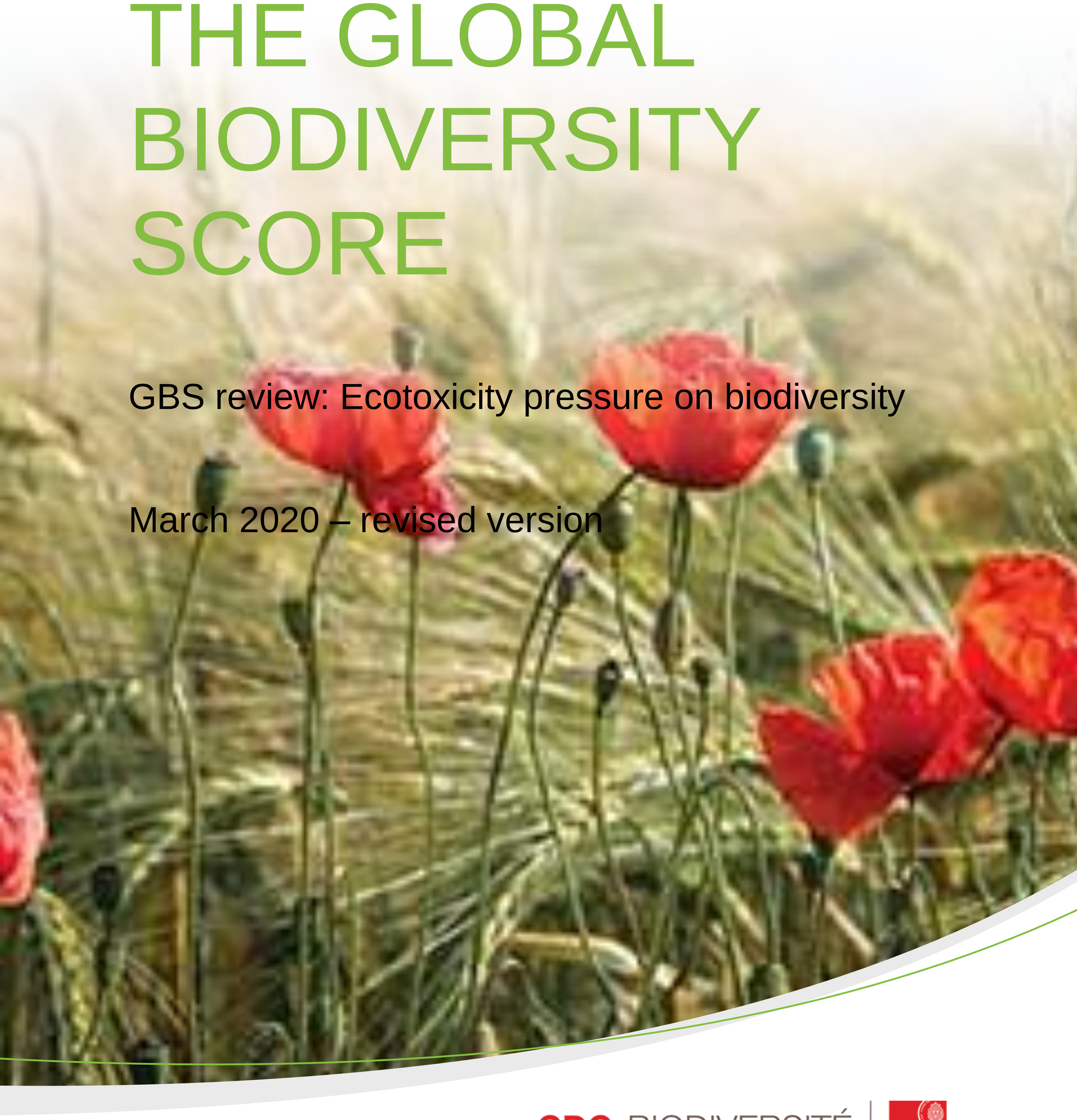
THE GLOBAL BIODIVERSITY SCORE



GBS review: Ecotoxicity pressure on biodiversity

March 2020 – revised version

CDC BIODIVERSITÉ

Caisse des Dépôts GROUPE

Content

Disclaimer

This work presents a preliminary methodology aiming to refine the GBS computation of the biodiversity impacts of substances causing ecotoxicity impacts. As explained below, this addition is as much a need as a challenge. Indeed, pollution is officially identified as a major and increasing direct driver of biodiversity loss in IPBES latest report (Díaz et al. 2019). Moreover, substances like pesticides are specifically targeted by current debates in the population as well as the political community. Including them in corporate biodiversity footprint assessment tools such as the GBS is thus key to enable companies to monitor their impacts as well as to match possible future regulations. The topic is especially important in France since the French government committed to reducing pesticide use by 50% by 2050[1] and public authorities are thus keen to have tools to measure the gains for biodiversity linked to such policies.

Ecotoxicity has been under the lights of Life Cycle Analysis for years due to both its human and environmental consequences. Although it is directly or indirectly accounted for in GLOBIO terrestrial and aquatic cause-effect relationships, **few pressure-impact relationships directly link chemical concentrations or chemical quantities to biodiversity impacts in MSA,** which is problematic to assess the impact of certain actions (e.g zero-pesticides). What is done here is thus completely different from what was done for other pressures accounted for in GLOBIO cause-effect relationships, since it is fully LCA-based. The key point is undoubtedly the translation of characterization factors expressed in LCA units – PDF.m².yr or species.yr – into MSA.m². Although discussed with some LCA experts within the Aligning Biodiversity Measures for Business (ABMB) working groups and through private exchanges, coming up with a robust PDF-MSA conversion methodology requires more work and a deeper involvement from the scientific community than what we have been able to conduct so far.

Contrary to the other reports related to the GBS tool, the work presented in this report is by no mean complete. Notably, the results presented hereafter should not be considered definitive nor validated. Everything in what follows is presented mainly as a first contribution to the bigger issue of biodiversity metric conversion. Observations and improvement propositions from readers are expected and welcome.

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[1] https://www.ecologique-solidaire.gouv.fr/sites/default/files/2018.07.04_PlanBiodiversite.pdf

Note to the reader

GBS review reports are not completely independent from each other. Readers of this report are advised to first read the reports dedicated to **Core concepts of the GBS** to ensure a good overall comprehension of the tool and the present report.

The following colour code is used in the report to highlight:

- Assumptions
- Important sections
- Developments of the GBS planned in the future

The GBS review reports are aimed at technical experts looking for an in-depth understanding of the tool and contribute to the transparency that CDC Biodiversité considers key in the development of such a tool. They focus on technical assumptions and principles. Readers looking for a short and easy-to-understand explanation of the GBS or for an overview of existing metrics and tools should instead read the general audience reports published by CDC Biodiversité (CDC Biodiversité 2017; CDC Biodiversité, ASN Bank, and ACTIAM 2018; CDC Biodiversité 2019c).

