QUANTIFIYING BIODIVERSITY LOSS RISK

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Biodiversity Intactness indices

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CONTENT

ABSTRACT

This research paper investigates the pros, cons and use cases of **three selected biodiversity indices** that assess in three different ways a given ecosystem biodiversity loss: **Biodiversity Intactness Index (BII), Mean Species Abundance (MSA), and Potentially Disappeared Fraction (PDF)**.

- **The MSA** measures the relative abundance of species that are present in the reference state of the considered site compared to their current abundance.
- **The BII** introduces a more complex formula that penalizes the appearance of new invasive and opportunistic species. It provides a more comprehensive measurement of biodiversity loss than MSA.
- **Last but not least, the PDF** focuses on species disappearance in diversity estimates.

In this paper, we explore the respective strengths and limitations of each index, emphasizing the importance of context-specific evaluations. We also delve into their modelling considerations.

By critically assessing these biodiversity indices, this study aims to contribute to the refinement of ecological assessment tools and guide researchers and finance practitioners in selecting appropriate metrics for their use cases including their financings' biodiversity footprint measurement.

KEY FINDINGS

The assessment of biodiversity indices reveals distinct strengths and weaknesses, underscoring the need for a nuanced approach in ecological evaluations.

Mean Species Abundance (MSA) and Potentially Disappeared Fraction (PDF) stand out for their simplicity and widespread applicability in measuring relative species presence compared to the reference (or undisturbed) state of the considered site. However, their sensitivity to sampling effort and potential biases, particularly regarding invasive species, requires careful interpretation. **Indeed, neither MSA nor PDF might fully capture the changing health of ecosystems as they do not penalize the emergence of new opportunistic species**.

KEY WORDS

- BIODIVERSITY INDICES
- BIODIVERSITY FOOTPRINT
- QUANTIFYING BIODIVERSITY DISTURBANCE
- BIODIVERSITY INTACTNESS
- MEAN SPECIES ABUNDANCE
- MSA
- BIODIVERSITY INTACTNESS INDEX
- BII
- POTENTIALLY DISAPPEARED FRACTION
- PDF

Biodiversity Intactness Index (BII) outshines MSA by penalizing such opportunistic species, enhancing accuracy. **Nevertheless, like MSA and PDF indices, the BII is also hampered by a weak weighting scheme that assigns equal weights to all species**.

Potentially Disappeared Fraction (PDF) that focuses on the loss of species, benefits from a greater modelling effort that should allow in the future to quantify invasive species pressure impact.

The three biodiversity indices are highly sensitive to sampling efforts and might encompass data quality issues.

Acknowledging the limitations of these indices, researchers should carefully select the indices based on study objectives and available data. **Combining these indices is recommended for a more comprehensive evaluation of ecosystem health, recognizing their complementary role in assessing biodiversity**.

INTRODUCTION

According to the World Wildlife Fund (WWF), populations of mammals, birds, amphibians, reptiles and fish have declined by an average of 69% between 1970 and 2018 **[1]**. This collapse is accelerating since "1 million animal and plant species are now threatened with extinction, more than ever before in human history" **[2]**.

Natural habitats loss and degradation, climate change, resources overexploitation, air, water and soil pollutions... **Human activities exert strong pressure on all forms of life** (plants, animals, fungi, bacteria, etc.), natural environments and their interactions, referred together as "biodiversity".

THE CONSEQUENCES OF BIODIVERSITY LOSS

The loss of species disrupts ecosystems and can have serious **consequences for human health and safety**. For example, since crops at least partially pollinated by animals account for 35% of global food production, a loss of biodiversity could threaten the sustainability of the whole world's food supply **[3]**.

The consequences are also economic since $44 trillion of economic value generation – over half the world's total GDP – is moderately or highly dependent on nature and its services **[4]**. Biodiversity also provides nearly twice the value in goods and services of what humans produce each year **[5]**. Its collapse would entail **significant medium and long-term economic costs for governments, economic players and citizens**.

Reversing the loss of biodiversity is still possible. But it requires almost $500 billion a year until 2030, whereas the world currently spends less than $150 billion on nature conservation, and $300 billion on environmentally damaging subsidies **[6]**. It is therefore essential that economic players start to act in the face of nature-related risks, in order to **redirect financial flows taking nature into consideration**.

THE EMERGING "BIODIVERSITY RISK" CONCEPT

Against this backdrop, the concept of "biodiversity risk" has been emerging in recent years in the financial area. It refers to the **financial threats and opportunities posed by biodiversity loss** to global economic, financial and geopolitical stability. It also includes the solutions and responses implemented by financial institutions, investors and companies.

Most of these players are now aware of the importance of assessing this risk and taking it into account in their processes, policies, decisions and products. However, **measuring and fully understanding this risk remains a complex issue and requires a shared analytical framework and methodology**.

THE TASKFORCE ON NATURE-RELATED FINANCIAL DISCLOSURES (TNFD)

The Taskforce on Nature-related Financial Disclosures (TNFD) is an international working group on nature-related financial risk disclosure and transparency created in July 2020. Its aim is to **help shift international financial flows away from activities with negative impacts on biodiversity** towards those with a positive impact.

This initiative has led to the creation and adoption of a **common framework** with appropriate tools to enable financial and economic players to identify, analyze, manage and disclose their risks, opportunities, impacts and dependencies on nature.

This collective initiative brings together multiple stakeholders: governments, consortia, private companies and financial institutions, supported by experts and scientists, as well as the partners behind the initiative, such as the UN, Global Canopy and WWF. **BNP Paribas has been involved in the initial design work for the TNFD in 2020** and is also represented among the 40 members of the working group set up for the official launch of the initiative in October 2021.

In September 2023, the TNFD published a list of indicators of the impact of business activities on biodiversity. They are grouped into **15 to 20 families of key indicators for each business sector.** The TNFD also provides 14 recommendations, general management principles, guides and common definitions and analysis frameworks to the companies.

THE TASKFORCE ON NATURE-RELATED RISKS OF THE NGFS

The Network for Greening the Financial System (NGFS) brings together 127 central banks. Since its creation in 2017, it has become the **global reference for the development of interoperable standards to "guide central banks and supervisors actions on nature-related risks"**.

In 2023, the NGFS published a new conceptual framework for nature analysis. It marks an important step towards filling the gaps in assessing the economic and financial implications of biodiversity-related risks, and providing a common evaluation language and methodology.

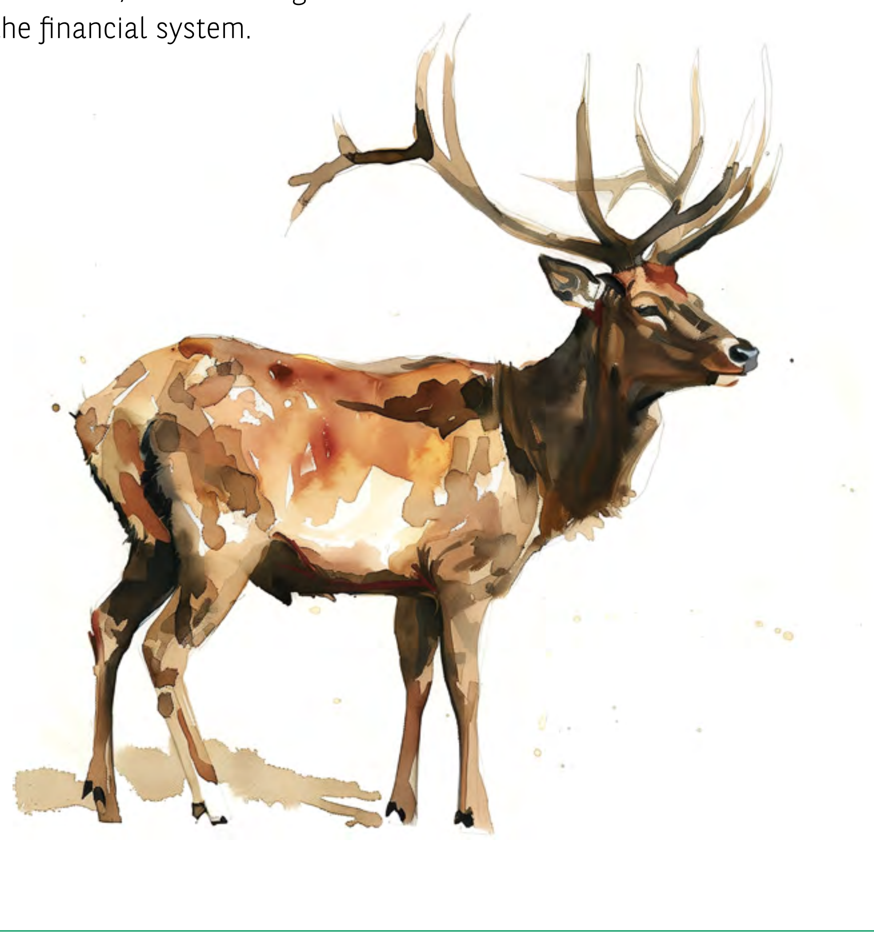
This **risk assessment framework comprises 3 phases**: identifying sources of physical and transition risks, assessing economic risks, and assessing risk to, from and within the financial system.

