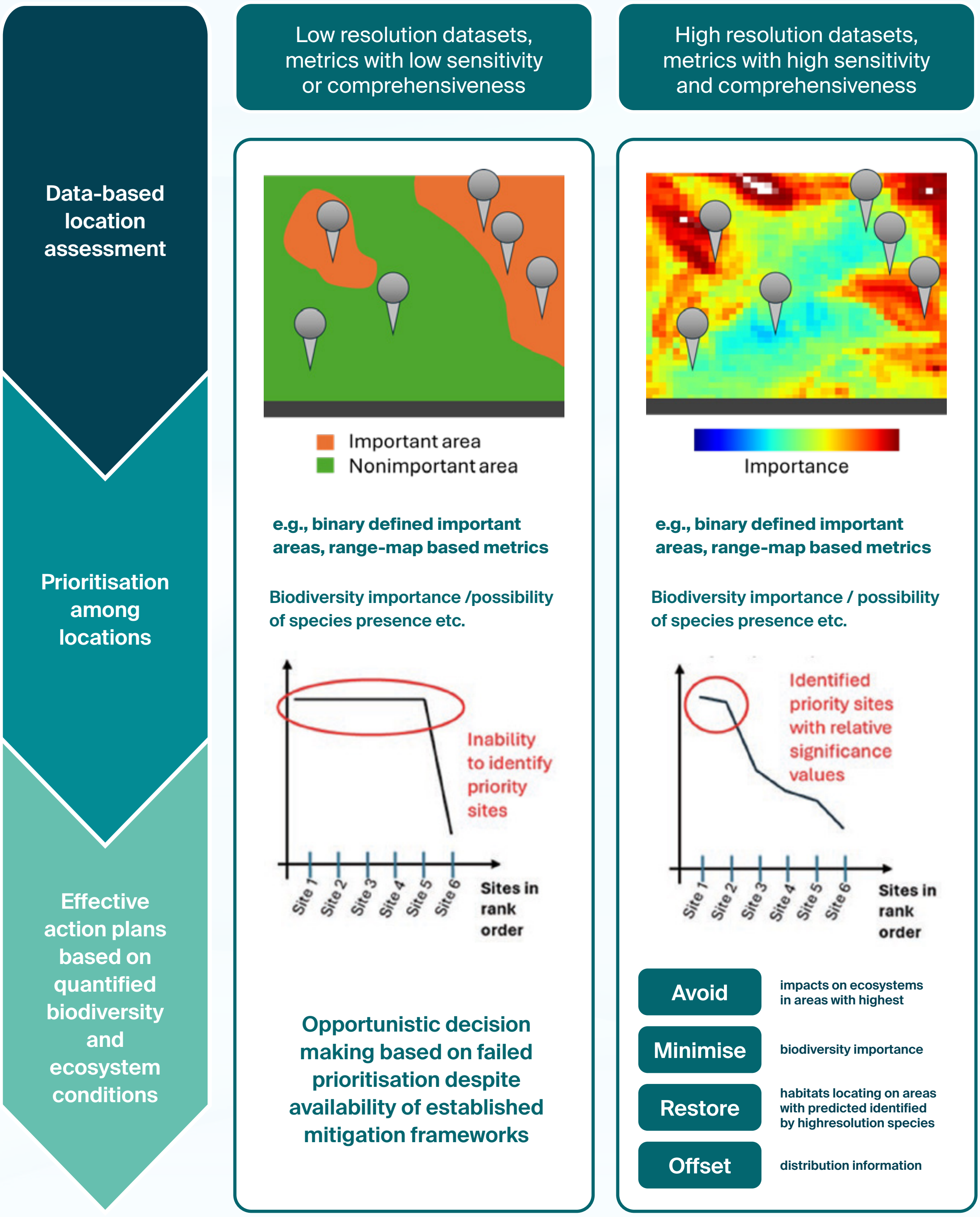
There is a need to develop nature-positive businesses that should be encouraged to invest in natural capital for sustainable use with biodiversity conservation and restoration.



To achieve this, the first step is to use appropriate data and algorithms to provide high-resolution visibility of the nature impact and exposure of current business activities, i.e. accounting nature-related risks and opportunities (Box 1).

In these views, Global Biodiversity and Nature Assessment Tool (GBNAT) and TN LEAD support locating business activities in terms of biodiversity and ecosystem services. GBNAT and TN LEAD focuses on the relationship between business activities and nature, and evaluates dependence on and impact of business activities on nature, and then disclose nature-related risk and opportunity as financial information.

Specifically, by overlaying the information of the company' s geographical location with spatial data of global-scale biodiversity and ecosystem services, GBNAT automatically provides the report on location-based assessment on the effect-response relationship of business and nature **(Figure 1).** Moreover, TN LEAD is tailored to the business activities of various industry sectors, which enables individual companies to in detail, quantitatively assess and analyse the impact of their business activities on nature, and also propose action plans to reduce negative impact towards nature positive by using scenario analysis including climate change.
This paper outlines the concept of GBNAT and TN LEAD and their methodologies involving algorithms, data layers and nature-related indices.



Box 1: Necessity of fine scale datasets in location assessment of biodiversity.

In order to harmonise business activities and biodiversity conservation, it is necessary to determine which business activities to be done in which locations. An essential part of this process is to understand the biodiversity and ecosystem conditions and priority of each site. If this process is done with inadequate data or metrics, all subsequent action plans may end up being ineffective.

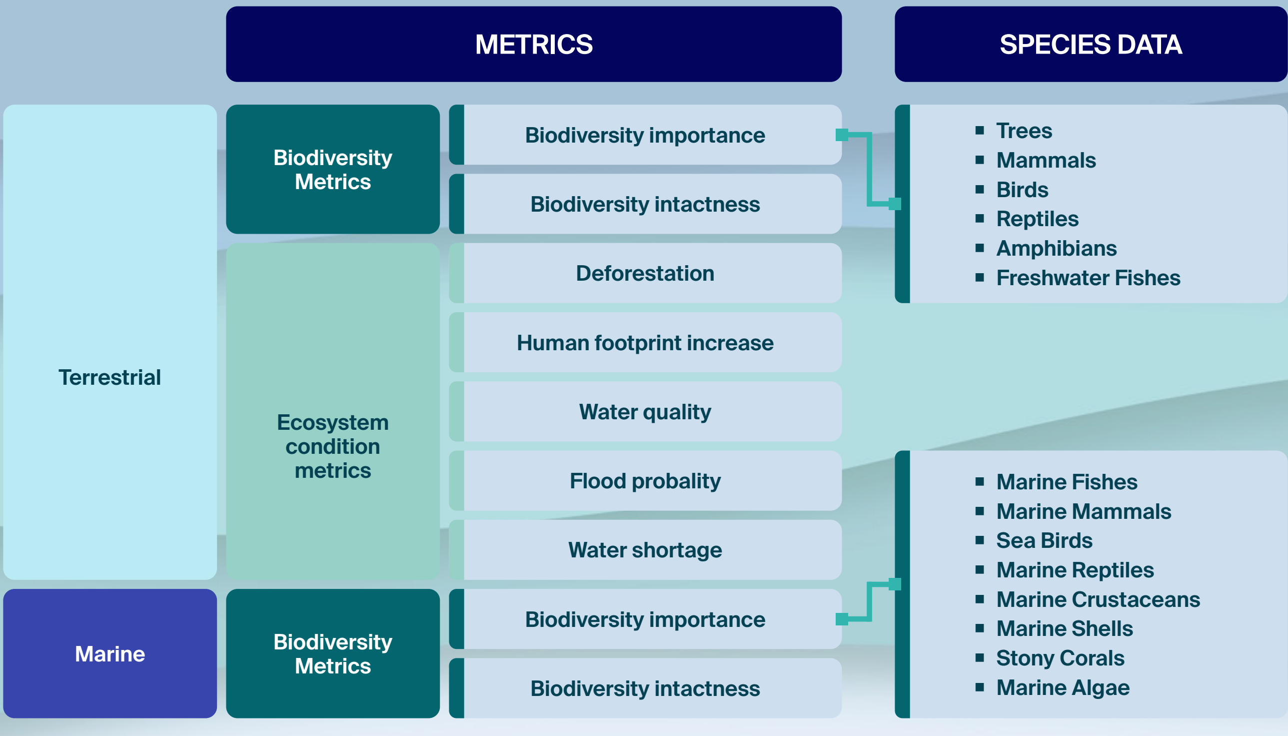
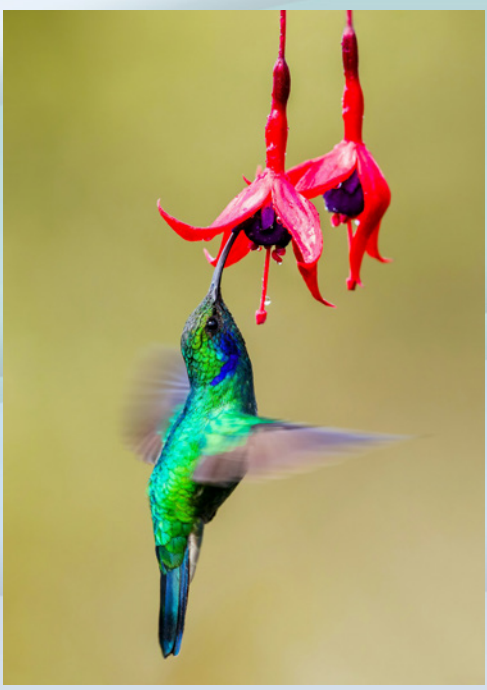