1 Context

1.1 Why assess the biodiversity impacts of ecotoxicity?

Pollution is among the five main direct drivers of change in nature in IPBES latest report (Díaz et al. 2019), see Figure 1. Although acknowledging the lack of quantitative assessments of pollution, the report highlights the increasing trends in air, water and soil pollution in some areas, qualified as one of the main sources of concerns and an exacerbating factor of negative trends in nature up to 2050. Contributors to pollution are numerous, encompassing noise, light, solid wastes (especially plastic) and all substances which presence in or introduction into the environment has harmful effects. Harmful substances include emissions of particules and airborne contaminants like mercury and fertilizers. Contaminants dissolved in/carried by water are also of particular concern. They originate from untreated urban sewage (organic pollutants, heavy metals, pharmaceutical residues, surfactants, microplastics), industrial and agricultural runoffs (nutrients, fertilizers, pesticides, insecticides, herbicides), oil spills and dumping of toxic compounds.

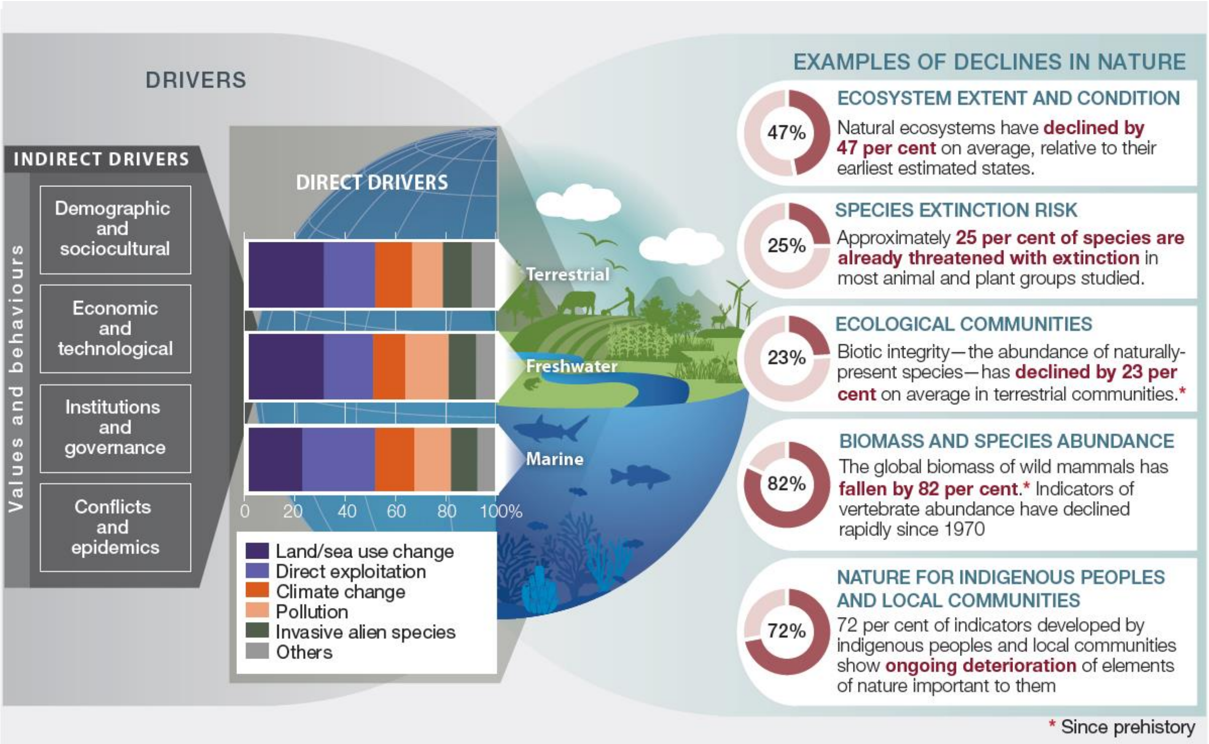

Figure 1: Direct and indirect drivers of change in nature and examples of declines. Source: (Díaz et al. 2019)

These facts call for the inclusion of the impacts of ecotoxicity (and more generally pollution) in corporate and investments biodiversity assessment tools, so that companies and investors get aware of their contribution to ecotoxicity in its various components, are enabled to make informed decisions to monitor and reduce their impacts and are held accountable by external parties. Currently, various components of pollution are partly accounted for in the GBS, namely noise, light, and pollution related to substance emissions (cf Section 1.2). Gaps in the accounting of the biodiversity impacts of chemical substances can be bridged thanks to a large and increasing body of science mainly stemming from chemical products regulation, the LCA-world and environmental modelling dealing with the environmental impacts of ecotoxicity. Indeed, thanks to atmospheric models, weather models, hydrology models, fate models and integrated assessment models, the sources and fate of harmful compounds is increasingly better documented. As well, pollution-related mechanisms (eutrophication, ecotoxicity and acidification) included in numerous LCA methods are useful starting points to derive quantitative biodiversity impact factors for chemical substances.

1.2 Ecotoxicity in GLOBIO cause - effect relationships

A POLLUTION-LIKE PRESSURES INCLUDED IN GLOBIO CAUSE EFFECT RELATIONSHIPS

Before diving specifically into ecotoxicity, the following paragraphs take a broader look at how pollution, including ecotoxicity, is taken into account in GLOBIO.

As such, GLOBIO cause effect relationships do not include a “pollution” pressure. However, similarly to LCA models distinguishing eutrophication, ecotoxicity and acidification, several pressures of both GLOBIO and GLOBIO-Aquatic cause effect relationships account for specific pollution types. They are summarised in Table 1. Note that neither GLOBIO nor LCA models directly account for the pollution related to solid wastes, especially plastics.

In GLOBIO cause effect relationships, the **terrestrial on-site biodiversity impacts of pollution are accounted for in the land use (LU) pressure** through the MSA value per land use type. For instance, the difference between the MSA value of extensive agriculture (30%) and intensive agriculture (10%) is partly due to the higher impacts of fertilizers, pesticides, insecticides, herbicides on on-site biodiversity in intensively managed croplands. The MSA value of urban areas (5%) includes on-site pollutions related to solid waste for instance, as well as the on-site impact of noise and light pollution. The LU pressure thus includes the on-site part of LCA “terrestrial ecotoxicity” and “terrestrial acidification” pressures. Also, **terrestrial off-site impacts of light and noise are accounted for in the encroachment (E) pressure**, while **terrestrial off-site impacts of airborne nutrients are accounted for in the pressure atmospheric nitrogen deposition (N)**. The latter pressure thus partly matches LCA “terrestrial acidification” pressure, although acidification is also caused by sulfates and phosphates.