QUANTIFYING THE IMPACT OF HUMAN ACTIVITY ON BIODIVERSITY IS ESSENTIAL

Quantifying the impact of human activity on biodiversity is a difficult task, given the amount of **interconnected factors** at play and the complexity of the very concept of biodiversity which encompasses a range of dimensions (variety of species, ecosystems and genes, ecological functions, etc). This quantification must therefore be able to combine field data, expert reports, measurements of biodiversity in a given territory, economic analyses and ecological modelling to simulate the potential impact of various scenarios on biodiversity.

Achieving this quantification is essential to implement conservation and sustainable policies and financial strategies in the service of nature. The tools, methodologies and recommendations provided by the TNFD and the NGFS represent a significant step towards achieving these goals.

This is the first publication of a series of papers aiming at contributing to the development of methodologies and tools to quantify financing portfolios biodiversity risks.



LITERATURE REVIEW

Several papers study the biodiversity indices that we focus on in our paper:

R J Scholes and R Biggs, 2005 **[7]**, introduced the Biodiversity Intactness Index as a metric to assess an ecosystem's health. This metric was expressed as a percentage of the preserved biodiversity from the pristine state. It allows to aggregate human impact on a given site. It was modelled as a function of the ecosystem's characteristics and anthropogenic pressures. This index was then used in the same paper to evaluate the biodiversity intactness of the region of southern Africa.

Some other articles compare advantages and limitations of different biodiversity indices:

Peter Fedor and Martina Zvaríkováv, 2019 **[8]** compared the Shannon-Wiener index for species diversity – which quantifies the amount of disorder of the site – and the Simpson index – which is a diversity measure that can be interpreted as the probability that two randomly selected species in the considered site belong to the same type of species. These indices measure the diversity of the ecosystem at a given date. Their values do not give an idea about the degradation of the ecosystem, instead, they give an idea about the amount of diversity that the ecosystem has. In fact, a high value of these indices means that there are many different species in the considered site, without any comparison with the pristine condition. Respectively, a small value of these indices implies that the ecosystem is not diverse, without any idea about the abundance of each species, and its evolution with respect to the reference state.

David Vačkář, Ben ten Brink, Jonathan Loh, Jonathan E.M. Baillie, Belinda Reyers, 2011 **[9]**, focused on key aspects of biodiversity indices for environmental sustainability. The paper discussed the ecological performance of leading biodiversity indices by examining whether an index is performant regarding the detection of extinction events, quantifying human impacts and other aspects.

For instance, the Red List Index is well suited for the detection of extinction events of a species. While species-based indices such as MSA, BII and NCI (Natural Capital Index) are able to detect and measure the local degradation of an ecosystem. In addition, the article discusses on the most impactful human pressure for each index: for BII, the main pressure is land use activities, meanwhile NCI and MSA rely on many major factors such as climate change, Nitrogen deposition and land cover. Finally, the article discussed the technical aspects of these indices. For instance, it discusses the weighting scheme used for each index: as an example, for MSA and NCI, each square meter is equally weighted. Also, these indices differ in the way they consider their baseline, for example, the Living Planet Index and the Red List Index use as a baseline a fixed reference year (1970 for Living Planet Index), meanwhile NCI, MSA and BII consider the reference state as a "low-impact" state.

Our paper focuses on the three biodiversity indices for human impacts quantification that are the most explored by financial institutions in their portfolios biodiversity footprinting assessments; MSA, BII and PDF. We compare their strengths, limitations and use cases. Additionally, we discuss the need to model the index as a function of various features, such as land use type, owing to the data constraint. It is worth mentioning that NCI[1] aggregates human impacts as well. But, due to data challenges, especially on current and baseline species abundances, an MSA index model was easier to develop. Indeed, the two indices are coupled and MSA is more intuitive. For this reason, we decided to focus on MSA.

1- NCI consists of two components: ecosystem quantity and quality. Quantity of an agricultural area for example is the remaining extent of an ecosystem in terms of area, that remained intact, after cultivation, while quality is the mean abundance of original species compared to a reference state.

MEAN SPECIES ABUNDANCE

The Mean Species Abundance (MSA) gives insights about local biodiversity intactness. Knowing that the abundance of a particular specie in a given site is defined as the number of individuals – plant or animal species – within the considered site, the MSA estimates the average abundance of species relative to a baseline (reference state) in a pristine site **[10]**. It should be noted that species that are not present in the pristine site are excluded from the calculation, meaning that MSA refers to the state of naturally present biodiversity.

MSA ranges from 0 to 1, where an MSA of 100% means that the considered ecosystem is undisturbed. An MSA of 0% should be interpreted as a complete loss of the original biodiversity.

In terms of mathematical formalization, we compute the ***MSA*** of a site ***S***, with respect to the reference state of the same site ***S_ref***.

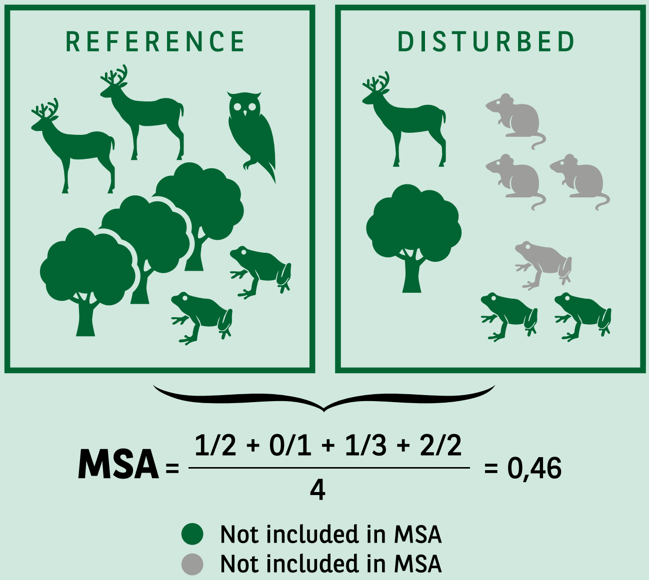
Let $N_{i,S}$ (resp. $N_{i,S\,ref}$) denote the abundance of species i in the site S (resp. S_{ref}) and $M\,S_{ref}$ the number of species in the site S_{ref} (It represents the number of native species in the site of interest).

The ***MSA*** of the site ***S*** is given by the following formula **[10]**:

$$MSA = \frac{1}{M_{S_{ref}}} * \sum_{i=1}^{M_{S_{ref}}} \min\left(\frac{N_{i,S}}{N_{i,S_{ref}}}, 1\right)$$

The ***min*** operator is used to prevent the index from being inflated by opportunistic species that benefit from habitat disturbance.

FIGURE 1: SIMPLIFIED MSA CALCULATION [10]



ADVANTAGES AND LIMITATIONS OF MSA

Pros: MSA is intuitive and simple to understand since its formula is straightforward and obvious. Computing this metric allows ecologists to quickly grasp the central tendency of species abundance, they can therefore know which site is more influenced by human activities compared with other sites.