Figure1: Datasets currently provided on GBNAT. In both terrestrial and marine realms, Biodiversity importance and Biodiversity intactness are available. In terrestrial realms, metrics that denote ecosystem conditions including Forest area change, Human footprint increase, Flood probability, Water shortage are also provided. Data layers were compiled at 10 arc-minute resolution (about 18.5 km at the equator).

Concept and methodology of GBNAT's global biodiversity metrics

Top-down and Bottom-up approaches for biodiversity assessment on business demand



NECESSITY FOR GLOBAL SCALE BIODIVERSITY METRICS

Biodiversity indicators are important for assessing biodiversity in relation to business - activities, as they allow the whole planet to be assessed within the same framework. There are two reasons for the necessity: one is the spatially hierarchical nature of biodiversity and the other is effectiveness in the socioeconomic context.

Global biodiversity (so-called γ-diversity) has been structured hierarchically on the geographical space, i.e. the biodiversity of a locality (so-called α-diversity) is influenced not only by environmental conditions at that location, but also by processes acting over a greater spatial and temporal scales such as historical climate changes or continental tectonics.

Notably, even if α-diversity is the same between localities, their importance in biodiversity is likely to vary. This is because each location has a different composition of organisms (so-called β-diversity), and each organism varies in its endemicity, functions, and endangerment.

Local extinction of species due to anthropogenic land/ocean modification (loss of α-diversity) impacts strongly on rare species and leads to simplification of species composition (loss of β-diversity) through the predominance of generalist or cosmopolitan species. An extension of this process of local species loss is regional/global-scale extinction of species (loss of γ-diversity).

Due to such hierarchical processes of species filtering/sorting at different spatial-scales makes it ineffective to focus site-level actions of conservation and restoration solely focusing on local processes. If key macroscale processes for the persistence of biodiversity are not captured, local actions are likely not to have their originally intended effect.

In addition, there are normally time lags in the ecosystem's response to human actions, e.g. extinction debts and colonization credits (Haddou et al. 2022). Because of this, we must understand our negative and positive effects on nature in a broader spatio-temporal context.

Therefore, it becomes essential to identify priority areas for effective actions by explicitly considering the uniqueness and complementarity of locally established biological communities based on the global distribution of biodiversity.

The current society is built on global-scale supply chains that share geographically localized natural capital across terrestrial and marine ecosystems. In order for the actions of individual companies to be properly assessed from the perspective of biodiversity conservation and restoration and to move towards the achievement of Nature Positive, it is necessary to assess the relationship between business activities and nature, and their dependence on and impact on nature, in relative terms, in the context of 'global supply chains' on which natural capital is based.

In other words, biodiversity indicators that enable multi-sectoral business activities across the globe to be assessed within the same framework are essential for guiding effective action in the area of finance that underpins the economic activities of individual companies.

APPROACHES TO MAP GLOBAL BIODIVERSITY FOR BUSINESS

Biodiversity importance based on stacking spatially explicit species geographical information have been well used in recent years, especially in the biodiversity compliance of the business sector. An example of such an indicator is the Species Threat Abatement and Restoration (STAR) metric (Mair et al., 2021).

This is defined as bottom-up metrics (as termed in Hawkins et al. 2023), provides spatially explicit site-specific information on the risk of species extinction per unit area and the opportunity for restoration: it is computed using IUCN's accumulated expertise in species range maps and influencing factors that threaten populations (International Biodiversity Assessment Tool 2023).

The other type of method models the relative loss from natural conditions due to human modification of the environment, which is defined as top-down intactness metrics (Hawkins et al. 2023).

This is exemplified in Mean Species Abundance (MSA) approach: calculation of the expected loss of species abundance under habitat modification based on aggregation of ecological surveys along gradient of human land use intensity (Newbold et al. 2015).

Such approaches allow for a unified assessment of the impact on biodiversity on a global scale with a coverage of spatial data on human activities (land development, deforestation, etc.; Schipper et al. 2019).

Limitations of Existing Methods and Innovation

Here, our approach integrates the advantages of these existing methods and minimises limitations, thereby presenting conceptual and methodological innovations.

i) METHODOLOGICAL INNOVATION 1: SPECIES DISTRIBUTION MODELLING (SDM)

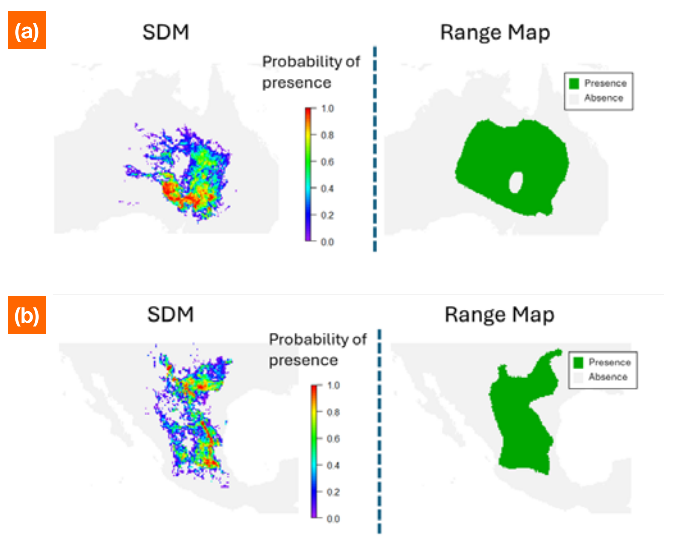
Expert-range maps are polygons drawn by researchers aimed to demarcate outer margins of species distribution (Marsh et al. 2022). By drawing the outer edges of species distributions, they specialise in conservatively delineating priory areas for protection especially for small ranged species. However, this feature allows false-positive present areas within the range **(Figure 1)**. The dominance of false positives makes it difficult to visualise the gradient of biodiversity importance in biomes such as regions with high gamma γ-diversity including tropical regions. This would not be helpful for business sectors, which want to know where business activities should be (or not be) conducted to minimise negative impacts on biodiversity in a region with high endemisms. Further, the IUCN range map only covers mammals, birds, amphibians and some large marine organisms, and additional efforts will be required to increase coverage.

Our proposed framework is based on ground-truthed species distribution data (occurrence records) that collected through natural history research, specimen information, remote sensing (satellite and drone data), eDNA surveys, biologging and high-amateur citizen surveys, encompassing 300,000 terrestrial and marine species including trees and marine invertebrates which are not covered in IUCN range maps.

Moreover, we apply species distribution modelling (SDM by machine learning) to presence-absence and/or presence-only records and predict fine scale species distribution in space and time, by taking into account a number of climate and environmental variables that determine species habitats.

Recently, more and more species occurrence records are available on digitised platforms such as GBIF (Global Biodiversity Information Facility) or OBIS (Ocean Biodiversity Information System) and intensively used in macroecological studies (Elith et al. 2011).

Figure 2: Types of species distribution data to calculate biodiversity metrics.



Types of species distribution data to calculate biodiversity metrics. Expert range map and predicted species distribution of **(a)** Leggadina forresti and **(b)** Peromyscus pectoralis. In the range map that demarcates the outer boundary of the species' distribution range, the distribution area is overestimated.

Notably, the benefit of the species distribution model using machine learning is that, in addition to providing a high spatial resolution of species distributions, it can also predict changes in species distributions over time. Species distributions change in response to environmental changes associated with short- and medium-term land use and long-term climate changes. Indeed, land alteration due to business activities shifts species distributions, or nature-friendly business activities can improve species habitats and restore species distributions. Therefore, machine-learning species distribution models are useful for scenario analysis of the impact of such business activities, although such assessments are difficult with expert range maps.

ii) METHODOLOGICAL INNOVATION 2: SPATIAL CONSERVATION PRIORITIZATION (SCP)

Another important aspect of biodiversity assessment is that we need to evaluate the diversity of individual sites relative to the biodiversity of the entire region/nation/globe (i.e. γ-diversity).