In GLOBIO-Aquatic cause effect relationships, **the off-site impacts of ecotoxicity on aquatic biodiversity are accounted for land use in catchment of rivers and wetlands (LUR and LUW)**. Indeed, land use intensity and land use type in catchment of rivers and wetlands are taken as proxies for nutrient and other harmful substances (pollution from urban sources) leaching into water bodies (J. H. Janse et al. 2015; Jan H. Janse, Bakkenes, and Meijer 2016). More details can be found in the GBS report dedicated to aquatic biodiversity (CDC Biodiversité 2020b). Together, this pressure basically match LCA “freshwater ecotoxicity” pressures.

Table 1: Pollution in GLOBIO cause effect relationships

GLOBIO cause effect relationships	Pressure	Type of pollution accounted for	LCA pressure correspondence
Terrestrial	Land use	On-site pollution, especially in agricultural and urban areas	Terrestrial ecotoxicity, *on-site only*
	Encroachment	Off-site pollution due to noise and light	*Not accounted for in LCA*
	Nitrogen deposition	Off-site pollution due to nitrogen deposition	Terrestrial acidification, *partial*
Aquatic	Land use in catchment	Leaching of substances in freshwater	Freshwater ecotoxicity
	Freshwater eutrophication	Eutrophication due to phosphorous and nitrates	Freshwater eutrophication, *lakes only*

Pollution in its various forms is thus partly accounted for in GLOBIO cause effect relationships and, consequently, in the biodiversity impact factors computed in the GBS. As such, **default and refined assessments conducted with the GBS partly include the biodiversity impact of pollution.** Among the missing impacts, several **important sources of chemical pollution are likely not accounted for** in GLOBIO and thus in the GBS. Indeed, the IMAGE-GLOBIO scenario data do not include particularly pollutant sites and activities like mines or isolated industrial sites. Considering that assessing properly the impacts of ecotoxicity is key in the current political context and that data exist to do so, we developed a methodology allowing the direct assessment of ecotoxicity in the GBS tool.

B PERIMETER OF THIS WORK: ECOTOXICITY

As explained above, in GLOBIO cause effect relationships, ecotoxicity impacts are sometimes intertwined with the impacts of other drivers (the difference in the MSA% of extensive and intensive agriculture embeds the use of pesticides but also varying pratices) and may rely on proxies (LUW and LUR). In fact, contrary to what exists in LCA, **basically no direct relationship linking quantities of chemicals to biodiversity impacts in MSA exists**[2]. Therefore, assessing the impact of actions specifically dedicated to ecotoxicity reduction is hardly possible as 1) likely no pressure-impact relationship exists for the substances of interest and 2) risks of double-counting are high if ecotoxicity specific impact is not disentangled from other impacts in GLOBIO pressures. Moreover, some activities contributing highly to ecotoxicity are not included in GLOBIO models, leading to an underestimation of their impacts on biodiversity.

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[2] The only existing direct pressure-impact relationships are those related to the pressure N – concerning nitrogen deposition in excess of the ecosystem critical load – and to the pressure FE – concerning nitrogen and phosphorous concentration in water. They do not belong to ecotoxicity though.

The ability to assess the ecotoxicity impact of chemical substances is key to allow companies to monitor their pollution reduction actions, especially in the food and industrial sectors. This topic also mobilises governmental actors at the national and international (especially European) levels, so that specific chemical pollution issues such as pesticide use should fall in the scope of corporate biodiversity assessment tools.

The work presented in this report addresses the issue related to the **refined assessment of ecotoxicity (chemical pollution) impacts in the GBS**. It proposes a preliminary methodology to derive substance-specific pressure-impact relationships expressed in MSA.m^2 while avoiding double-counting of pollution impacts related to the other pressures already included in the tool.

Before reading further, please make sure that you have read the DISCLAIMER in Section Erreur ! Source du renvoi introuvable.**.**

2 Methodology overview

Currently, the default and refined assessments done with the GBS partly account for the impact of ecotoxicity. However, as explained above, it is done through the biodiversity impact factors related to the pressures LU, LUR and LUW which do not directly involve quantities of chemical substances but rather proxies for chemical substances use and leaching mixed with other biodiversity impactant factors. The methodology allowing the refined assessment of the biodiversity impact of chemical substances is thus two-fold

1. Derive pressure-impact relationships linking emissions of hazardous substances to impact expressed in MSA.m^2 following the model of LCA characterization factors;

2. Establish rules to distangle the ecotoxicity impact from other impacts embedded in some GLOBIO pressures to avoid double-counting when a refined assessment of ecotoxicity is conducted.

The first part is conducted based on the translation of characterisation factors documented by the harmonised life cycle assessment method ReCiPe into the framework of the GBS. The second part is based on a detailed study of the rationale and functioning supporting GLOBIO models.

3 Dimensioning the impact of ecotoxicity

3.1 Data used

ReCiPe 2016 (Huijbregts et al. 2017) is the latest version of the harmonised life cycle impact assessment (LCIA) model ReCiPe. LCIA models like ReCiPe are used in LCA studies to translate substance emissions and resource extractions into environmental impacts. The translation is done thanks to characterization factors (CFs) indicating the environmental impact per unit of stressor (e.g. per kg of resource or emission). The CFs are of two types

- Midpoint CFs, which allow the translation of stressors into an intermediary unit common to all stressors of a certain impact category, e.g. kg CO_2-eq when the stressors studied are GHG emissions;
- Endpoint CFs, allowing the translation of stressors expressed in intermediary units into impacts on three areas of protection: human health, ecosystem quality and resource scarcity. For ecosystem quality, the endpoint characterization factor is species.year, referring to the local species loss integrated over time.

ReCiPe 2016 mid- and endpoint CFs for all pressures and stressors are publicly available. In particular, mid- and endpoint CFs related to terrestrial and freshwater ecotoxicity for respectively 18 593 and 30 991 substances are documented. The midpoint CFs (ecotoxicity potential of the substance, ETP) translate kilograms of emitted substance into kg 1.4DCB-eq, while endpoint CFs translate kg 1.4DCB-eq into species.yr. Besides, for both types of CFs, three values are documented corresponding to three distinct perspectives:

- The individualistic perspective, based on short-term interest, undisputed impact types and technological optimism regarding human adaptation;
- The hierarchist perspective, based on scientific consensus with regard to the time frame and plausibility of impact mechanisms;
- The egalitarian perspective, most precautionary approach considering the longest time frame for all impacts.

The endpoint CF does not vary between the three perspectives and is equal to 6.95^{-10} species.year/kg 1.4DCB-eq. However, the midpoint CFs often vary so that, for each substance at least one but often two or three values are available. Table 2 presents a simplified view of ReCiPe 2016 data related to freshwater ecotoxicity and the midpoint CFs of some substances.

Table 2: ReCiPe midpoint CFs related to Freshwater ecotoxicity. FWETP: freshwater ecotoxicity potential. Source: ReCiPe 2016.