Cons: MSA formula does not penalize or account for the appearance or the development of invasive species. In fact, let us consider a site, that still contains all his native species, with the same abundance for each specie as in the reference state, in addition to other new invasive and opportunistic species. MSA index will be equal to 1, even if the ecosystem wasn't preserved. In other words, despite the appearance of invasive species in this site, its biodiversity seems undisturbed according to its MSA.

Besides, the MSA weights equally all species. Hence, rare species have exactly the same weight as abundant species.

Computing MSA requires a huge amount of data. Indeed, we should have access to the data of each species all over the world in both its reference and current state to compute the exact observed MSA for each site on earth which is an impossible task. This without including the unknown terrestrial animal diversity also called "dark taxa" **[11]**. The lack of data justifies the need for modelling MSA to be able to extrapolate MSA to sites where no data is available. Indeed, MSA could be seen as a function of a set of the sites features (land use, road density, Nitrogen deposition, Hunting).

MODELLING CONSIDERATIONS

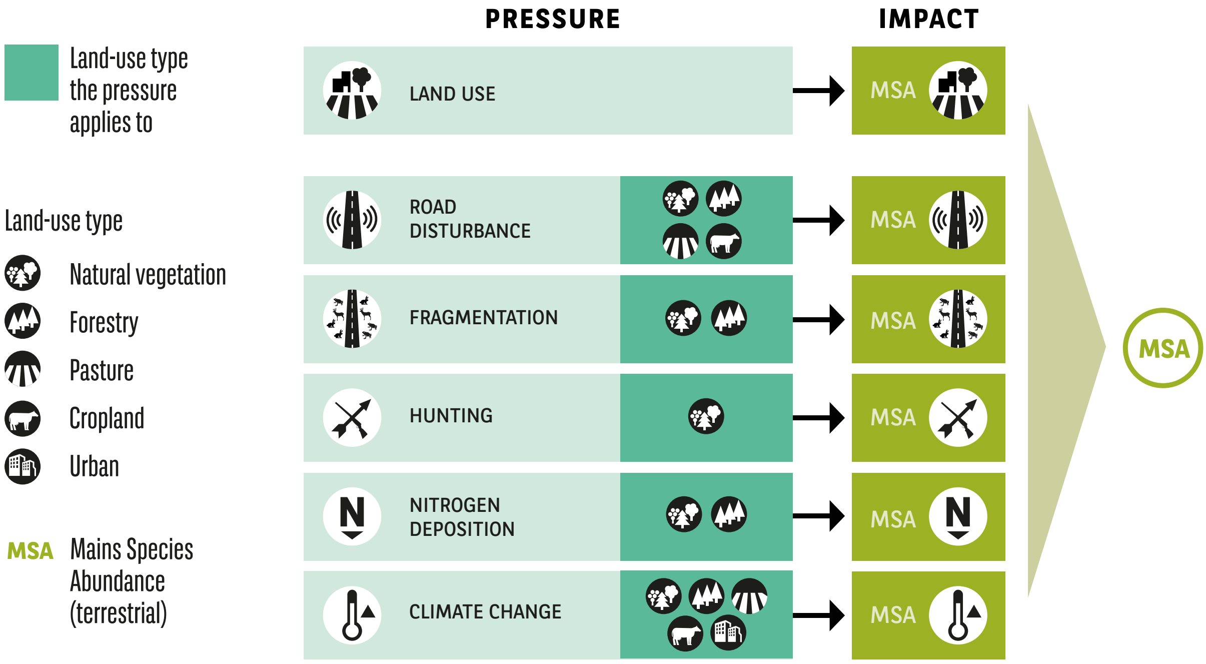
In partnership with various collaborators, PBL Netherlands Environmental Assessment Agency has developed the GLOBIO3 model to quantitatively assess global human impacts on biodiversity and ecosystems, serving as a valuable tool for informing and supporting policymakers. GLOBIO3 model is based on general linear mixed effects models, it aims at evaluating the potential impacts of human activities, such as agriculture and urbanization, on biodiversity and ecosystems globally. It uses quantitative relationships between environmental pressure factors (Land use, road disturbance, fragmentation, hunting, nitrogen deposition, climate change) and biodiversity. The overall change in biodiversity is calculated in terms of MSA (Mean Species Abundance of original species).**[12]**

The diagram below illustrates how GLOBIO3 model is structured.

The GLOBIO3 model relies on a framework of cause-and-effect relationships that delineate six human-induced impacts on biodiversity: **land use, climate change, atmospheric nitrogen deposition, infrastructure, habitat fragmentation, human encroachment**.

The data corresponding to each impact were brought from external sources and using some other models as IMAGE model, to generate land cover and land use data.

FIGURE 2: GLOBIO3 MODEL STRUCTURE AND MAIN FEATURES [10]



To aggregate the impact of each anthropogenic pressure, a quantitative relationship was set between each driver and the ***MSA*** index. In other words, a linear mixed effects model was fitted, for each anthropogenic pressure, to deduce how the ***MSA*** varies with respect to this pressure. For each pressure ***X***, we define MSA_X the function that represents the dependence between the ***MSA*** index and the pressure ***X***. Once these models are set, it's possible to compute the ***MSA*** for each region, using the following formula:

$$MSA(r) = \prod_{i=1}^{6} MSA_{X_i}$$

Where: X_i represents the i^{th} impacts driver.

After computing the $MSA(r_i)$ index for each subsite, it's possible to compute the global ***MSA*** index, of a site containing many subregions, by averaging using the regions' areas.

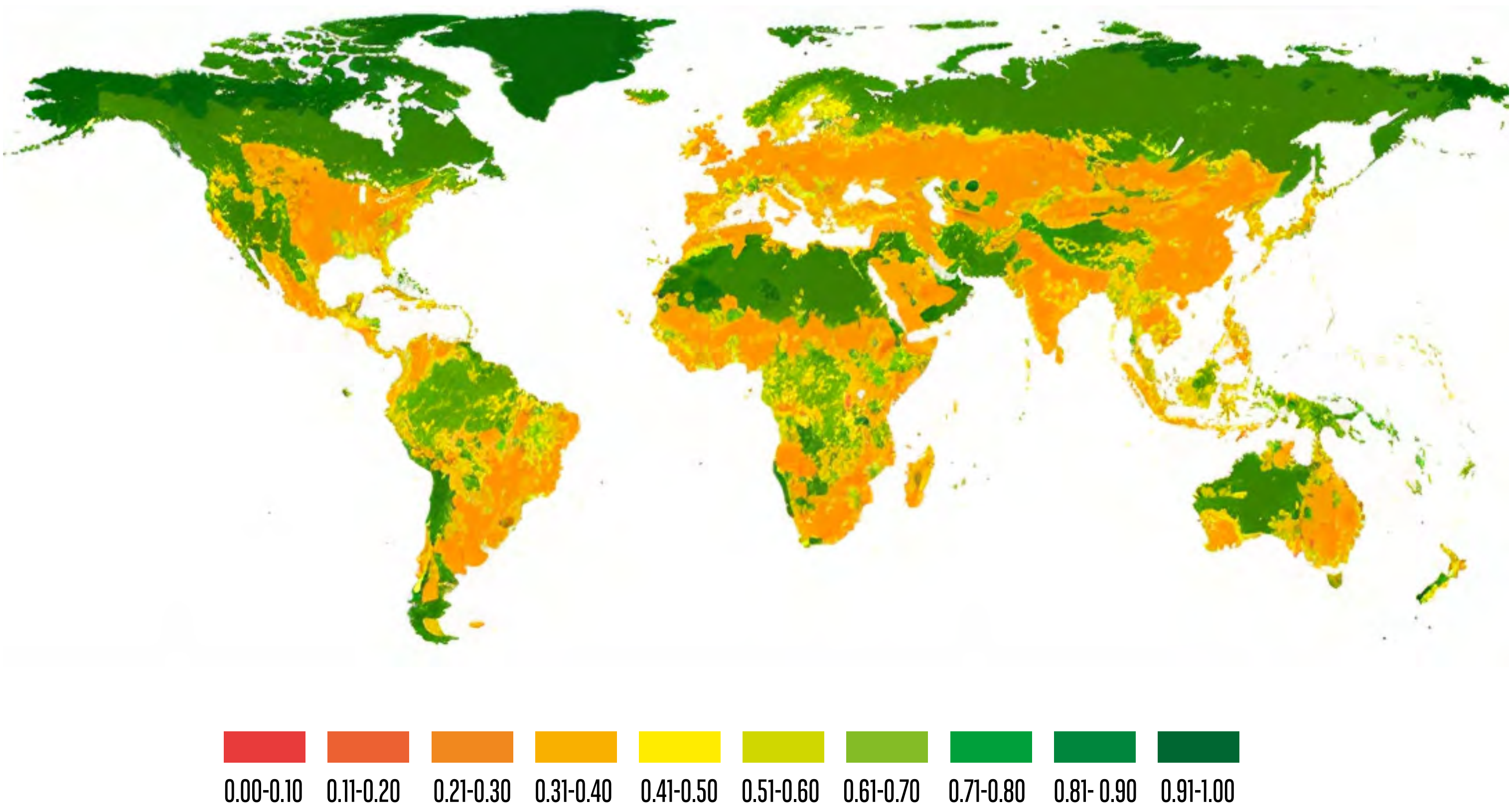
Let ***R*** denote the number of subregions of our site, the global ***MSA*** across all the subregions is computed using the formula below:

$$MSA(r) = \frac{\sum_{i=1}^{R} MSA(r_i) * Area(r_i)}{\sum_{i=1}^{R} Area(r_i)}$$

Where: $Area(r_i)$ stands for the area of the subregion r_i.

GLOBIO3 model allows to generate the following map for the MSA index in 2015.

FIGURE 3: MSA WORLD MAP IN 2015 USING GLOBIO MODELLING [13]



We see in the map that Northeastern part of Russia (Siberia) and Alaska appear to be intact. In other words, their biodiversity is still as it was in the reference state. This is due to the fact that these two parts of the globe aren't inhabited by humans, which explains their good MSA level. On the other hand, many regions of the globe appear to be very impacted by human activities, such as western Europe, the United States and China.

BIODIVERSITY INTACTNESS INDEX

The Biodiversity Intactness Index (BII) is a different metric designed to quantify the extent to which an ecosystem retains its original biodiversity in the face of anthropogenic disturbances. Essentially, it provides a numerical representation of how well an ecosystem preserves its natural state. **[14]**

This ratio offers a quantitative measure, usually expressed as a percentage, indicating to what extent the subsite S is similar to its reference state S_{ref}. BII ranges also from 0 to 1, where a BII of 100% means that the ecosystem is undisturbed while BII of 0% means a complete loss of the original biodiversity.

The BII of a given site S could be computed using the following formula of its compositional similarity (CS):

$$BII = CS = \frac{2\sum_{i=1}^{P} \min(N_{i,S}, N_{i,S_{ref}})}{\sum_{i=1}^{P} (N_{i,S} + N_{i,S_{ref}})}$$

FIGURE 4: EXAMPLE OF A SIMPLIFIED ECOSYSTEM BEFORE AND AFTER HUMAN IMPACTS

Where:

$N_{i,S}$ is the abundance of a species i in the site S and $N_{i,S\,ref}$ the abundance of the same species i in the reference state of the same site S.

P is the total number of species (native and invasive included) in the site S. (We also consider native species that no longer inhabit in the considered site).

Here we will be presenting a simple case to compute the BII index.

The green specimens represent the intersection between the reference state and the disturbed one in terms of individual species. In other words, it represents the lower abundance for each species in both sites, while the species in black and white represent the individuals that disappeared or appeared in the disturbed site. The diagram represents the union of both states of the site.

The BII of this site is equal to:

$$BII= \frac{CS= 2(\min(3,0)+\min(2,5)+\min(1,0)+\min(3,1)+\min(4,1))}{(3+0+2+5+1+0+3+1+4+1)} = 0.4$$

Let us divide our region ***S*** to ***R*** subregions (each subregion is denoted ***ri***). Let $P_{(ri)}$ denote the number of species (native and invasive) in the sub-region ***r***. The BII index for the region ***S*** is expressed as follows **[7]**:

$$BII(S) = \frac{\sum_{i=1}^{R} CS(r_i) * P(r_i) * Area(r_i)}{\sum_{i=1}^{R} P(r_i) * Area(r_i)}$$

ADVANTAGES AND LIMITATIONS OF BII

Pros: The Biodiversity Intactness Index offers a numerical value, facilitating comparisons and analyses of biodiversity across different regions. In addition, unlike ***MSA***, the BII penalizes the introduction of new invasive species and abnormal levels of abundance of specific species, whether there's an increase or decrease in their abundance. Hence, the BII's quantification of the alterations in biodiversity resulting from human activities is more comprehensive than the MSA's one.

Cons: As the formula suggests, to compute BII of a region, we need to have access to the abundance data of each species. This stands for each region all over the globe. This is impossible, due to data limitations and the complexity of accessing to some sites to take in-site measurements. Hence, BII computations rely heavily on modelling like the MSA (see Modelling BII below for more clarifications on modelling uncertainties). Finally, in the formula of BII, we notice that all species are accounted in the same way. Hence, the BII does not reflect relative abundance across species. Besides, species that are highly abundant would have a greater weight than other species. For instance, let us suppose that in a region A, there are 1 million bees, and 5,000 lions in the reference state, after several years, we still have 1 million bees, but we have 100 lions, the BII of this region will be equal to 99.7%! This numerical value does not reflect the dramatic decrease of lions' population in this region. Treating all species equally may not accurately reflect their ecological significance or contribution to overall biodiversity. Some species may play more critical roles in an ecosystem, and their abundance or decline could have disproportionate effects on ecosystems' health.

MODELLING BII

Given the challenges posed by data constraints, it becomes imperative to model BII as a function of various features. This approach enables to understand well how each driver of impact influences biodiversity intactness. For instance, such model can show how different land use types, like pasture, urban development, and cropland, can significantly impact biodiversity, compared with other land use types. By incorporating these features into the index, we enhance its applicability and robustness in regions with limited data.

In this context, the model developed by **PREDICTS team [13]** can be cited as one of the most accurate models of BII. This model tends to set quantitative relationships between human activities and their impacts on biodiversity, by modeling the effect of these activities on the Biodiversity Intactness Index.

The main features considered in this model are Land use type, road density and human population.