For example, the degree of negative impact would be different when logging part of a large expanse of temperate forest versus logging a forest on an oceanic island with many endemic species. In that case, even if the area lost by logging is the same, the marginal loss of biodiversity on a global scale should be greater in the latter case.

Although metrics that focus only on local areas can measure changes per unit of time due to human activities, they cannot assess what those changes mean for the entire biodiversity on the planet.

The algorithms of spatial conservation prioritization, developed in the field of systematic conservation planning, make this possible. The technique was originally developed as a method for solving optimization problems, such as minimizing the cost of conserving biodiversity or maximizing the amount of biodiversity that can be protected with limited conservation resources. In recent years, it has been generalized as a conservation benefit maximization problem, and the algorithm for solving this problem is implemented in the software Zonation, which is widely used in conservation practices (Zonation: Moilanen et al.,2014, 2022).

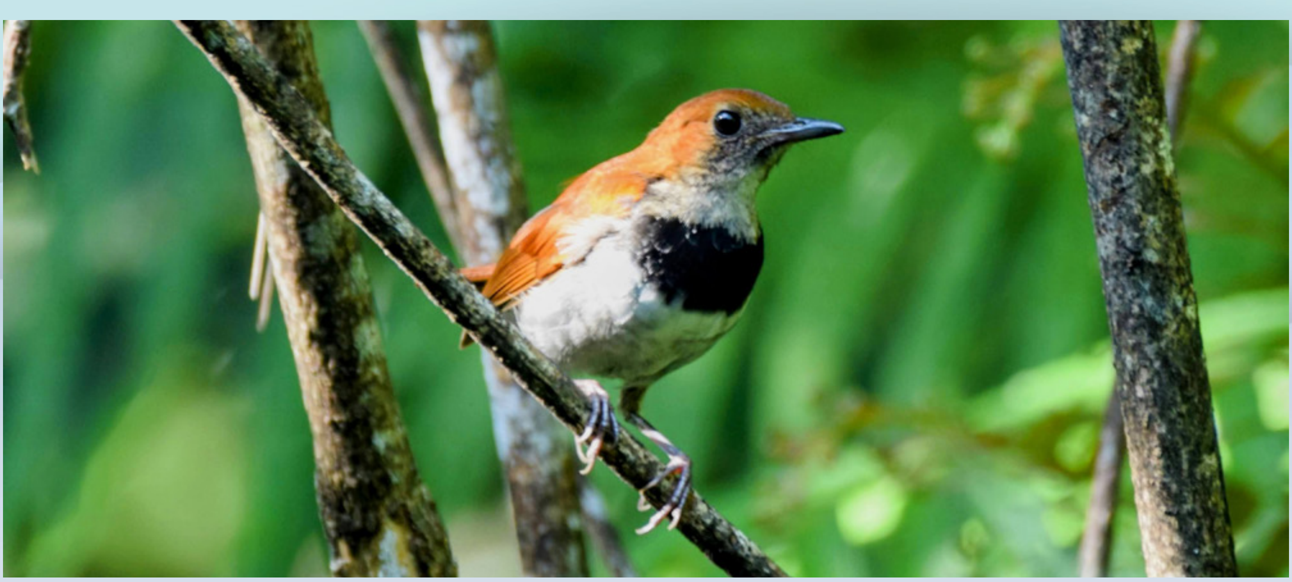
Zonation calculates conservation priorities for all sites included in the target area. The conservation priorities score has a number of advantages in biodiversity assessments. One is that it can rank conservation priorities for individual sites by evaluating the "conservation value" of each site using species distribution data as input and successively eliminating sites with the lowest conservation value.

This priority score can be used not only to identify sites to be conserved, but also to evaluate the performance of existing conservation areas, identify sites with low negative impact, and identify sites where high positive impact can be expected.

In addition, due to the nature of the algorithm of sequential site removal, it is possible to determine the percentage of residual distribution of each species contained per land area. This indicates what percentage of the distribution of organisms can be captured by a given fraction of land area. This allows us to quantify the conservation effectiveness of a particular human action as the degree of diminishing relative extinction risk (Shiono et al., 2021).

This, conservation priority score by Zonation is a powerful measure of biodiversity importance, which can be used not only to identify priority areas for conservation action, but also to estimate in advance the potential negative and positive impacts of implementing actions at a given location.

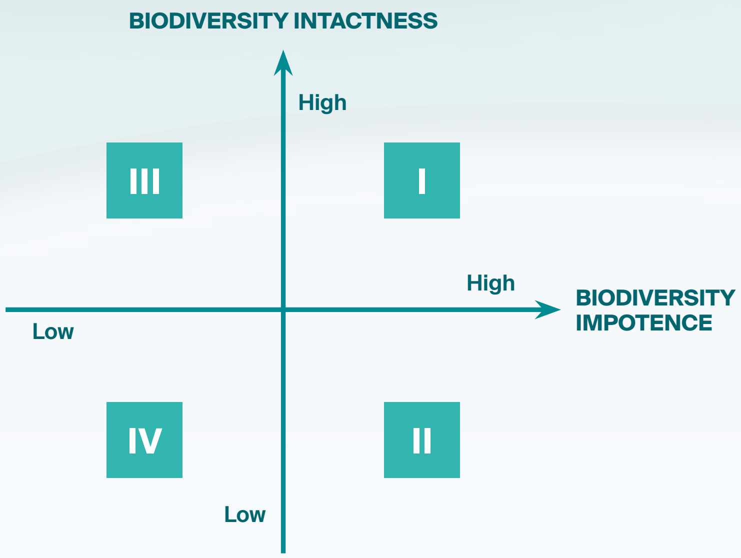
In a later section, we further discuss methods, and its advantages of our species distribution models as well as algorithms used in determining global-scale biodiversity importance at given localities using the predicted species distributions.



iii) CONCEPTUAL INNOVATION: MULTIDIMENSIONAL CONTEXT ASSESSMENT.

The notable feature of the intactness metrics is that those models explicitly assess the impact of human activities on biodiversity conditions. However, there is a significant conceptual limitation in the top-down intactness approaches, which ignore site-specific species diversity features, among other methodological limitations (Hawkins et al. 2023): thus, it fails to take into account the importance of biodiversity at each location when assessing species loss as a relative value. This can be avoided by careful consideration of context specificities, keeping in mind the characteristics and importance of biodiversity in focal regions, but in many business practice situations such expert knowledge is not always accessible.

Rather, we propose to place business locations along both axes of top-down intactness and bottom-up importance **(Box 2).** This conceptual innovation of multidimensional biodiversity axes allows us to explicitly deal with context specificity of biodiversity around business locations.



Box 2: The multidimensional contextualization of biodiversity around business locations.

By combining biodiversity intactness (top-down measure) and biodiversity importance (bottom-up measure), locations can be classified into four major categories.

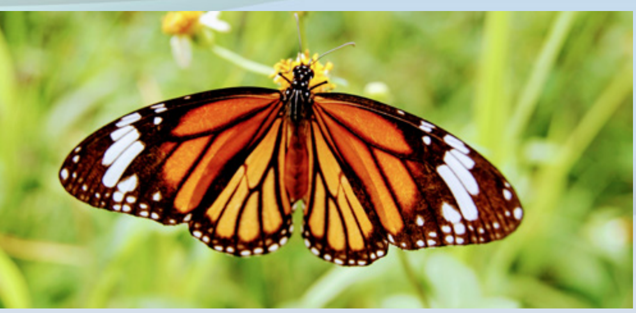
These classifications provide context for each site to understand the current status and potential of biodiversity and lead appropriate actions.

I. Biodiversity importance and intactness are high.
Priority areas to be protected.
Negative impacts of business activities could lead to significant risks for biodiversity.

II. High biodiversity importance but low intactness.
While high potential conservation importance, nature has been degraded already.
High effectiveness of nature-positive activities are expected.

III. Low biodiversity importance and high intactness, i.e. low human pressure.
Because of low conflict with other human activities, areas would be suitable for uses of natural commodities and ecosystem services (e.g. renewable energy plants)

IV. Biodiversity importance and intactness are low.
While conservation effectiveness is not high, there is a large potential for improvement in natural areas through restoration activities.