CAS number[3]	Substance	Emission compartment	FWETP (kg 1.4DCB-eq)		
			Individualistic	Hierarchic	Egalitarian
100016	4-NITROANILINE	urban air	1.34E+00	1.33E+00	1.33E+00
100414	ethylbenzene	urban air	2.11E-05	2.11E-05	2.11E-05
100425	styrene	urban air	5.36E-06	5.36E-06	5.36E-06
100447	Benzyl chloride	urban air	4.07E-03	4.07E-03	4.07E-03
100516	benzyl alcohol	urban air	3.72E-03	3.72E-03	3.72E-03
100527	benzyldehyde	urban air	2.69E-03	2.68E-03	2.68E-03
101053	ANILAZINE	urban air	4.87E+01	4.87E+01	4.87E+01

3.2 Methodology to compute biodiversity impact factors

A COMPUTATION PROCEDURE

The rationale behind the method developed is very simple: if an endpoint CF linking kilograms of 1.4 DCB-eq to biodiversity impacts expressed in MSA% or MSA.km² can be found, then the combination of ReCiPe terrestrial and freshwater ETPs with this CF will provide refined ecotoxicity impact factor for all substances and compartments documented in ReCiPe 2016 data. Impact factors computed based on the individualistic ETPs are considered optimistic, while impact factors involving hierarchic ETPs are central and those relying on egalitarian ETPs are conservative.

Based on this reasoning, computing refined terrestrial and freshwater ecotoxicity impact factors “only” requires the availability of an endpoint CF expressed either in MSA.km²/kg 1.4DCB-eq or in MSA%/kg 1.4DCB-eq. Unfortunately, such factor does not exist today. The remaining option is to rely on ReCiPe endpoint CF expressed in species.yr/kg 1.4DCB-eq, and convert them into MSA.km²/kg 1.4DCB-eq. This comes down to **deriving a species.yr-MSA.km² conversion factor**.

B UNIT CONVERSION FACTOR

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[3] The CAS registry number is a unique numerical identifier assigned by the Chemical Abstracts Service to every chemical substance described in the open scientific literature.

Deriving conversion factors between LCA and GLOBIO units is a methodological challenge. It was touched on by the work done within the Aligning Biodiversity Measures for Business (ABMB) initiative led by UNEP-WCMC in 2018-2019. ABMB working sub-group 3B entitled “Metrics and midpoint characterisation factors” chaired by CDC Biodiversité. One of the aims of the sub-group was to address the issue of metric conversion. Most of the reflections presented hereafter stem from the work done within subgroup 3B, in particular from an Appendix dedicated to the conversion between MSA and PDF (potentially disappeared fraction of species) written by CDC Biodiversité and reviewed by a few sub-group members.

The main metrics considered hereafter are

- Mean Species Abundance (MSA), a metric reflecting biodiversity intactness varying between 0 (0% abundance remaining) and 1 (100% intact ecosystem) and computed as

$$MSA = \frac{1}{N_{reference\ species}} \sum_{i=1}^{N_{reference\ species}} \mathrm{Min}\left(\frac{A_{observed}(i)}{A_{intact}(i)}, 100\%\right),$$

Where

MSA = mean abundance of original species,

$N_{reference\ species}$ = total number of species in an undisturbed ecosystem,

$A_{observed}(i)$ = abundance of species i in the observed ecosystem,

$A_{intact}(i)$ = abundance of species i in an undisturbed ecosystem.

Often, as in the GBS, MSA is integrated over space leading to impacts expressed in MSA.km², MSA.ha or MSA.m².

- Potentially Disappeared Fraction (PDF), one of LCA typical metrics reflecting the fraction of species going extinct due to the stressor, varying between 0 (no impact) and 1 (100% of the species potentially extinct). Most often in LCA, PDF is integrated over space and time, yielding impacts expressed in PDF.m².year.
- Species, and other metric used in LCA when it is integrated over time, yielding impacts expressed in species.year. Results expressed in species.yr (resp. PDF.m².yr) can be converted into PDF.m².yr (resp. species.yr) by dividing (resp. multiplying) the impact by the average species density. Terrestrial average species density is $1.48.10^{-8}$ species/m² and freshwater average species density is $7.89.10^{-10}$ species/m³. Hence:

$$species.yr_{terrestrial} = 1.48.10^{-8} \times PDF.m^2.yr_{terrestrial}\ ,$$

$$species.yr_{freshwater} = 7.89.10^{-10} \times PDF.m^3.yr_{freshwater}$$ [4].

3.2.B.1 Handling space integration

Spatial integration means that the biodiversity measure is integrated over space, basically multiplying the biodiversity measure by the area over which it is measured. Thus, MSA.m^2 means MSA multiplied by m^2 and not MSA by m^2.

Over an ecosystem of area S with a homogeneous biodiversity value, this translates into:

$$\int_{x=0}^{x=S} [biodiversity\ value\ (MSA\ or\ PDF)].dx = S \times [biodiversity\ value]$$

For instance 10% MSA over an area S of 10 km² = 10% x 10 km^2 = 1 MSA.km^2.

In order to be able to use the PDF-MSA relationship, space integration needs to be handled. The best way to derive PDF or MSA from spatially integrated PDF.m^2 or MSA.m^2 would be to divide the latter by the area over which they have been integrated. However, it is often impossible since this area is usually unknown.

An alternative might be to (i) assume that impacts are uniformly distributed over the area considered and (ii) use an average biodiversity density of the area to quantify how much biodiversity is affected. Point (i) has significant drawbacks as biodiversity impacts are rarely uniformly distributed. As the average biodiversity density of an ecosystem is usually unknown, point (ii) implies the use of a less precise biodiversity density, such as a global biodiversity density. This in turns assumes that biodiversity is uniformly distributed over space, which is also debatable.

Since PDF or MSA global average density (MSA.m^2/m^2 or PDF.m^2.yr/m^2) are not available, the global average species densities of 1.48.10^{-8} species.m^{-2} for terrestrial biodiversity[5] and 7.89.10^{-10} species.m^{-3} for aquatic biodiversity (Huijbregts et al. 2017) are used instead. PDF.m².yr could thus be translated into disappeared species or affected species, *i.e.* species.yr.

3.2.B.2 Handling time integration

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[4] Ignoring the time and spatial dimensions, we could consider rough PDF-MSA relationships stating that $MSA = 1 - PDF$. Indeed, on a given ecosystem (say 100 km2 of forest) if the potentially disappeared fraction of species is 20%, considering that the remaining MSA is 80% does not seem too inaccurate. The challenge thus lies in handling the time and space integration in both metrics. Though, in theory PDF and MSA are defined very differently and this simple relationship has no theoretical underpinnings. PDF is the fraction of species that is exposed above their acute EC50, *i.e.* the level where 50% of species are affected, at an environmental concentration, while MSA is an average abundance.