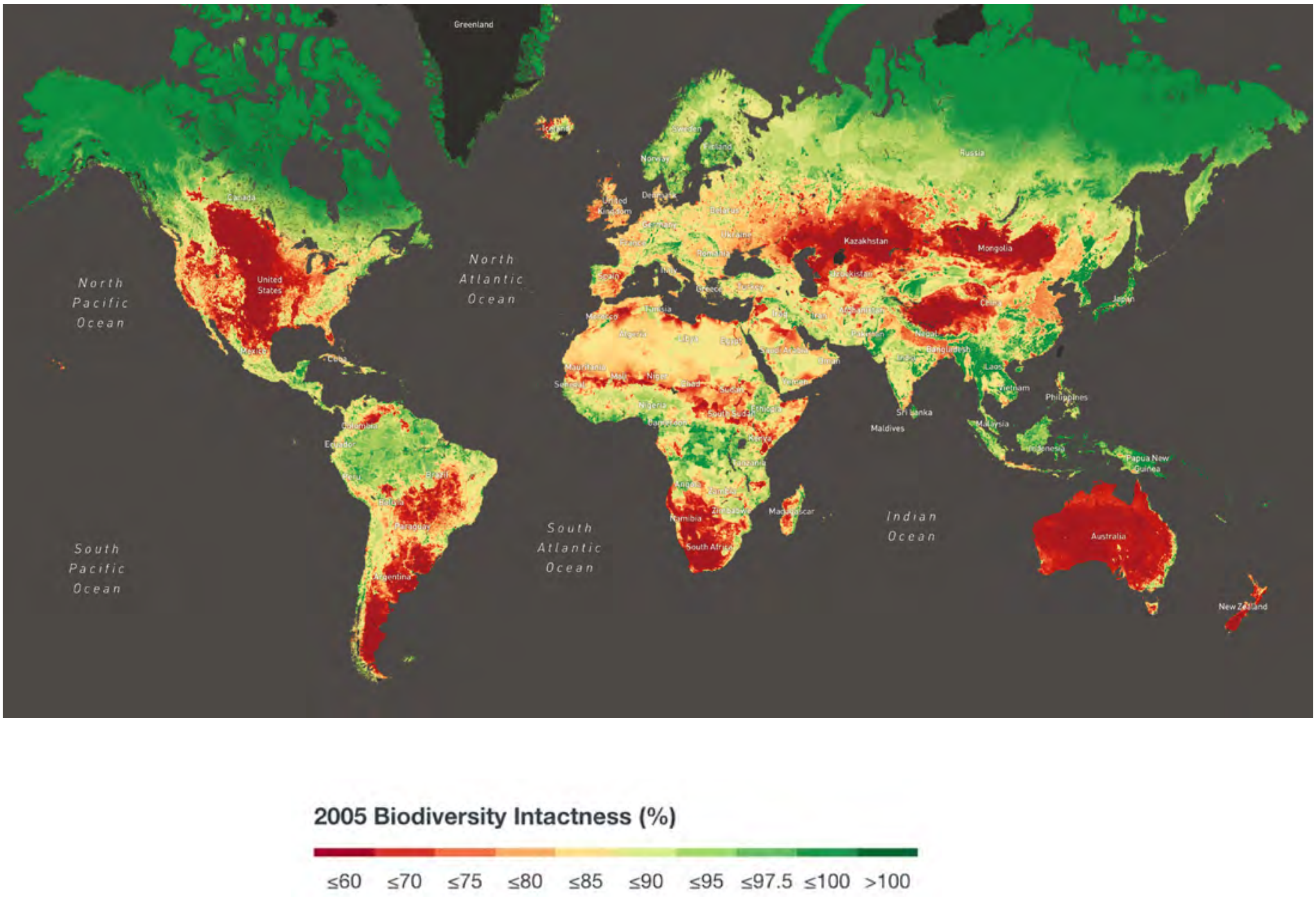
PREDICTS model is a linear mixed effects model, structured as explained below.

First, as we have seen in the **BII** formula presented above, computing this index requires a full knowledge of the species in each site of the globe and their abundance. This data is required to compute the total abundance of all species and the compositional similarity of a site with its reference state. It is worth mentioning that the compositional similarity is a metric used in this framework to quantify to what extent a site is similar to its reference state. **The idea behind PREDICTS is to model the total abundance and the compositional similarity as a function of the features mentioned before** (Land use type, road density and human population). To set this relationship, the PREDICTS team based their study on the PREDICTS database that gathers many ecological data, including abundance data of many sites all over the world. **The idea is to establish a linear relationship between these features and the quantities that we need to compute: total abundance and compositional similarity. [7][15][16]**

Once this relationship is set, it is possible to compute the BII for each pixel of the globe, knowing its features.

The following map was generated using PREDICTS model. It shows the BII for each site in the world.

FIGURE 5: BII MAP USING PREDICTS MODEL [17]



Most of the BII geographical trends are similar to MSA ones. Indeed, Alaska and Siberia seem to be also intact according to their BII, which is quite intuitive as there are barely no human activities there. We also notice that the United States biodiversity is among the most disturbed ones. However, we also notice that Australia biodiversity is highly impacted by human activities, which was not observable in the MSA map presented before. This could be caused by the development of many invasive species **[18][19]**, which is penalized in BII computation, while not in the MSA index formula.

POTENTIALLY DISAPPEARED FRACTION OF SPECIES

Life Cycle Assessment (LCA) methodology allows to measure biodiversity footprint by providing a comprehensive analysis of environmental impacts associated with all stages of a product's life cycle. Potentially Disappeared Fraction (PDF) is the impact unit recommended by the Life Cycle Initiative hosted by UN Environment for indicating damage to ecosystems in LCA. This metric was introduced in 1998 to model land use impacts on plants **[20]**.

Mathematically, the metric is defined as the proportion of locally extant species that get extirpated (i.e. disappear) as a result of exposure to pressures such as environmental pollution.

Let PDF(S) denote the potentially disappeared fraction of species at a site ***S***. Let S_{ref} denote the same site without any environmental pressure.

The number of species in S_{ref} is given by $N_{S\,ref}$. For a species ***i*** at the site ***S***, $x_{i,S}$ is defined such that:

$$x_{i,S} \begin{cases} 1 \text{ if species i is not present at S} \\ 0 \text{ if species i is present at S} \end{cases}$$

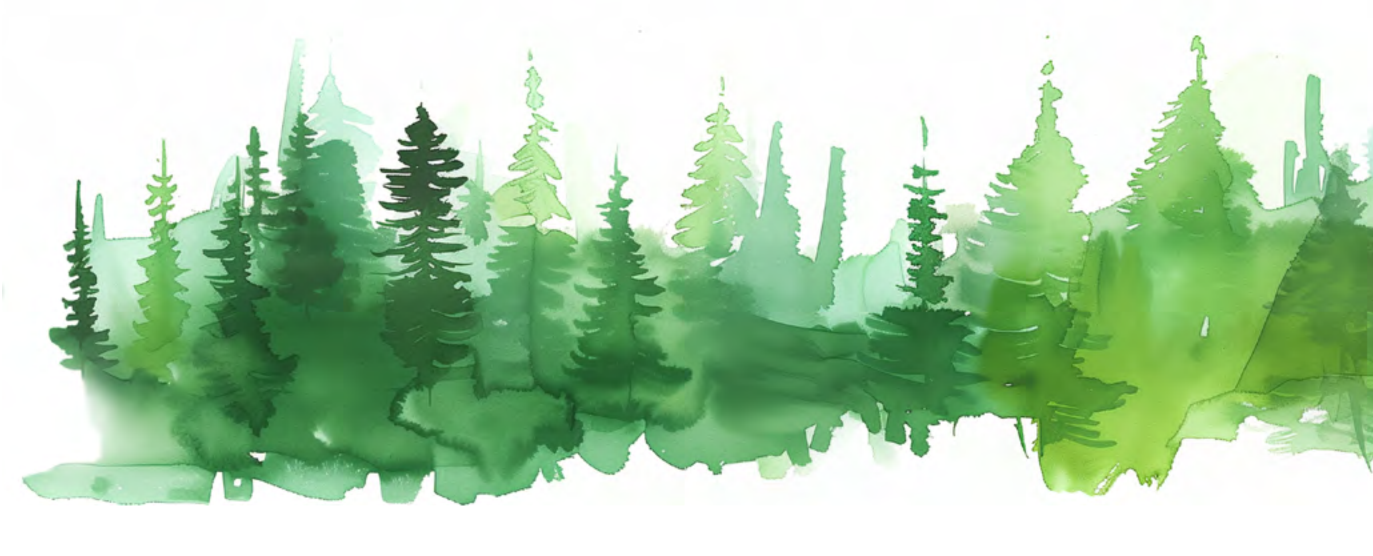
We therefore have the following formula **[21]**:

$$\mathrm{PDF}(S) = \frac{1}{N_{S_{ref}}} \sum_{i \in S_{ref}} x_{i,S}$$

A PDF of 0 means that the species richness of the site is still intact and a PDF of 1 means that all species in the site have disappeared.

GLOBAL PDF VS LOCAL PDF:

PDF, by definition, measures the fraction of species that locally disappear. This metric does not capture whether a species disappears on a global level. Yet, a globally lost species is gone forever, whereas a regionally lost species may be recovered through repopulation if it was not endemic. Both assessments are needed, the global assessment to avoid irreversible biodiversity loss and the regional assessment to make sure that ecosystems can maintain their functions, even if they have a lower contribution to overall global species diversity. Global PDF was developed in order to quantify an irreversible extinction of species on a global level. Kuipers et al. (2019) presented a scaling approach,



Global Extinction Probability (GEP) that uses species range sizes, global conservation status (IUCN, 2021a) and species richness to indicate the extent to which regional species loss in the respective area may contribute to global species loss. It is possible to convert the classic form of PDF to a global PDF by multiplying it by the GEP.