So far, we have discussed methodological and conceptual foundations of our framework to identify priority areas in biodiversity related business risks and opportunities on which GBNAT is based.

In the following sections, we present our detailed methodologies implemented in GBNAT, e.g., calculation of global biodiversity metrics and ecosystem condition metrics **(Figure 1)**, with a special focus on our original biodiversity importance metrics.

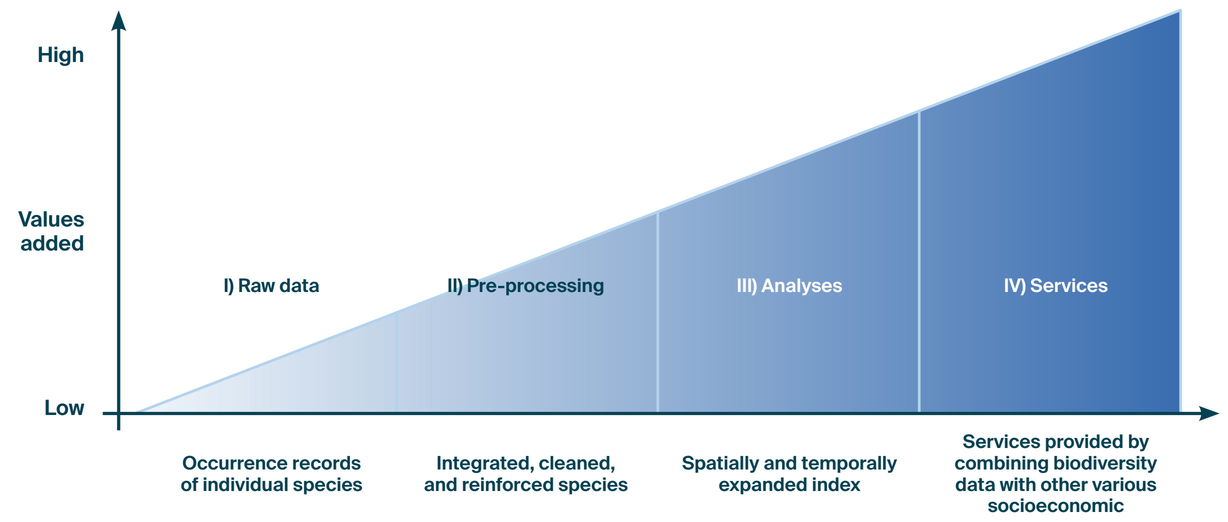
Methodologies for species distribution data and global biodiversity importance metrics

The collection of business-relevant biodiversity-related data is essential for sustainability-related financial disclosures. On the other hand, it is almost impossible for companies to collect nature-related data on their own, as it is essentially external in the context of their business.

This is where the business sector needs various publicly available data. However, the developers of these open-access data are not nature-related experts in the same way as the business stakeholders, making it extremely difficult for them to develop highly complete dataset and effective tools in response to business needs. This section therefore firstly describes the process of developing nature-related data with effectiveness for financial disclosures before the explanation of measures and indicators used in biodiversity compliance.

PROCEDURE OF DATA COMPILATION AND THE RELATED ANALYSIS

In order to use the suitable data for biodiversity compliance in business, it is necessary to better understand the process of generating nature-related data in the data value chain involving different levels of information.



Box 3: Biodiversity Data value chain

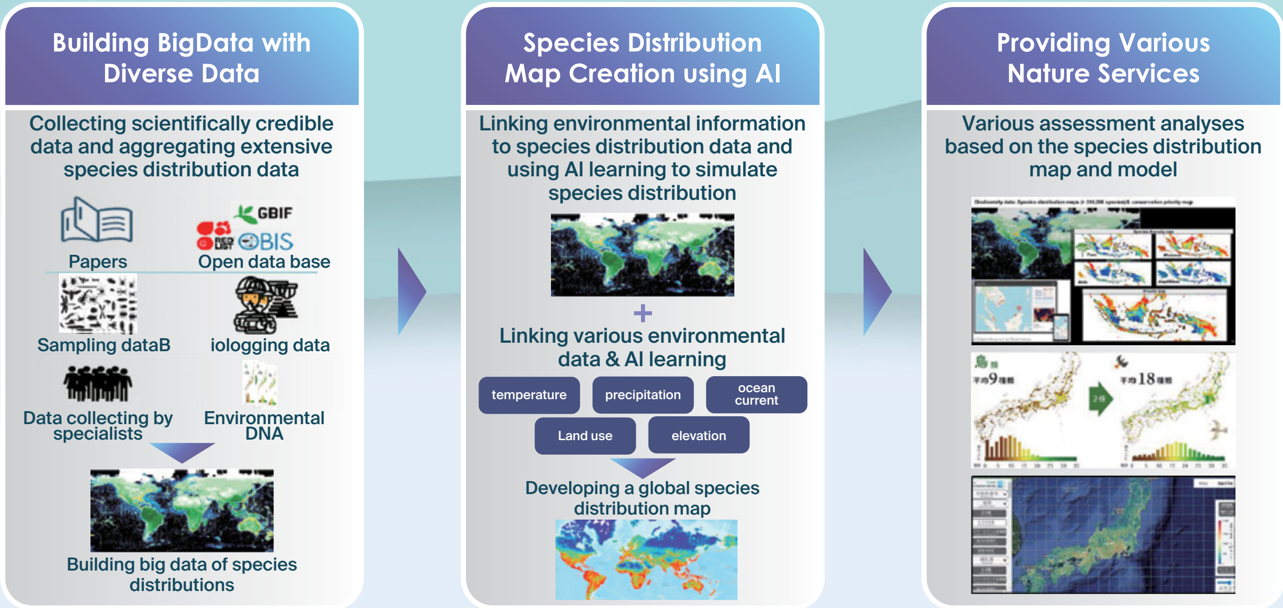
Biodiversity data value chain. The added value of biodiversity data increases in the order of i) raw data, ii) pre-processing, iii) analysis and iv) services. Raw data are observation data on the distribution of individual organisms. Pre-processing converts and integrates the raw data into a unified format and further purifies and enhances the data. In the analysis, various biodiversity indices are calculated from the processed data in space and time. Finally, the biodiversity data are combined with other data, services are provided and the data are monetised.

The data value chain in biodiversity information is broadly divided into four stages **(Box 3)**: **i)** raw data collecting, **ii)** data pre-processing, **iii)** data analysing and iv) developping services (such as GBNAT) provided to the public. The added value of the data increases with each successive stage. Raw data are voluntarily provided mainly by the academic sector: for example, there are lists of biological specimens, monitoring data of various taxa and ecosystems across terrestrial and ocean. These data depend on individual researchers in the form of survey data attached to their publications or by research institutions: they have made it publicly available.

In the case of biodiversity data, it is impossible to directly use the raw data (e.g. monitoring and eDNA data etc.) as they are, so data pre-processing is required to convert the raw data into a standardised format, and also to correct data bugs and geocoding accuracy. Pre-processing can be further divided into three phases: data standardisation/integration, data purification and data enhancement.

Data analysis involves the calculation of biodiversity features in space and time. In this analysis, environmental data, such as climate and land use, also be standardised to the same resolution as the biodiversity data. For example, the outputs of such analyses are shown in the Map of life **(https://mol.org/)** and the Japanese Biodiversity Mapping Project **(https : //biodiversity-map.thinknature-japan.com/)**. Finally, services implementing data for business use are developed using the analyzed data as the above mentioned.

These procedures and its importance may not be fully recognised in the assessment and analysis of nature-related risk and opportunities in the business.



Species distribution models for mapping biodiversity in finer scales for business needs

SPECIES OCCURRENCE RECORDS

Occurrence records of species were retrieved from the publicly available datasets such as Global Biodiversity Information Facility (GBIF), Ocean Biodiversity Information System (OBIS) and the global version of Japan Biodiversity Mapping Project (J-BMP) and published papers including Kusumoto et al. (2023) and Kusumoto et al. (2020). These occurrence data were cleaned for each species in line with species-specific habitat maps (e.g., Lumbierres et al. 2022) and also standardised by using country/region-specific checklists including GlobalTreeSearch (Beech et al. 2017).