[5] The species density (1.48.10-8 species.m-²) applied to the total terrestrial area (140 million km²) gives a total number of 2 072 000 terrestrial species.

Similarly to spatial integration, time integration means that the biodiversity impact is integrated over time (which is a bit trickier to conceptualize), basically multiplying the biodiversity impact by the time over which it will occur. Thus, species.yr means species multiplied by year and not species per year.

Over a period of time of T, if the impact on biodiversity is constant over time, this translates into:

$$\int_{t=0}^{t=T} [biodiversity\ impact\ (MSA\ or\ species)].dt = T \times [biodiversity\ impact]$$

Dealing with the time integration requires to know the shape of the impact curve that was assumed to compute the impact and the considered time frame. Knowing these, the footprint could be broken down into its annual components (impacts on year 1, impacts on year 2, etc. until impacts on year N). In Figure 1 and in the GBS framework, the impact on year 1 is called the dynamic footprint, and the persistent impact (which does not vary compared to the initial dynamic footprint) is called the static footprint.

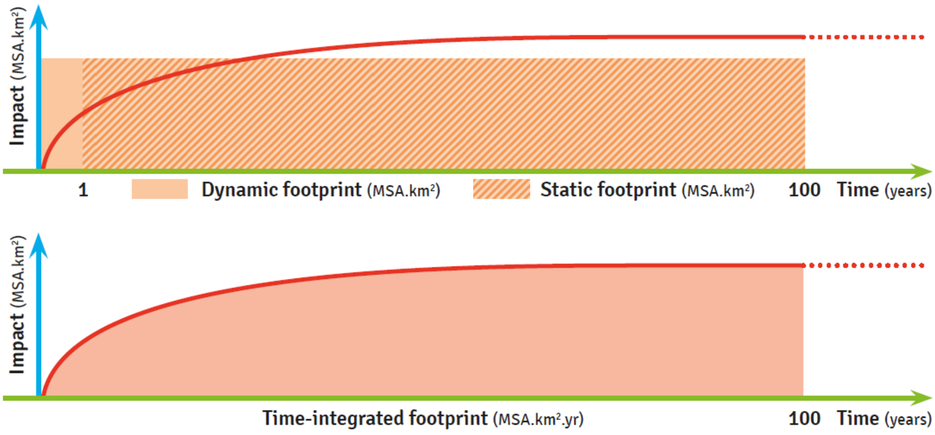

Figure 1. Illustration of the impact assessed through time-integration and the approximation of the impact through a "rectangular shape" assumption. MSA is used as an example but the principle is the same with any metric.

Most often we know which time frame was considered in the computation of endpoint CF in PDF.m².yr – ReCiPe for instance provides 3 categories of CF based on three different time horizons. The issue of the shape of the impact curve is less easily solved. For climate change we know that the considered time-horizon is 100 years and that the impact curve basically follows a rectangular shape so dividing the impact by 100 could be appropriate. This may however not be the case when the impulse-response function is not rectangular.

3.2.B.3 A simpler way

Considering that handling the time and space integrations properly was not possible due to lack of information, a simpler approach was envisaged. As explained above, PDF and MSA are similar in their meaning so that it was decided to **focus on the PDF-MSA relationship**. The species-MSA relationship can be deduced from the PDF-MSA relationship by applying the species density (cf above).

A <u>first guess</u> can be formulated: we know that the maximum PDF is 1 and that the time horizon considered in ReCiPe's hierarchic scenario is 100 years. In this framework, it thus appears that the MSA.m^2-PDF.m^2.yr ratio can hardly be higher than 100. On the contrary, it could likely be smaller than 1, especially for stressors with very short lifespans. As such, according to the stressor, the MSA.m^2-PDF.m^2.yr ratio is likely in]0;100][6].

The idea to verify this first guess is to derive a PDF-MSA relationship based on the ratio of impact factors available in both metrics for some pressures, and for which temporal and spatial horizons are known. To our knowledge, two pressures qualify for that: **land use** and **climate change**.

3.2.B.3.1 Using impact factors related to land use

Land occupation is a pressure accounted for in ReCiPe and GLOBIO. Indeed, the so-called "static land use" impacts in the GBS framework correspond to land occupation. Thus, land occupation impacts in PDF.m^2.yr and in MSA.m^2 are available. Considering that effects in ReCiPe hold for a spatial area of 1 m^2 and a time horizon of 1 year, they can be compared to MSA.m^2 losses for each GLOBIO land use. Based on an in-house matching of ReCiPe and GLOBIO land uses, MSA.m^2-PDF.m^2.yr ratios can be computed. Results are presented in Table 3. **The computed ratio varies between 0.76 and 1.60. Yet, they are not enough to derive a relationship between MSA and PDF since they concern PDF.m^2.yr and MSA.m^2.** In our understanting, time integration is not dealt with similarly for climate change and land occupation in LCA. Therefore, we also explore the impact factors related to climate change.

Table 3: Comparison of PDF and MSA loss for each land use. In-house land use matching. 1: designates equal values rather than the ratio 0/0. Sources: (Mark Goedkoop et al. 2013; Alkemade et al. 2009)*

ReCiPe land use	Local effect PDF.m^2.yr	GLOBIO land use	Static impact (MSA.m^2)	Ratio (MSA.m^2/PDF.m^2.yr)
Monoculture Crops/Weeds	0.95	Irrigated cropland	0.95	1
Intensive Crops/Weeds	0.89	Intensive cropland	0.90	1.01
Extensive Crops/Weeds	0.85	Extensive cropland	0.70	0.82
Monoculture Fertile Grassland	0.69	*No equivalent*	-	-
Intensive Fertile Grassland	0.48	*No equivalent*	-	-
Extensive Fertile Grassland	0.25	Pasture - moderately to intensively used	0.40	1.60
Monoculture Intertile Grassland	0.41	*No equivalent*	-	-

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[6] The interval excludes 0 since, as explained earlier, MSA is a more sensitive indicator than PDF. Thus, we cannot think of situations in which the PDF would change without MSA being also affected.