The GEP of species group g in region j (which can be a grid cell, an ecoregion, or any other spatial unit) is given by the following formula **[22]**:

$$GEP_{g,j} = \frac{\sum_S \frac{\sum_i A_{s,j,i} * O_{s,j,i} * TL_S}{\sum_{j,i} A_{s,j,i} * O_{s,j,i}}}{\sum_S TL_S}$$

Where $A_{s,j,i}$ is the area of grid cell i in ecoregion j occupied by species s (belonging to species group g), $O_{s,j,i}$ is the occurrence-weight value [0–1, dimensionless] of occurrence certainty O of species s in pixel i and region j and TL_s is the IUCN threat level weight value [1–8, categorical approach, dimensionless] of species s (belonging to group g).

If all species were endemic to the local ecoregion j, $GEP_{g,j}$ would equal to 1.

Then, we can compute the global PDF for a species group g in an ecoregion j **[23]**:

$$PDF_{g,j,global} = GEP_{g,j} * PDF_{g,j}$$

A taxon-aggregated global PDF can finally be calculated as the average of the PDF across the taxa. This means that each taxon (bird species, amphibians, reptiles, mammals and plants) receives equal weight, independent of the number of species within each taxon present in the region. If there are m taxonomic groups present in ecoregion j, the taxon-aggregated global PDF of ecoregion j is given by **[24]**:

$$PDF_{j,global} = \frac{\sum_g PDF_{g,j,global}}{m}$$

Knowing $GEP_{g,j}$ factor is equal or smaller than 1, $PDF_{j,global}$ is equal or smaller than PDF_j (local PDF of the ecoregion j).

MODELLING PDF

In practice, the PDF is rarely measured with direct biodiversity state data due to their availability constraints. Instead, and at the price of increased uncertainty, the PDF is measured within the life cycle assessment framework. First, let us quickly explain the LCA methodology. LCA consists of three phases: the life cycle inventory collection, the life cycle impact assessment phase and the interpretation.

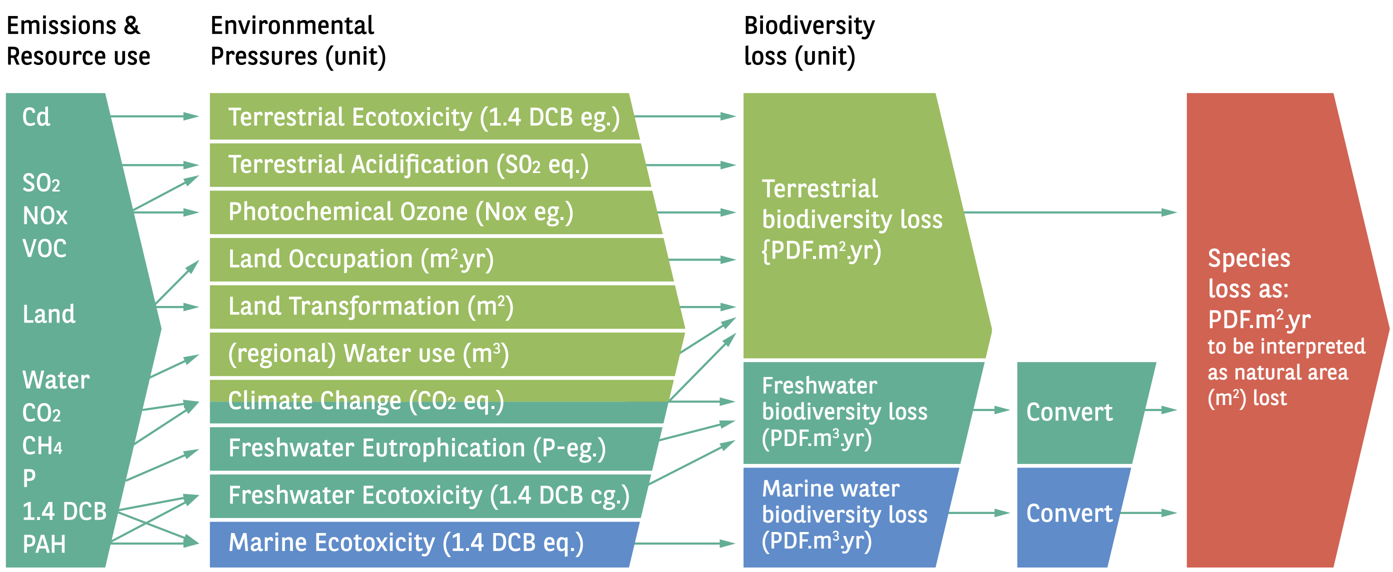
The inventory phase consists in collecting all the emissions created and the resource used throughout the life cycle of a process. If we take the example of producing one million Euro of wheat in France, the inventory would include how much nitrogen and how many greenhouse gas emissions have been released in the environment, how many liters of water have been consumed, how many tons of wheat have been harvested and how much land has been used.

The life cycle impact assessment (LCIA) groups the inventory results into different environmental pressures categories called impact categories in the LCIA documentation. ReCiPe is one of several LCIA methods that are available. Behind each environmental pressure, there is a sub-model. The biodiversity pressures covered by LCIA methodologies include land use, climate change, water consumption, terrestrial acidification, eutrophication and ecotoxicity.

Finally, during the interpretation phase, the biodiversity impacts, expressed in ***PDF.m².yr***, can be compared. Each impact pathway is considered to act independently and synergistic effects are not accounted for. Under this assumption, we can sum the individual biodiversity loss impacts and have one final aggregated value, expressed in ***PDF.m².yr*** **[25]**.

The whole LCA methodology is summed up in figure 1, using ReCiPe as the LCIA model.

FIGURE 6: ReCiPe IMPACT ASSESSMENT MODULE [26]



As we mentioned above, there are sub-models behind each environmental pressure category. We are going to the take a closer look at one of these models.

Biodiversity is very frequently modelled thanks to species area distributions. The species area relationship (SAR) is a prevalent ecological concept that associates an area with species richness.

The classic form of SAR is expressed as a power function where the area ***A*** and the number of species ***N*** are related by the equation:

$$N = c * A^z$$

In this equation, ***c*** and ***z*** are parameters based on regional, taxonomic, and sampling-specific factors **[27]**.

Within LCA frameworks, this model is used to estimate the number of species that are lost N_{Loss} by comparing the original species count N_{Ref} and habitat area A_{Ref} against the reduced habitat area after a land use change A_{New}.

$$N_{Loss} = N_{Ref} * \left(1 - \left(\frac{A_{New}}{A_{Ref}}\right)^Z\right)$$

To illustrate this, consider a scenario where a portion of a pristine forest, originally hosting a certain number of species N_{Ref}, is deforested. The remnant forest constitutes the new area A_{New}. Dividing N_{Loss} by N_{Ref} will then give us the potentially disappeared fraction (PDF) of species due to this environmental change.

$$PDF = 1 - \left(\frac{A_{New}}{A_{Ref}}\right)^Z$$

Here are two maps showing the land use impacts for croplands, first for PDF and then for global PDF **[23]**.

FIGURE 7: TAXON-AGGREGATED PDF FOR CROPLANDS (LAND USE IMPACTS)