MODEL AND ENVIRONMENTAL VARIABLES

Using these presence-only (or presence-absence) distribution data, we predicted the potential distribution of individual species by machine learning of Maxent version 3.4.0 in 10 arcmin resolution (about 18.5 km at the equator). In species distribution modelling (SDM), we used environmental factors, including climatic (Fick & Hijmans 2017), soil (Poggio et al. 2021), topographical (Takaku et al. 2016) and land-cover/use conditions (Bontemps et al. 2013), as predictor variables (table 1). A set of environmental variables used in the SDM model is listed in Table 1. These environmental variables were those whose importance has been confirmed by previous studies (Lehtomäki et al. 2019 ; Kubota et al. 2015).
We confirmed the accuracy of each model using the area under the receiver (AUC) operating characteristic curve. In terrestrial realm, global distribution of broadleaf trees (88,406 species), mammals (3,780 species), birds (10,775 species), reptiles (5,557 species), amphibians (5,624 species), and freshwater fishes (5,964 species) were used, totalled 120,106 species. In the marine realm, targeted taxonomic groups were marine fishes (12,800 species), marine mammals (100 species), marine reptiles (65 species), marine algae and seagrass (822 species), seabirds (230 species), marine crustaceans (8,514 species), Scleractinia corals (636 species), and marine shells (7,659 species), totalled 30,826 species.

Table 1: Environmental variables for SDM.

Realm	Variable Name	Category
terrestrial	Solar Radioation	atmosphere
terrestrial	Water Vapour Pressure (max, mean, min)	atmosphere
terrestrial	Wind Speed (max, mean, min)	atmosphere
terrestrial	Land Area	geometry
terrestrial	Latitude	geometry
terrestrial	Longitude	geometry
terrestrial	Bioclims	climate
terrestrial	Lgm Bioclims	historical climate
terrestrial	Land cover type (forest, farm grassland, urban, wetland, water)	land cover
terrestrial	Rivers (steam power, length, number of rivers)	river
terrestrial	Soil (10 variables for chemical and physical properties)	soil
terrestrial	Elevation (max, mean, min)	topography
marine	Waveheight	wave
marine	Chemical varibles (18 variables such as salinity or niterate)	chemical
marine	Lgm topograhpy	historical climate
marine	Ice Cover (annual, summer, winter)	ice
marine	Tide Average	physical
marine	Primary Productivity	productivity
marine	Chlorophy II-A (max, mean, min, range, summer, winter)	productivity
marine	Sea Surface Temperature (max, mean, min, range, summer, winter)	temperature
marine	Seabed Temp	temperature
marine	Water Column Temp	temperature
marine	Depth	topography
marine	Slope	topography
marine	Aspect	topography
marine	Distance to Shore	topography
marine	Port Distance	topography
marine	Windspeed	wind

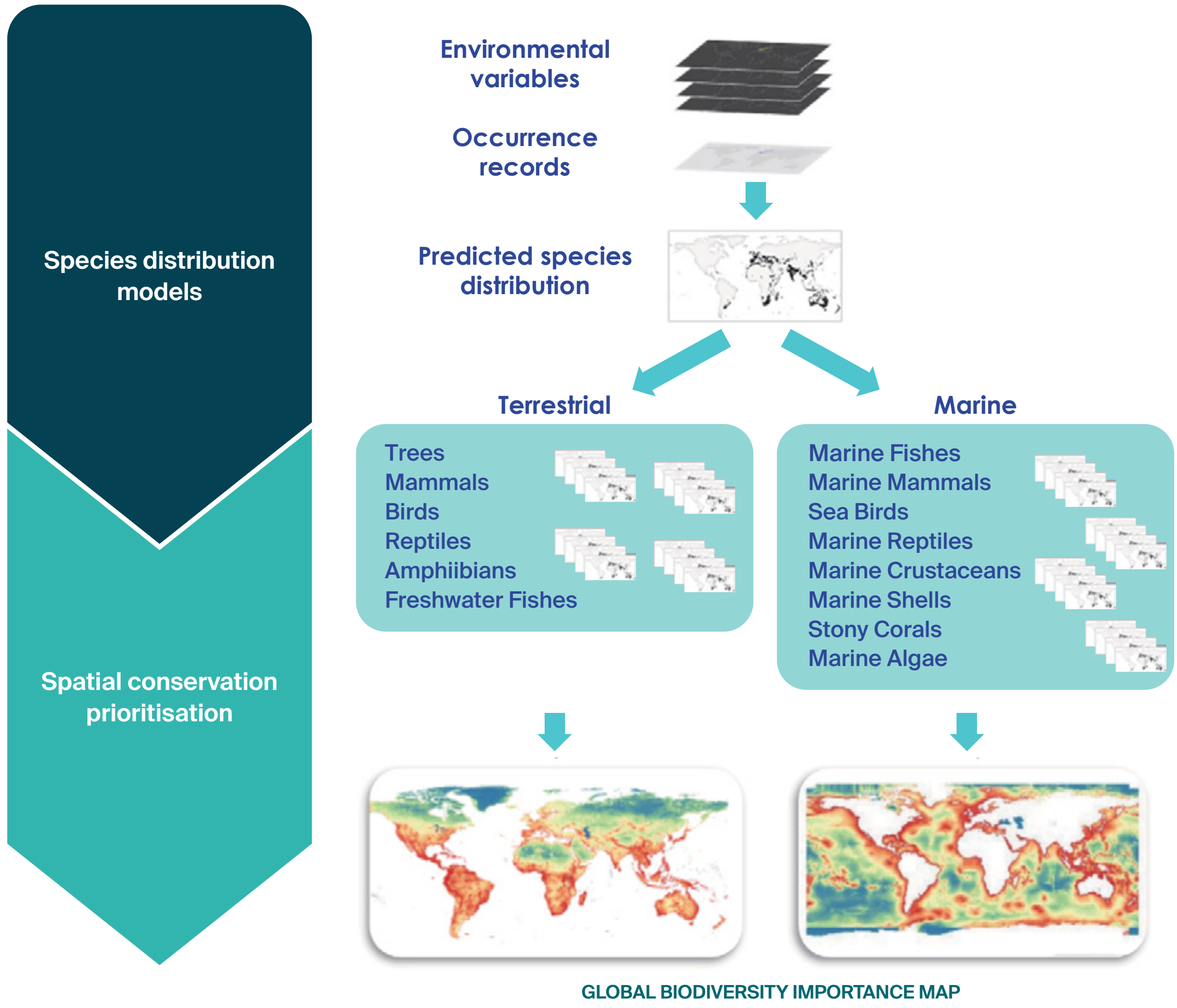
Spatial Conservation Prioritisation for bottom-up metrics of global biodiversity importance

ABOUT ZONATION

Zonation is a meta-algorithm for identifying conservation priority areas (Moilanen 2007; Lehtomäki et al. 2019 and Moilanen 2013), which prioritises each unit for biodiversity conservation by successively excluding the management unit with the least loss of the feature set (i.e., biodiversity). Moilanen et al. (2014) describes the features of Zonation as follows: “Zonation produces a complementarity-based and balanced ranking of conservation priority over the entire landscape (Moilanen et al. 2005), rather than satisfying specific targets at minimum cost”.

Zonation evaluates the importance of biodiversity based on how irreplaceable the biodiversity of one location is in the entire landscape. We globally computed the importance of biodiversity by using species distribution maps on a global scale as input to Zonation. The flow of the prioritisation analysis using SDM and Zonation **Box 4**.

Box 4: Flow of prioritisation analysis using species distribution model and Zonation



Species-by-species distribution models are applied to a number of taxonomic groups across terrestrial and marine realms.
The predicted distributions of individual species are then input to the Zonation computation.
This flow is applied for land and sea respectively, to create a global biodiversity importance map for both realms.

MODELS OF CONSERVATION VALUE - ADDITIVE BENEFIT FUNCTION

There are two types for the model of conservation value, namely, core are zonation (CAZ) and additive benefit function (ABF). In general, the former focused on conserving the most important feature while the latter formulates an accumulation of avoided loss of features by protecting a given site.
The CAZ is based on the meta-population perspective, which assumes that the distribution range (broad population size) of a species should be kept as large as possible, In our biodiversity importance metrics, we used the ABF that is based on the species-area relationship, which assumes that the extinction rate of a species should be kept as low as possible and that protected areas should be allocated in a way that maximises conservation benefits.

Therefore, The ABF is generally a good choice if the features are acting as surrogates for a larger regional species pool and trade-offs between features are allowed to achieve cost-efficient coverage of species (Moilanen et al. 2014). In other words, this benefit function identifies important areas from the perspective of covering the total biodiversity, avoiding an excessive bias toward the objective of rare species conservation.

INPUT FEATURES

We used the predicted suitability layer for each species in the subsequent spatial prioritisation analyses. Terrestrial and marine realms were analysed separately.

In order to remove bias of taxon-specific richness (e.g., plants have a huge number of species, while mammals have a relatively very small number of species), species were weighted as the following function:

$$w_i = 1 / N_i,$$

where wi specifies the weight for species belonging to taxonomic group i and Ni represents total abundance of species belonging to taxonomic group i.