Extensive Infertile Grassland	0	Natural grassland	0	1*
Monoculture Tall Grassland/Herb	0.92	Pasture - man-made	0.70	0.76
Intensive Tall Grassland/Herb	0.61	*No equivalent*	-	-
Extensive Tall Grassland/Herb	0.31	Pasture - moderately to intensively used	0.40	1.29
Monoculture Broadleaf, mixed forest and woodland	0.19	Forestry selective logging	0.30	1.58
Extensive Broadleaf, mixed and yew LOW woodland	0	Natural forest	0	1*
Broad-leafed plantation	0.37	Forestry plantation	0.70	1.89
Coniferous plantations	0.47	Forestry plantation	0.70	1.48
Mixed plantations	0.76	Forestry plantation	0.70	0.92
Continuous urban	0.96	Urban areas	0.95	0.99
Vineyards	0.42	*No equivalent*	-	-

3.2.B.3.2 Using impact factors related to climate change

Climate change is the second pressure accounted for in both ReCiPe and GLOBIO. The advantage of using climate change impact factors to derive a PDF-MSA ratio is that, for this pressure, the time and space horizons considered are known: 100 years for both models, 140 million km^2 (ReCiPe) and 133 million km^2 (GLOBIO) for the area of terrestrial ecosystems. Thus, two options exist

1. Simply comparing the effect factors related to temperature increase, expressed in PDF.°C^{-1} and MSA loss.°C^{-1};
2. Convert the impact factor of 2.8.10^{-9} species.yr/kg CO$_2$-eq used by the Biodiversity Footprint for Financial Institutions (BFFI) tool (CREM and PRé Consultants 2016; CDC Biodiversité 2019) into PDF.m^2.yr/kg CO$_2$-eq and compare it to the impact factor of climate change used in the GBS in MSA.km^2/kg CO$_2$-eq (taken from (Wilting et al. 2017), see (CDC Biodiversité 2020c) for more details).

Both options are explored hereafter.

<u>Option 1</u>: ReCiPe 2016 documents an effect factor of 0.037 PDF.°C^{-1}, while two values for the effect factor in MSA are available in the literature:

- 0.0521 MSA.°C^{-1}: global effect factor estimated by (Arets, Verwer, and Alkemade 2014)
- 0.067 MSA.°C^{-1}: effect factor computed by (Wilting et al. 2017) as the weighted average of biome-specific effect factors estimated by (Arets, Verwer, and Alkemade 2014)

Choosing the first effect factor yields a MSA over PDF ratio of 1.41, while the second yields a ratio of 1.81. Results are gathered in Table 4.

Table 4: Comparison of climate change PDF and MSA effect factors

Climate change effect factor (PDF.°C^{-1})	Climate change effect factor (MSA.°C^{-1})	Ratio (MSA/PDF)
0.037 (Huijbregts et al. 2017)	0.0521 (Arets, Verwer, and Alkemade 2014)	1.41
	0.067 (Wilting et al. 2017)	1.81

This option provides an MSA%-PDF ratio, which can hardly be used since LCA CFs are expressed in PSA.m².yr. Though interesting, it is not kept in the remaining of th report.

<u>Option 2</u>: In BFFI, the effect factor used for climate change is 2.8.10^{-9} species.yr.kg CO$_2$-eq^{-1}. Applying the average terrestrial species density yields an impact of

$$\frac{2.8^{-9}}{1.4.10^{-8}} = \ 0.20\ \mathrm{PDF.m^2.yr.kg\ CO_2eq^{-1}}.$$

In the GBS, the climate change impact factor is 4.37.10^{-9} MSA.km².kg CO$_2$-eq^{-1}, *i.e.* 4.37.10^{-3} MSA.m².kg CO$_2$-eq^{-1}. These effect factors yield an **MSA-PDF ratio of 2.1.10^{-2}**. This ratio is by far the smallest of the ratios obtained so far. It is important to note that the impact factor computed in BFFI relies on an integrated absolute global temperature potential (IAGTP) of 6.5.10^{-14} °C/kg CO$_2$-eq while IAGTP used by the GBS is 4.76.10^{-14} °C/kg CO$_2$-eq. If the GBS had used the IAGTP used in the BFFI, the climated change impact factor would be 5.97.10^{-3} MSA.m²/kg CO$_2$-eq and the **MSA-PDF ratio would thus be 3.0.10^{-2}**.

This conversion has two limitations. First, the figures are for climate change global impacts (on the whole planet) and would be different if the impacts of (global) climate change was assessed on a smaller ecosystem: the number of species lost per degree of temperature increase would be lower. Therefore, using this conversion implies that it is used at a global scale, over about 140 million km^2 of terrestrial land. Second, keep in mind that this species-MSA% relationship is estimated based on climate change impacts. Then, it somehow encompasses the abundance-to-extinction dynamic specific to climate change, *i.e.* the way in which climate change affects both abundance and extinction. Indeed, a pressure might cause a loss of abundance of 10% for all the species (MSA = 10%) but no extinction (0 species lost), the conversion factor would then be null. Hence computing the species-MSA conversion factor on results related to climate change and using the factor for other pressures implies that the pressures have the same pattern as does climate change regarding the way they impact species extinction and abundance.

3.2.B.3.3 General results of the approach

Table 5 gathers the results obtained through the various computation approaches described above. While the order of magnitude of the MSA.m²-PDF.m².yr ratio is 1 for land use, it is closer to 50 for climate change. Compared to our guessed interval]0;100], computing the ratio for two stressors thus reveals that the MSA.m²-PDF.m².yr ratio includes at least in [1;50] (but can be broader). As stated, we anticipate that the ratio is smaller than 1 for some stressors. However, since this assumption cannot be verified on real examples yet, we choose to stick to the values obtained for land use and climate change for now.

Table 5: Summary of the results obtained through various computation approaches

Approach	Obtained range for MSA.m²-PDF.m².yr ratios
Land use	0.76 – 1.60
Climate change, option 1	*Not kept due to units in MSA% and PDF*
Climate change, option 2	0.021 – 0.030

Applying the species density to these ratios allows to convert the obtained values into species.yr. As presented above, the terrestrial species density is $1.48.10^{-8}$ species.m^{-2} and the freshwater species density is $7.89.10^{-10}$ species.m^{-3}. In GLOBIO-Aquatic model, impacts on aquatic biodiversity are given in MSA.m² without consideration of volume. This is certainly due to a will from PBL experts that GLOBIO and GLOBIO-Aquatic models remain compatible, all the more than:

1. The volume of soil matter and the height of trees could argue for using a volumic unit also for terrestrial biodiversity;
2. The average depth of freshwater ecosystems considered in GLOBIO-Aquatic (rivers, streams, lakes and wetlands) is likely limited. Based on ReCiPe freshwater volume of rivers and lakes (126,700 km³) and GLOBIO-Aquatic total area of rivers and lakes (2,479,564 km²), the average depth of rivers and lakes on Earth is 51m. Including wetlands in the perimeter of freshwater ecosystems (wetlands are not included in ReCiPe freshwater ecosystems) will decrease this average depth.

To stick with GLOBIO's framework, we choose to use MSA.m² for all biodiversity impacts. Considering that the average depth of freshwater ecosystems is 51m, species density in species.m^{-3} should be multiplied by 51m to get freshwater species density in species.m^{-2}[7]. Applying the species density and average height of the water column to the ratios obtained above gives:

- 1 MSA.m² ranging between $2.96.10^{-10}$ and $2.37.10^{-8}$ species.yr (terrestrial biodiversity);
- 1 MSA.m² ranging between $8.05.10^{-10}$ and $6.44.10^{-8}$ species.yr (aquatic biodiversity).