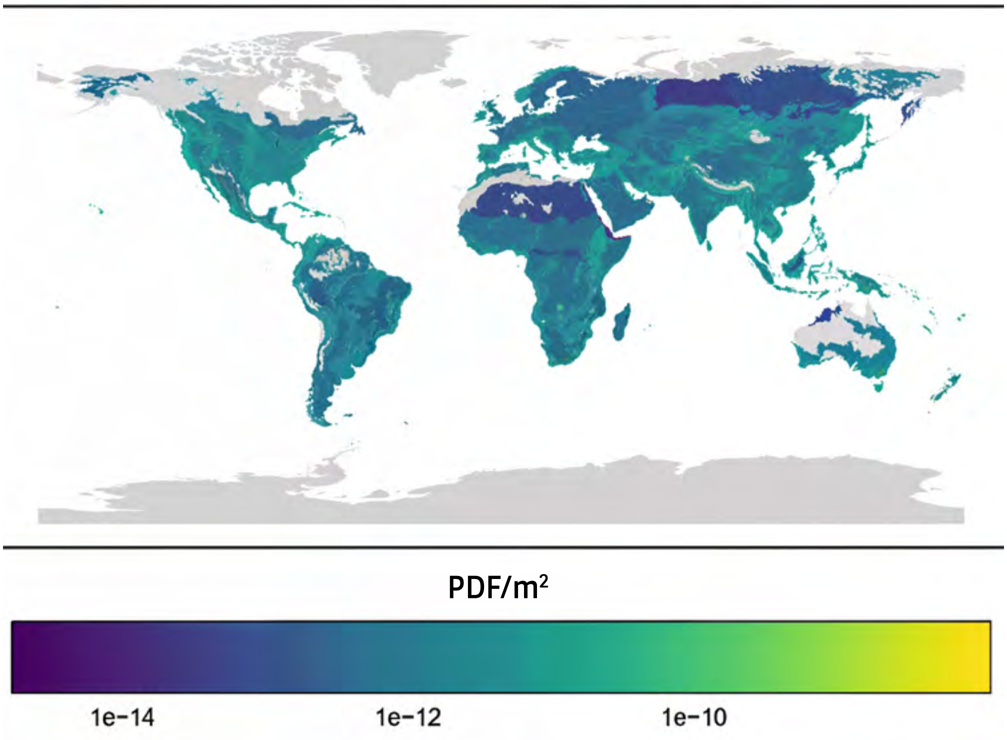
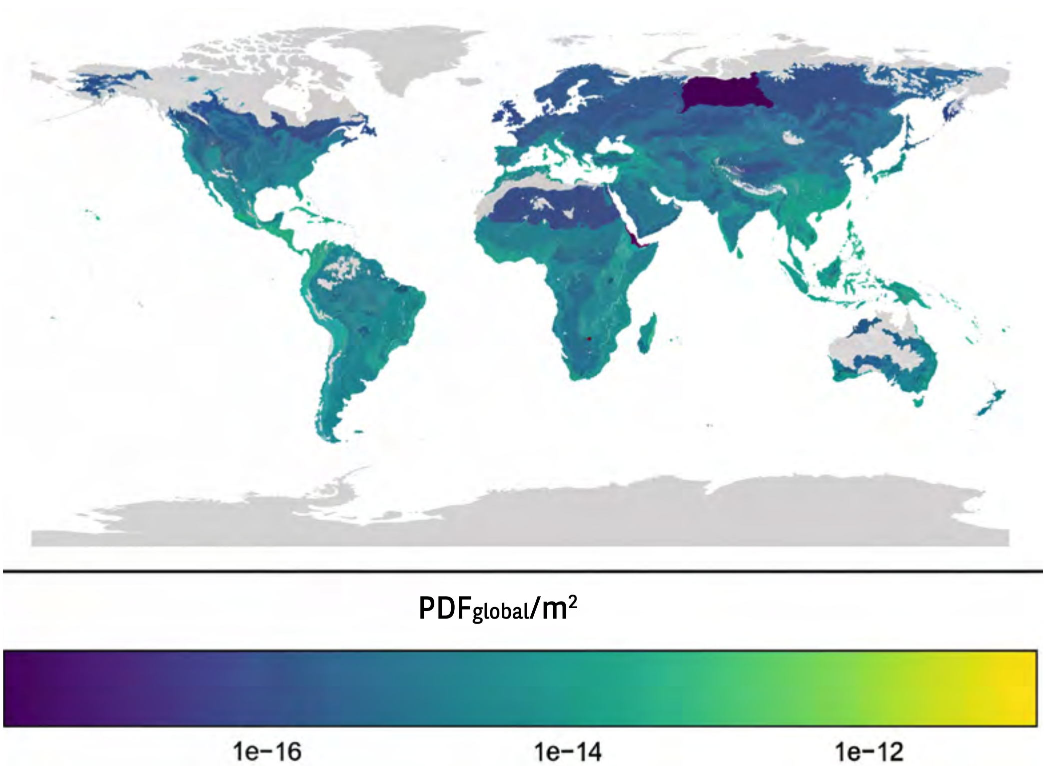


FIGURE 8: TAXON-AGGREGATED GLOBAL PDF FOR CROPLANDS (LAND USE IMPACTS)



The maps show the loss of species because of land use change to croplands. Gray signifies no data; this indicates either absence of cropland in these regions or missing species data.

Since there are few croplands in the Sahara and in northern parts of the world like Siberia, these places have very low PDF values and appear in dark blue on the map. On the contrary, countries with a high density of croplands like Spain and Italy are more affected and appear in turquoise shades on the map.

We also see in the maps that the values of global PDF are lower than the values of PDF. This is logical because a species that disappears locally may not disappear globally.

ADVANTAGES AND LIMITATIONS OF PDF

Pros: PDF measures biodiversity loss in a way that is easy to understand by many people and not just by experts of the field: given a location, what fraction of species have disappeared. Since the output is a numerical value, it can be compared between locations, pressures and under different assumptions. Data availability is a major challenge for all biodiversity indicators. For a species richness metric like PDF, we only need to find one individual per species and area. For an abundance metric like MSA or BII, an estimate of the number of all individuals is required. This explains why species abundance estimates like MSA or BII require more data than species richness estimates like PDF.

As the reference unit in LCA to measure biodiversity impacts, PDF has benefitted from a great modelling effort. Notably, the impact of invasive species is rarely considered in biodiversity assessment methods because it has been hard to model. Yet, invasive species is one of the five pressures identified by the IPBES as the main drivers of biodiversity loss. Recent studies have started to model it in PDF **[28]**, again showing that PDF is a leading metric when it comes to the number of models that exist. Another example of this is ecotoxicity. The impact of ecotoxicity has been modelled in PDF but not yet in MSA. This is why MSA experts use the PDF model and then try to translate it in MSA, which they can hardly do successfully since there is no direct conversion between MSA and PDF.

In addition to providing species richness information, PDF can be converted into a global PDF that takes into account the species threat level.

Cons: PDF presents some limitations. Indeed, like MSA, it does not penalize the appearance of invasive species. Its local version -the simplest one- the indicator equally weighs all species of a site like MSA and BII, regardless of their rareness or their vulnerability. Therefore, the disappearance of an endemic species is considered as impactful as the disappearance of a species that is not endemic. Yet the latter can be recovered through repopulation while the former is lost forever. This shows that PDF needs to be assessed carefully when it comes to endangered species. Using global PDF or species rarity indexes in complement with PDF is a way to address this issue.

To compute the PDF of a region, we need to have access to data about the presence of species. Direct data measures are costly and hard to put in place. As a result, PDF computations rely heavily on modelling like the MSA and the BII. This modelling comes with an increased uncertainty in the results.