In this weighting strategy, the weights for each species are adjusted so that each of the taxonomic groups has the same impact on the overall prioritisation, as is done in Lehtomäki et al. 2019. When using Zonation in the context of conservation practices, it is useful to include layers such as habitat conditions.

In biodiversity importance metrics, however, we only used species layers in prioritisation analysis since the aim of the metrics is to show the degree of each site's importance in terms of biodiversity distribution.

Methodologies and data for mapping biodiversity intactness and ecosystem condition metrics

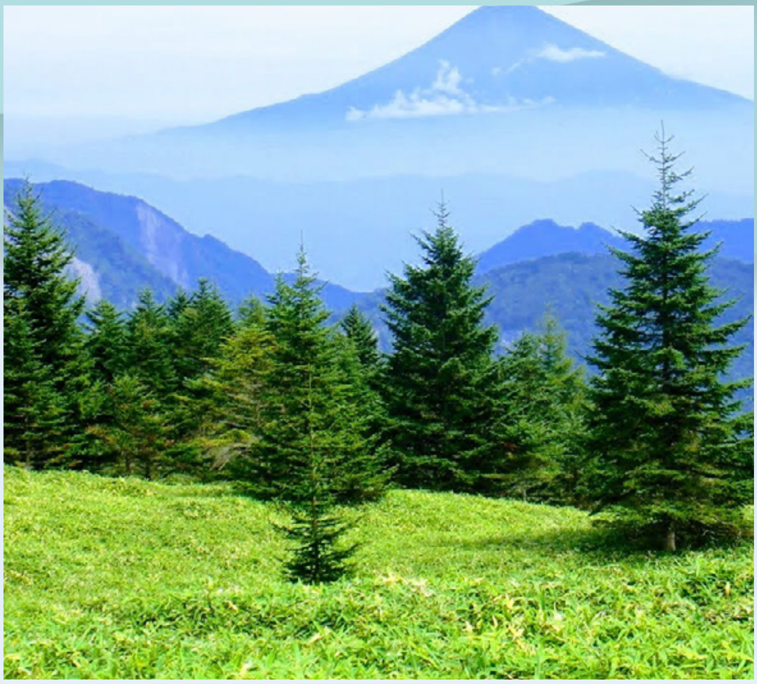
Biodiversity intactness

TERRESTRIAL INTACTNESS

The rate of species loss (i.e., MSA value) along the intensity of human land alteration were adopted from Cambridge Institute for Sustainability Leadership (2020).

MSA values are given for three levels of land alteration intensity (minimal, light, and intense) for natural forests, secondary forests, croplands, and pastures, respectively.

We combined this value with the spatial data layer of habitat map (Jung et al. 2020) to produce spatial representation of biodiversity intactness index. Since sourced habitat data layers were in 300 metre resolutions, we aggregated the value into 10 arc-minute using the mean.

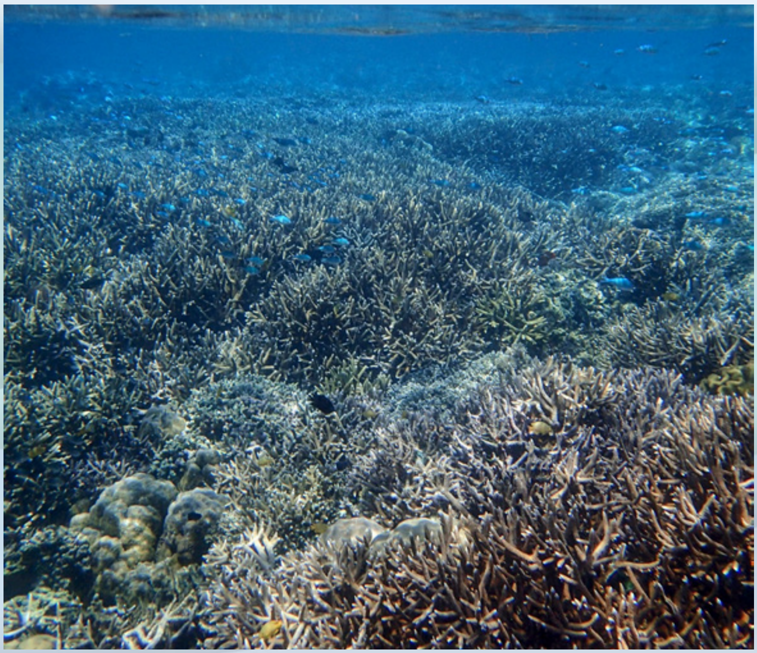


MARINE INTACTNESS

An established framework on direct indicators to quantify the intactness of ocean ecosystem is still lacking. In our framework, among existing approaches, we used the intensity of human development and resource use in the ocean, calculated by Halpern et al. (2019), as an indicator of the degree of intactness.

This indicator is the cumulative value of 14 indicators for human pressure to the ocean ecosystem, including climate change, fisheries, light pollution, organic pollution, and shipping.

The most recent data currently available (2013) was aggregated into a 10 arcminute grid using mean values.



Ecosystem condition metrics

RATIONALE FOR CHOICE OF DATA LAYERS.

In order to detect nature-related risks and opportunities for companies, it is necessary to refer to a set of indicators, rather than single aggregated metrics, that precisely capture the current status of ecosystems and nature with regard to multiple drivers of nature change (IPBES/3/INF/4).

For example, recent explanations of habitat loss such as deforestation and freshwater conditions are ones of considerable importance. Spatial distribution map, on a global scale, of such metrics corresponding to business risks and opportunities is essential as background information to identify priority locations in relation to business sectors, thereby improving the effectiveness of corporate financial disclosure and/or decision making.

Here, GBNAT offers a set of ecosystem condition metrics: Deforestation for a recent reduction of forest area, Human footprint increase for recent increase in human pressure to nature, Flood probability for current flood risk, and Water shortage for drought risk. Note that those metrics are in line with the recommended core global metrics by Taskforce on Nature-related Financial Disclosures (TNFD 2023). Other metrics referred in the recommendation, such as GHG and other pollutant emissions, as well as marine ecosystem condition layers, are to be included in GBNAT, soon.

DEFORESTATION

Forest distribution data was obtained from global forest cover datasets (Potapov et al. 2022), which predicted canopy height at 1 arc-second (about 30 metre at the equator) from 2000 to 2020 using manually collected training datasets and Landsat imageries. We defined forest at 5 metre in canopy height and calculated the reduction in forest cover between 2000 and 2020 at 10 arc-minute.

Areas where deforestation is in progress are valued positively, while areas where forest cover is expanded are denoted as a value of zero. The values were scaled as the percentage of reduced forest cover relative to the whole land area within the target 10 arc-minute gridcell.

HUMAN FOOTPRINT INCREASE

The human footprint metrics was first developed by Venter et al. (2016), which aggregates human pressure to the ecosystem by land development, agriculture and navigable waterways. In GBNAT, data layers calculated by Mu et al. (2022) for 2000 and 2019 in 1 km resolution were used to obtain a data layer for the increase in human footprint.

The source data layers, giving human footprint score for each grid cell in 0 - 50 scale, were aggregated by 10 arc-minute resolution using mean values and increase in human footprint was calculated as an absolute change in footprint score values.

WATER QUALITY

We used Biochemical oxygen demand (BOD) as a comprehensive measure of water quality. Gridded BOD data was obtained from the World Bank dataset (see Damania et al. 2019) from 1992-2010. BOD values are represented in 0.5 degree (30 arc-minute) resolution. Values are averaged through 1992-2010 and then downscaled to 10 arc-minute using bilinear interpolation. Further, we modelled a relationship between BOD values and environmental variables including topography, land cover, climate, soil (extracted water-related environmental variables used for SDMs), and pollutant emission data (Crippa et al. 2018) using Random Forest algorithm, then projected to data-deficient grid cells.

WATER SHORTAGE

The AWARE factor represents how much surplus water is available after ecological and human demands are met, relative to the global average, with larger values indicating a greater likelihood of water shortage (1: global average, 10: 10 times less available water remaining to the global average). The commonly used water stress (the ratio of demand to supply of water) can be high for large populations, even in areas with a high abundance of water in absolute quantity. The AWARE index is an indicator that takes into account the absolute amount of water that is redundant and thus better represents the risk of water scarcity. AWARE factor (Boulay et al. 2018) version 1.2c was obtained at watershed levels from the WULCA website. As was done for water quality data, we used downscaling and modelling-projection to create a 10 arc-minute degree data layer.