The upper and lower bounds of these ranges are used in the GBS to compute the range of the endpoint CFs expressed in MSA.m²/kg 1.4DCB-eq. The endpoint CFs are then multipled by the freshwater and terrestrial ETPs of each ReCiPe substance to compute the corresponding refined ecotoxicity biodiversity impact factors in MSA.m²/kg of substance. The lower bound is considered as the optimistic impact factor, while the upper bound is the conservative impact factor. A central value is computed based on the upper

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[7] Doing so assumes that species density is constant over the water column. This assumption could be refined if data on the variation of species density over the water column was available.

bound of the MSA.m²-PDF.m².yr ratio related to climate change (0.03). The obtained endpoint CFs are gathered in Table 6.

Table 6: Ecotoxicity endpoint CFs expressed in MSA.m²/kg 1.4DCB-eq

Ecosystem impacted by toxicity	Endpoint CF (species.yr/kg 1.4DCB-eq)	Endpoint CFs (MSA.m²/kg 1.4DCB-eq)		
		Conservative	Central	Optimistic
Terrestrial	$1.14.10^{-11}$	$4.81.10^{-4}$	$2.57.10^{-2}$	$3.85.10^{-2}$
Freshwater	$6.95.10^{-10}$	$1.08.10^{-2}$	$5.76.10^{-1}$	$8.64.10^{-1}$

4 Attributing the impact of ecotoxicity

Following the functioning of GLOBIO pressures presented in Section 1.2, the objective here is to establish rules to deal with double countring, *i.e.* find ways to “switch-off” the ecotoxicity part of the concerned GLOBIO pressures. As presented in Table 1, on-site terrestrial ecotoxicity is embedded in the terrestrial pressure Land use (LU), while freshwater ecotoxicity is embedded in the aquatic pressures Land use in catchment of rivers (LUR) and Land use in catchment of wetlands (LUW).

4.1 Static and dynamic impacts

In the GBS framework, impacts temporality is dealt with through the concepts of **“static” and “dynamic” impacts** in which static impacts refers to persistent impacts, while dynamic impacts relate to changes that occurred within a certain time frame (e.g. one year, or the period assessed). More details on the static/dynamic framework of the GBS and how it compares to time-integration can be found in (CDC Biodiversité 2020a).

In the particular case of the pressure LU, static impacts take into account the area occupied by each land use type, while dynamic impacts are computed only based on the land uses that expand or shrink during the assessment period. In the case of LUR and LUW, the variation in the scenario-based computed impacts in GLOBIO-IMAGE are redistributed to land uses in the catchment areas according to their resective surface area to compute dynamic and static impacts. In the assessments, static impacts are accounted for only once based on the land use mix at the beginning of the evaluation period and dynamic impacts account for changes that occurred during the assessment period.

The computation of LCA CFs is based on an emission flux yielding a constant steady-state concentration in the ecosystem. In a way similar to how we considered annual water consumption to be a proxy of the rate of water withdrawal, and thus to be associated to a static impact, emissions contributing to the “regular” flux maintaining the concentration constant should be considered as causing a static impact. Only increase in concentrations, approximated by increases in emissions, will lead to deviations from the steady-state concentration and to dynamic impacts. **This methodological question is critical and we would be very keen to hear the experts’ opinion on it.**

4.2 LUR, LUW and freshwater ecotoxicity

(Jan H. Janse, Bakkenes, and Meijer 2016) explain that LUR and LUW are considered as proxies of the amount of substances leaching into freshwater bodies due to the concerned land uses (all land uses for LUW, urban, croplands and pastures for LUR). Conceptually, if the list of substances leaching into water due to the company’s activity is exhaustive and the company operates in agriculture, forestry or if the sites are located near cities (thus corresponding to GLOBIO urban areas)**, the refined ecotoxicity impact computed thus replaces the dynamic LUR and LUW impacts**. Dynamic LUR and LUW impacts for the period are thus set to 0 for these cases, while the refined ecotoxicity impact is incorporated into the assessment results. Future work and discussions with experts should provide ground to refine this assumption.

4.3 LU and terrestrial ecotoxicity

Contrary to LUR and LUW, terrestrial LU mixes on-site terrestrial ecotoxicity with other drivers of biodiversity loss related to land uses, *e.g.* habitat loss, degradation or uniformization and destructive practices. Thus, **contrary to LUR and LUW, refined terrestrial ecotoxicity covers only partly land use related impacts and cannot be considered as fully replacing the LU dynamic impacts.**

Acknowledging the fact that no information enabling the estimation of the respective share of on-site ecotoxicity and other land use-related impact drivers is provided in GLOBIO literature, we decided to keep the computed dynamic LU impacts unchanged and report refined ecotoxicity impacts separately. **This assumption is strong and we are aware that it generates double-counting.** This will be clearly underlined in the results if such cases happen. Though very conservative, this option seemed better than arbitrary claiming that land use dynamic impacts would be reduced by [X]% when a refined assessment of terrestrial ecotoxicity impacts is conducted. Most importantly, more work is needed to analyse the MSA land use impacts and distangle the contribution of all its underlying components. Such work is undoubtebly wider than the GBS tool and calls for the contribution of parties other than CDC Biodiversité.

5 Linkage with the input-output approach

EXIOBASE emissions account documents the {region; industry} emissions of 36 non-GHG emission items in 4 compartments (air, water, soil and “undefined”). Note that the 36 items do not correspond to 36 distinct substances. Indeed, several items refer to the same substance spelled differently (for instance B(a)P and Benzo(a)pyrene, PCBS and PCBs, PCDD_F and PCDD/F)[8] and some items are substance aggregates (for instance Pxx and Emissions nec). Anyway, **the input-output integration requires to match EXIOBASE substances and compartments with ReCiPe substances and compartments**.

EXIOBASE substances are matched manually to the best corresponding ReCiPe substance(s). Despite the very large number of substances documented in ReCiPe, only 20 EXIOBASE items over 36 – corresponding to 12 substances and 2 aggregates – could be matched. Sometimes, several ReCiPe substances match one EXIOBASE item (for instance metals and metal ions). Then, the match is made with both substances and the impact factor used is the average of both substances impacts factors. The correspondence table is presented in Table 7.

EXIOBASE emissions compartments (air, water, soil and “undefined”) are matched to ReCiPe emissions compartments following the correspondence table presented in Table 8. The EXIOBASE “air” and “soil” compartments are matched to the two corresponding air and soil compartments in ReCiPe and the impact factor used is the average of the substance’s impact factors in both compartments, thus assuming that the emissions occur equally in both compartments. The EXIOBASE “water” compartment is matched to the ReCiPe “freshwater” compartment, thus assuming that no emission occurs in marine water due to the fact that marine biodiversity is not included in the GBS. As a consequence, the freshwater ecotoxicity impacts computed with the IO model are likely slightly overestimated.