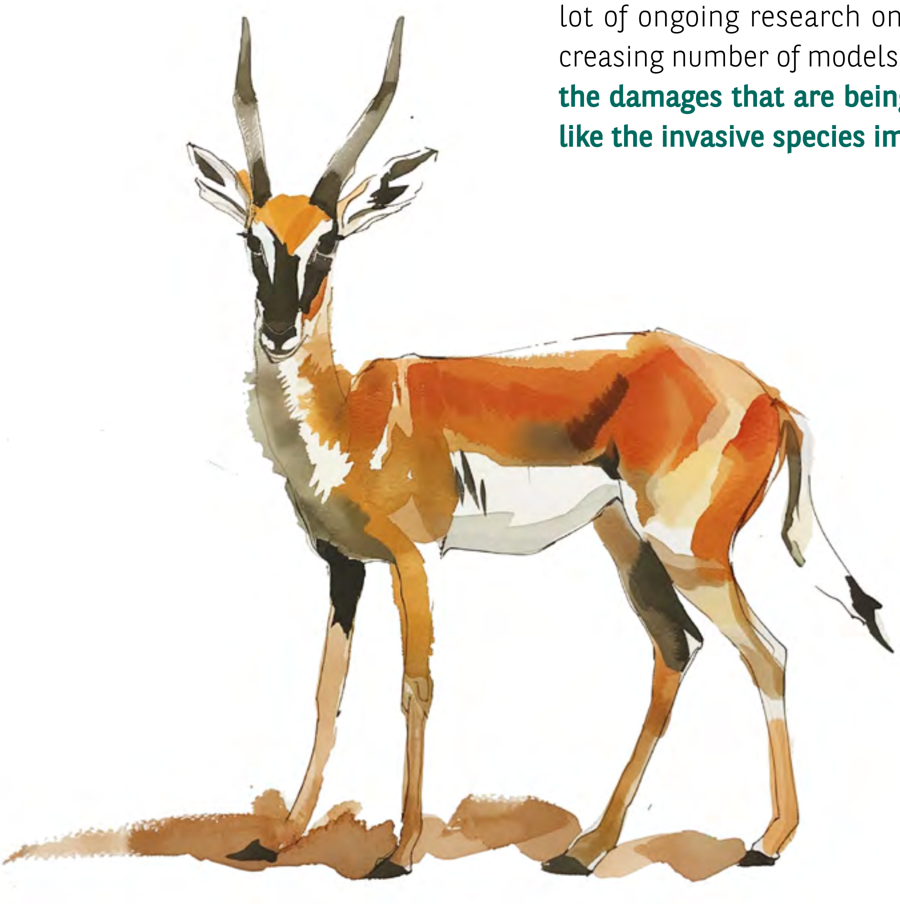
DISCUSSION

Thanks to the GLOBIO modelling of the MSA as a function of a few environmental pressures like land use and climate change, scientists were able to compute it for the present and the past using historical values of the considered pressures. They were also able to project it in the long-term using sustainability scenarios like the SSP1xRCP2.6 scenario **[13]**. **The MSA metric is being more and more used as the biodiversity footprint metric**.

Like the carbon footprint concept that attributes greenhouse gas emissions to the economy players, several studies like the CDC biodiversity one used the MSA.km² as the unit for biodiversity footprint **[29]**. By extension of this company-level computation, **MSA was recently explored to compute financial portfolios biodiversity footprints as the aggregation of financed companies' footprints**.

The BII index is similar to the MSA as it quantifies a change in biodiversity intactness of a considered site relative to a reference state. It can also be modelled as a function of several environmental pressures thanks to PREDICTS model. **It mitigates some of the MSA weaknesses as it considers the invasive species impact on the ecosystem.** Further studies are necessary to assess whether it could also be used for sustainability scenarios modelling and as an enhanced biodiversity footprint unit

The PDF index can be estimated via ReCiPe model which is an LCA model. In LCA, PDF is computed for each environmental pressure and the impacts are then summed to get a biodiversity footprint expressed in PDF.m².yr. It is broadly used when assessing biodiversity loss. **It could mitigate some of MSA and BII weaknesses as its global version takes into account the threat level and endemic status dimensions of species**. Besides, there is a lot of ongoing research on PDF and an ever-increasing number of models that **try to capture all the damages that are being done to biodiversity like the invasive species impact**.



CONCLUSION

Mean Species Abundance (MSA), Biodiversity Intactness Index (BII) and Potentially Disappeared Fraction of species (PDF) indices can inform biodiversity conservation policies and financial strategies, helping decision-makers in prioritizing areas for preservation and restoration efforts, by distinguishing and prioritizing the most endangered areas and the least impacted ones. They are currently used or explored by financial institutions in order to measure their investments and financings biodiversity footprint.

The simplicity and widespread applicability of MSA in measuring relative species abundance contrast with its limitations related to sampling effort and bias towards rare species. On the other hand, BII allows to penalize opportunistic species but faces the same data quality and equal weighting of species challenges. PDF, in its global version, mitigates the equal weighting of species challenge but doesn't take into account the invasive species impact. These intactness indices could be complemented by threatened species indices like the Rarity Weighted Richness (RWR) index and the Species Threat Abatement and Restoration (STAR) metrics that effectively address the underrepresentation of rare or threatened species. **Recognizing the contextual nature of these indices, it is obvious that no single index is sufficient for assessing ecosystem health. Instead, their complementary nature emphasizes the importance of employing them together to achieve a more comprehensive understanding and a more robust biodiversity evaluation.**

This study contributes to the broader discussion on ecological assessments, paving the way for further research and refinement of biodiversity indices to better assess financial portfolios biodiversity footprint.

BIBLIOGRAPHY

[1] *WWF (2022). Living Planet Report 2022 – Building a nature-positive society*. Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). WWF, Gland, Switzerland.

[2] *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*. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany, 56 pages.

[3] *IPBES (2016). The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production.* S.G. Potts, V. L. Imperatriz-Fonseca, and H. T. Ngo (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 552 pages. https://doi.org/10.5281/zenodo.3402856

[4] *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy* - World Economic Forum, 2020.

[5] *Biodiversité: présentation et enjeux,* French Ministry of Ecological Transition, 2023.

[6] *NGFS conceptual framework launch speech* - François Villeroy de Galhau (Governor of the Bank of France), 2023.

[7] Scholes, R., Biggs, R. (2005). *A biodiversity intactness index*. Nature 434, 45–49. https://doi.org/10.1038/nature03289

[8] *Biodiversity indices.* P Fedor, M Zvaríková (2019). Encycl. Ecol 2, 337-346.

[9] David Vačkář, *Ben ten Brink, Jonathan Loh, Jonathan E.M. Baillie, Belinda Reyers (2011)*. Review of multispecies indices for monitoring human impacts on biodiversity.

[10] Alkemade, R., van Oorschot, M., Miles, L. et al. (2009). *GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss*. Ecosystems 12, 374–390. https://doi.org/10.1007/s10021-009-9229-5

[11] Srivathsan, A., Ang, Y., Heraty, J.M. et al. (2023). *Convergence of dominance and neglect in flying insect diversity*. Nat Ecol Evol 7, 1012–1021. https://doi.org/10.1038/s41559-023-02066-0

[12] Alkemade, R., van Oorschot, M., Miles, L. et al. (2009). *GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss*. Ecosystems 12, 374–390. https://doi.org/10.1007/s10021-009-9229-5

[13] Schipper AM, Hilbers JP, Meijer JR, et al. (2020). *Projecting terrestrial biodiversity intactness with GLOBIO 4.* Glob Change Biol.; 26: 760–771. https://doi.org/10.1111/gcb.14848

[14] *What is the Biodiversity Intactness Index?* Natural History Museum.

[15] De Palma, A., Sanchez-Ortiz, K., Phillips, H., Purvis, A. (2021) Calculating the Biodiversity Intactness Index: the PREDICTS implementation. https://github.com/adrianadepalma/BII_tutorial

[16] De Palma, A., Sanchez-Ortiz, K., Phillips, H., Purvis, A. (2021) Calculating the Biodiversity Intactness Index: the PREDICTS implementation. https://zenodo.org/badge/latestdoi/169256761

[17] *World Resources Institute.*

[18] Céline Deluzarche (2018). P*our éradiquer les espèces invasives, l'Australie n'a pas peur de jouer à l'apprenti-sorcier.*

[19] *Australia's invasive species.* Australian Government, Department of the Environment and Heritage, 2004.

[20] Müller-Wenk, R. (1998). *Land Use - the Main Threat to Species: How to Include Land Use in LCA*. Institut für Wirtschaft und Okologie, Universität St. Gallen (IWÖ-HSG), St. Gallen.

[21] Rossberg, A. et al. (2023). *A metric for tradable biodiversity credits linked to the Living Planet Index and global species conservation.*

[22] Verones, F. et al. (2022). *Global extinction probabilities of terrestrial, freshwater, and marine species groups for use in Life Cycle Assessment.*

[23] Kuipers et al. (2021). *Considering habitat conversion and fragmentation in characterization factors for land-use impacts on vertebrate species richness.*

[24] Verones, F. et al. (2017). *Resource footprints and their ecosystem consequences.*

[25] Verones, F. et al. (2015). *Harmonizing the assessment of biodiversity effects from land and water use within LCA.*

[26] *Biodiversity Footprint for Financial Institutions.* Netherlands Enterprise Agency (2021).

[27] Rosenzweig, M. L. (1995). *Species diversity in space and time.*

[28] Borgelt, J. et al. (2024). *What Is the Impact of Accidentally Transporting Terrestrial Alien Species? A New Life Cycle Impact Assessment Model.*

[29] *Raise corporate biodiversity ambition & aim at no net loss*, (2020). CDC Biodiversité, Schneider Electric.

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