FLOOD PROBABILITY

A gridded flood risk layer (CHRR and CIESIN 2005), originally at 2.5 arcminute leve, was obtained then downscaled to 10 arc-minute. In the sourced dataset, the flood frequencies are given in 10 decile class bins. Next, we modelled the risk values by land cover, climate variables, and human footprint before the year of 2000 using Random Forest algorithm. We then projected the value using predictor variables at 2020. This projected value can be interpreted as the flood risk value in 2020, scaled by the flood risk decile value at 2000. We note that the resulting map of flood risk was generally comparable to results derived from climate model projections (Hirabayashi et al. 2021).

Worked examples in the context of biodiversity compliance

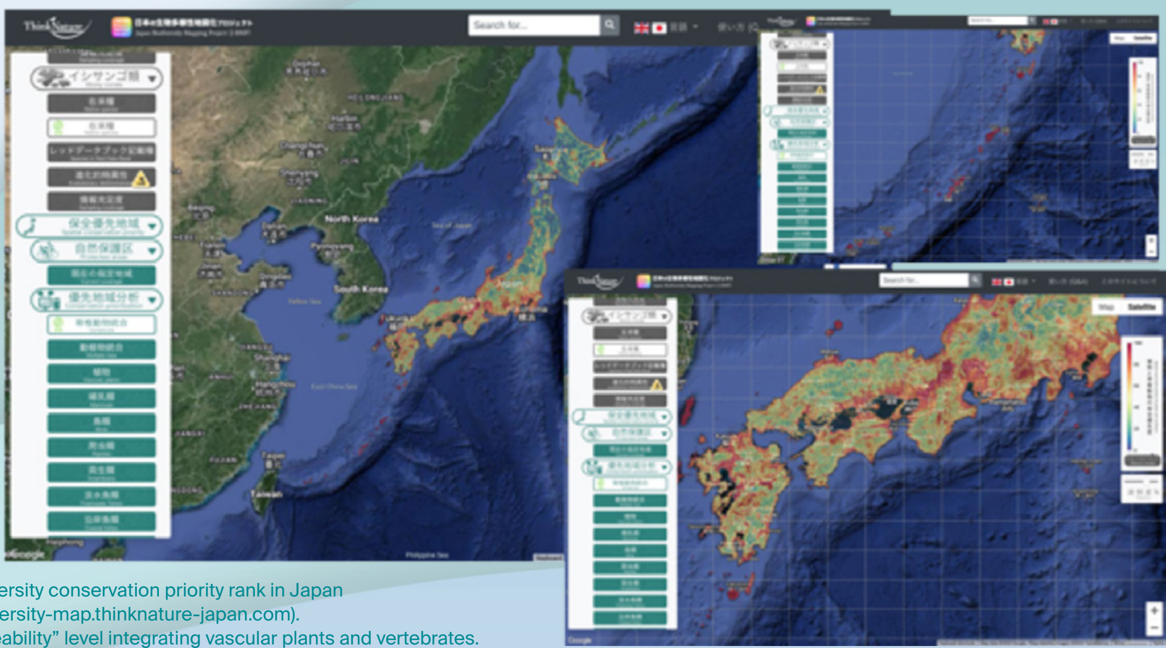
As explained above, overlaying species distribution maps provides numerical information on the biodiversity characteristics of each location, such as where many species are present or where rare species are distributed. Biodiversity map data can therefore be used to assess important areas of biodiversity conservation and restoration.
A promising methodology of systematic conservation planning is a conservation priority indicator based on the Zonation analysis (Moilanen et al. 2022).

For example, terrestrial land in Japan is divided into 1 km meshes and the natural environment of each mesh is ranked as spatial conservation priority (Lehtomäki et al. 2019) based on the amount of species that would be lost if the natural environment of each mesh were destroyed, e.g. by land development.

Specifically, land units that are not of conservation importance, where the number of species is scarce and only common species are distributed, are successively identified and finally ranked in terms of conservation priority for all meshes by highlighting where they are most important, i.e. where the number of species is rich and rare species are distributed.

As the conservation priority index for each land unit corresponds to the relative amount of biodiversity loss if that land is lost, it can be interpreted that the higher the conservation priority rank of a land parcel, the more important it is for conservation and the higher the risk of biodiversity loss if it is developed there.

The conservation priority rank can therefore be described as the 'irreplaceability' of biodiversity.



Map of biodiversity conservation priority rank in Japan
(https://biodiversity-map.thinknature-japan.com).
The "irreplaceability" level integrating vascular plants and vertebrates.

Mapping priority ranks calculated on the basis of Japan's biodiversity map data has led to various discoveries and is making a significant contribution to conservation measures. For example, the Ryukyu Islands are subtropical islands, so in addition to being rich in species in the transition zone between the tropics and the temperate zone, they are also home to many endemic species that have evolved on the islands.

This makes the land and sea of Okinawa Prefecture highly 'irreplaceable' and literally 'visible' as the most important area in Japan for biodiversity conservation. In fact, in Okinawa Prefecture, Guidelines for the Conservation and Sustainable Use of Biodiversity in Okinawa have been formulated based on the conservation priority indicators, and conservation cards system for land and sea units has been developed **(https://biodiversity.okinawa/guide/index.html).**

Furthermore, biodiversity map data is also being used to formulate an action plan for Okinawa Prefecture's regional biodiversity strategy.

Guidelines for the Conservation and Sustainable Use of Biodiversity in Okinawa **(https://biodiversity.okinawa/en/guide/index.html).**

Our data and tools have been widely used in response to the recent trend of publicising and promoting biodiversity initiatives by educators, companies and governments.

Especially, business sector is beginning to use our technology services as a basis in assessing nature-related risks and opportunities in line with the TNFD, for example, when determining the business location related to biome/ecosystem and evaluating dependencies of business activities and its impacts on biodiversity features (e.g. Shiseido Company 2023; Tokyu Fudosan Holdings 2023 ; MITSUI & CO., LTD. 2024; Okinawa Cellular Telephone Company 2024).

It is also expected that effective actions by companies to mainstream biodiversity initiatives by linking them to public awareness and participation will become increasingly important in the future.

Our message

The economy of biodiversity implementing nature-positive business

Biodiversity is the foundation of human society and this is referred to as natural capital. Until now, nature conservation has been argued in opposition to economic growth.

The dichotomous conservation debate has been "do we protect nature or do we develop it and take economic development?" However, as depicted in the SDGs wedding cake model, the idea that biosphere is a necessary condition for socio-economic sustainability has become mainstream.

That is why, in response to carbon neutrality (net zero emissions) in the fight against global warming, nature positive toward 'Living in Harmony with Nature' have been set as an international goal. The business sector is being called upon to make a commitment to achieving these goals. However, nature positive is easier said than done, and the challenge is to develop a business model that encourages investment in nature.

Think Nature is a start-up that is taking on this challenge. It aims to industrialise biodiversity, based on the idea of "delivering to society the nature-related big data accumulated through fieldwork around the world and the results of research such as AI technology that visualises the value of nature".

In the context of sustainability, business sectors are required to identify the relationship between their business activities and nature, and evaluate their dependence on and impact on biodiversity and ecosystem services (including carbon dynamics), and then disclose nature-related risk and opportunity.

As the users of corporate disclosure information are institutional investors and financiers, individual companies should gain an advantage in finance through appropriate disclosure.

More importantly, individual companies are required to avoid climate- and nature-related risks identified in the process of disclosure, to acquire new business opportunities, and to contribute to the financial cycle for climate change mitigation and biodiversity conservation and restoration through business innovation. Think Nature takes an innovative scientific approach to sustainability-related disclosure.

We support companies in their nature transformation by providing high-resolution assessment of nature values and focusing on actionable and effective plans in order to promote net-zero and nature positive in the business context.

References

Beech, E., Rivers, M., Oldfield, S. & Smith, P.P. (2017) GlobalTreeSearch: The first complete global database of tree species and country distributions. Journal of Sustainable Forestry, 36, 454–489.

Bontemps, S. et al. (2013). Consistent global land cover maps for climate modelling communities: current achievements of the ESA's land cover CCI. In Proceedings of the ESA living planet symposium, Edimburgh (Vol. 13, pp. 9-13).

Boulay, A.M. et al. (2018). The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). The International Journal of Life Cycle Assessment, 23, 368-378.