Table 7: Correspondence table between EXIOBASE items and ReCiPe substances

EXIOBASE item	ReCiPe substance(s)
As	As(III), As(V)
B(a)P	benzo[a]pyrene
Benzo(a)pyrene	benzo[a]pyrene

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[8] The reason for the existence of these different spellings is unknown to CDC Biodiversité.

Cd	Cd(II)
Cr	Cr(III), Cr(VI)
Cu	Cu(II)
HCB	hexachlorobenzene
Hg	Hg(II)
Ni	Ni(II)
PAH	PAH, polycyclic aromatic hydrocarbons
Pb	Pb(II)
PCB	PCBS
PCBs	PCBS
PCDD/F	Dibenzo-p-dioxin, Dibenzofuran
PCDD_F	Dibenzo-p-dioxin, Dibenzofuran
Se	Se(IV)
SOx	SULFURIC ACID
Zn	Zn(II)
B(b)F, B(k)F, Benzo(b)fluoranthene, Benzo(k)fluoranthene, CO, Indeno, Indeno(1,2,3-cd)pyrene, N , NH3, NMVOC, NOx, NOX, P, PM10, PM2.5, Pxx, TSP, *Emissions nec*	*No match*

Table 8: Correspondence table between EXIOBASE and ReCiPe emissions compartments

EXIOBASE compartment	ReCiPe compartment(s)
air	Agricultural air, rural air
water	freshwater
soil	Agricultural soil, industrial soil

undefined	*No match*

Based on the substance- and emission compartment matchings, the **M matrix** providing ecotoxicity impacts in MSA.km²/t of EXIOBASE substance in each compartment is computed. Spatial matching is not needed since ReCiPe CFs are not spatialised, hence the **substance-compartment specific impact factors are repeated across all EXIOBASE regions.** The **D matrix** documenting substance emissions in each compartment in kg/MEUR for all {region; industry} pairs is computed simply thanks to the emission account.

6 Example

Considering the exploratory status of this work, no extended example nor tests were elaborated. The impacts computed for the production of EUR 1 million of French wheat are presented hereafter for the sake of illustration and in a first attempt to assess the plausibility of the MSA ecotoxicity impact factors. Ecotoxicity impacts expressed in MSA.m²/kg of ReCiPe substance can be computed following the methodology presented in Section 3.2 and can be provided upon request.

Table 9 presents the ecotoxicity impacts of the production of EUR 1 million of French wheat. Terrestrial and Aquatic ecotoxicity impacts in MSA.m² are presented. For each pressure, three impacts are computed based on the three values of the endpoint CF obtained (central, conservative, optimistic, in MSA.m²/kg 1.4DCB-eq, see Table 6). The LU, LUR and LUW dynamic and static impacts are provided to enable comparison. Although very preliminary, **the general order of magnitude of the results seems correct as is in the same range or below the GLOBIO-based impacts.**

Table 9: Ecotoxicity impacts of the production of EUR 1 million of French wheat

Scenario	Terrestrial ecotoxicity impact (MSA.m^2)	Aquatic ecotoxicity impact (MSA.m^2)	Reminder, corresponding pressure impacts (MSA.m^2)			
			LU		LUR + LUW[9]	
			Dynamic	Static	Dynamic	Static
Conservative	28 146	8	21 644	5 340 000	269	148 000
Central	18 764	5			86	47 700
Optimistic	351	0.1				

7 Limits and perspectives

As clearly stated in the Disclaimer and throughout the report, the whole content of this report is preliminary and calls for further work. Notably, the PDF.m^2.yr-MSA.m^2 conversion factor computation and the attribution rules presented above should not be applied as such in future biodiversity footprint assessments. Discussions involving especially MSA and LCA experts are needed to tackle methodological issues which largely outbound the GBS framework. Indeed, such discussions will serve the community of biodiversity footprint tool developers as a whole, as well as other parties interested in biodiversity assessment.

8 References

Alkemade, Rob, Mark van Oorschot, Lera Miles, Christian Nellemann, Michel Bakkenes, and Ben ten Brink. 2009. 'GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss'. *Ecosystems* 12 (3): 374–90. https://doi.org/10.1007/s10021-009-9229-5.

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[9] Conservative value computed based on the conservative intensities (`_cut`) and central values computed with central intensities (`_wm`).

Arets, Eric J.M.M., Caspar Verwer, and Rob Alkemade. 2014. ‘Meta-Analysis of the Effect of Global Warming on Local Species Richness’.

CDC Biodiversité. 2019. ‘Global Biodiversity Score: A Tool to Establish and Measure Corporate and Financial Commitments for Biodiversity’. 14. Biodiv’2050 Outlook. CDC Biodiversité.

———. 2020a. ‘GBS Review: Core Concepts’.

———. 2020b. ‘GBS Review: Freshwater Pressures on Biodiversity’.

———. 2020c. ‘GBS Review: Terrestrial Pressures on Biodiversity’.

CREM, and PRé Consultants. 2016. ‘Towards ASN Bank’s Biodiversity Footprint; A Pilot Project’.

Díaz, S., J. Settele, E. Brondízio, H. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. Brauman, and S. Butchart. 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 (IPBES)’. IPBES.

Huijbregts, Mark A. J., Zoran J. N. Steinmann, Pieter M. F. Elshout, Gea Stam, Francesca Verones, Marisa Vieira, Michiel Zijp, Anne Hollander, and Rosalie van Zelm. 2017. ‘ReCiPe2016: A Harmonised Life Cycle Impact Assessment Method at Midpoint and Endpoint Level’. *The International Journal of Life Cycle Assessment* 22 (2): 138–47. https://doi.org/10.1007/s11367-016-1246-y.

Janse, J. H., J. J. Kuiper, M. J. Weijters, E. P. Westerbeek, MHJL Jeuken, M. Bakkenes, R. Alkemade, W. M. Mooij, and J. T. A. Verhoeven. 2015. ‘GLOBIO-Aquatic, a Global Model of Human Impact on the Biodiversity of Inland Aquatic Ecosystems’. *Environmental Science & Policy* 48: 99–114.

Janse, Jan H., Michel Bakkenes, and J. Meijer. 2016. ‘Globio-Aquatic’. *Technical Model Description* 1.

Mark Goedkoop, Reinout Heijungs, Mark Huijbregts, An De Schryver, Jaap Struijs, and Rosalie van Zelm. 2013. ‘ReCiPe 2008: A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level. First Edition (Version1.08)’.

Wilting, Harry C., Aafke M. Schipper, Michel Bakkenes, Johan R. Meijer, and Mark A. J. Huijbregts. 2017. ‘Quantifying Biodiversity Losses Due to Human Consumption: A Global-Scale Footprint Analysis’. *Environmental Science & Technology* 51 (6): 3298–3306. https://doi.org/10.1021/acs.est.6b05296.

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