Center for Hazards and Risk Research - CHRR - Columbia University, and Center for International Earth Science Information Network - CIESIN - Columbia University. 2005. Global Flood Hazard Frequency and Distribution. Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC).
https://doi.org/10.7927/H4668B3D. Accessed 02/05/2024

Cambridge Institute for Sustainability Leadership (2020) Measuring business impacts on nature: A framework to support better stewardship of biodiversity in global supply chains. https://www.cisl.cam.ac.uk/system/files/documents/biodiversity-metric-supplementary-material.pdf

Carmenta, R. et al. (2023). Connected Conservation: Rethinking conservation for a telecoupled world. Biological Conservation 282: 110047.

CHRR and CIESIN (2005) Global Flood Hazard Frequency and Distribution. Center for Hazards + Risk Research (CHRR) and Center for International Earth Science Information Network (CIESIN), NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/ndh-flood-hazard- frequency-distribution

Crippa, M. et al. (2018). Gridded emissions of air pollutants for the period 1970–2012 within EDGAR v4. 3.2. Earth Syst. Sci. Data 10 (4): 1987-2013.

Damania, R. et al. (2019). Quality unknown: the invisible water crisis. World Bank Publications.

Dasgupta, P. (2021). The economics of biodiversity: the Dasgupta review. Hm Treasury.

Di Minin, E., Veach, V., Lehtomäki, J., Montesino Pouzols, F., & Moilanen, A. (2014). A quick introduction to Zonation.

Elith et al. (2011) A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17: 43-57.

Fick, S.E. and R.J. Hijmans, 2017. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37 (12) : 4302-4315.

Haddou, Y., Mancy, R., Matthiopoulos, J. et al. (2022) Widespread extinction debts and colonization credits in United States breeding bird communities. Nat Ecol Evol 6, 324–331. https://doi.org/10.1038/s41559-021-01653-3

Halpern, B. S., Frazier, M., Afflerbach, J., Lowndes, J. S., Micheli, F., O'Hara, C., ... & Selkoe, K. A. (2019). Recent pace of change in human impact on the world's ocean. Scientific reports, 9(1), 11609.

Hawkins F. et al. (2023) Bottom-up global biodiversity metrics needed for businesses to assess and manage their impact. Conservation Biology 38: e14183. https://doi.org/10.1111/cobi.14183

Hirabayashi, Y., Tanoue, M., Sasaki, O., Zhou, X., & Yamazaki, D. (2021). Global exposure to flooding from the new CMIP6 climate model projections. Scientific Reports 11(1): 3740.

International Biodiversity Assessment Tool (IBAT) (2023) https://www.ibat-alliance.org

IPBES (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services—Advance Unedited Version

Jung, M., Dahal, P.R., Butchart, S.H.M. et al. A global map of terrestrial habitat types. Sci Data 7, 256 (2020) https://doi.org/10.1038/s41597-020-00599-8

Keith, D.A. et al. (2022) A function-based typology for Earth's ecosystems. Nature 610(7932): 513-518.

Kubota, Y., Shiono, T., & Kusumoto, B. (2015) Role of climate and geohistorical factors in driving plant richness patterns and endemicity on the east Asian continental islands. Ecography 38(6): 639-648.

Kusumoto, B., Chao, A., Eiserhardt, W. L., Svenning, J. C., Shiono, T., & Kubota, Y. (2023) Occurrence-based diversity estimation reveals macroecological and conservation knowledge gaps for global woody plants. Science Advances 9(40): eadh9719.

Kusumoto, B., Costello, M. J., Kubota, Y., Shiono, T., Wei, C. L., Yasuhara, M., & Chao, A. (2020) Global distribution of coral diversity: Biodiversity knowledge gradients related to spatial resolution. Ecological Research 35(2): 315-326.

Lenzen, M. et al. (2012) International trade drives biodiversity threats in developing nations. Nature 486(7401): 109-112.

Liu, J. et al. (2013) Framing sustainability in a telecoupled world. Ecology and Society, 18(2).

Lumbierres, M. et al. (2022) Area of Habitat maps for the world's terrestrial birds and mammals. Scientific Data 9(1): 749.

Lehtomäki, J., & Moilanen, A. (2013) Methods and workflow for spa- tial conservation prioritization using zonation. Environmental Modelling & Software 47: 128–137. https://doi.org/10.1016/j.envso ft.2013.05.001

Lehtomäki, J., Kusumoto, B., Shiono, T., Tanaka, T., Kubota, Y., & Moilanen, A. (2019) Spatial conservation prioritization for the East Asian islands: A balanced representation of multitaxon biogeography in a protected area network. Diversity and Distributions 25(3): 414-429.

Mair, L., Bennun, L.A., Brooks, T.M. et al. (2021) A metric for spatially explicit contributions to science-based species targets. Nat Ecol Evol 5: 836–844. https://doi.org/10.1038/s41559-021-01432-0

Marsh, C.J. et al. (2022) Expert range maps of global mammal distributions harmonised to three taxonomic authorities. Journal of Biogeography 49(5): 979-992.

Milner-Gulland, E.J. et al. (2021) Four steps for the Earth: mainstreaming the post-2020 global biodiversity framework. One Earth 4(1): 75-87.

MITSUI & CO., LTD. (2024) The LEAP approach to Mitsui's Forest.https://www.mitsui.com/jp/en/sustainability/environment/biodiversity/leap/index.html

Moilanen, A., Franco, A. M. A., Early, R. I., Fox, R., Wintle, B., & Thomas, C. D. (2005) Prioritizing multiple-use landscapes for conservation: Methods for large multi-species planning problems. Proceedings of the Royal Society B: Biological Sciences 272: 1885–1891. https://doi. org/10.1098/rspb.2005.3164

Moilanen, A et al. (2014) Zonation—Spatial conservation planning methods and software. Version 4. User Manual 290.

Moilanen, A. (2007) Landscape Zonation, benefit functions and target- based planning: Unifying reserve selection strategies. Biological Conservation 134: 571–579.

Moilanen, A., Lehtinen, P., Kohonen, I., Jalkanen, J., Virtanen, E. A., & Kujala, H. (2022) Zonation 5 v1.0rc2 (release candidate 2) software upload. Zenodo. https://doi.org/10.5281/zenodo.5899003

Mu, H. et al. (2022) A global record of annual terrestrial Human Footprint dataset from 2000 to 2018. Scientific Data 9(1): 176.

Newbold, T. et al. (2016) Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. Science, 353(6296), 288-291.

Cambridge Institute for Sustainability Leadership. (2020). Measuring business impacts on nature: A framework to support better stewardship of biodiversity in global supply chains. University of Cambridge Institute for Sustainability Leadership. https://www.cisl.cam.ac.uk/system/files/documents/biodiversity-metric-supplementary-material.pdf

Nicholson, E. et al. (2021) Scientific foundations for an ecosystem goal, milestones and indicators for the post-2020 global biodiversity framework. Nature ecology & evolution 5(10): 1338-1349.

Paul, C., Hanley, N., Meyer, S. T., Fürst, C., Weisser, W. W., & Knoke, T. (2020) On the functional relationship between biodiversity and economic value. Science Advances 6(5): eaax7712.

Poggio, L., De Sousa, L. M., Batjes, N. H., Heuvelink, G. B., Kempen, B., Ribeiro, E., & Rossiter, D. (2021) SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty. Soil 7(1): 217-240.

Potapov, P. et al. (2022) The global 2000-2020 land cover and land use change dataset derived from the Landsat archive: first results. Frontiers in Remote Sensing 3: 856903.

Schipper, A.M. et al. (2020) Projecting terrestrial biodiversity intactness with GLOBIO 4. Global Change Biology 26(2): 760-771.

Shiono, T., Kubota, Y., & Kusumoto, B. (2021). Area-based conservation planning in Japan: The importance of OECMs in the post-2020 Global Biodiversity Framework. Global Ecology and Conservation, 30, e01783.

Shiseido (2023) Shiseido Climate/Nature-related Financial Disclosure Report May 30, 2023. https://corp.shiseido.com/jp/sustainability/env/pdf/risks_report.pdf

Takaku, J., Tadono, T., Tsutsui, K., & Ichikawa, M. (2016) Validation of" AW3D" global DSM generated from Alos Prism. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences 3: 25-31.

TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures.

Tokyu Fudosan Holdings 2023 TNFD Report. https://www.tokyu-land.co.jp/english/news/uploads/9d673385902152099957f636e9326c737d261afc.pdf https://tokyu-fudosan-hd-csr.disclosure.site/pdf/environment/tnfd_report.pdf

Tollefson, J. (2019) One million species face extinction. Nature, 569(7755): 171.

Venter, O. et al. (2016) Global terrestrial Human Footprint maps for 1993 and 2009. Scientific data 3: 1–10.