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Policy report

Biodiversity footprints in policy- and decision-making

Briefing on the state of play, needs and opportunities, and future directions

Institute for European Environmental Policy

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EXECUTIVE SUMMARY

This briefing has two objectives:

1. To review the state of knowledge and current application of biodiversity footprints and assemble relevant experience in methodologies for footprints on biodiversity, ecosystems and ecosystem services;
2. To identify key future needs and opportunities for using biodiversity footprint information to support more sustainable policy- and decision making.

What is a biodiversity footprint?

There is no commonly agreed definition. For the purposes of this briefing, biodiversity footprint is defined as "***The impact of a commodity, company, person or community on global biodiversity, measured in terms of biodiversity change, as a result of production and consumption of particular goods and services***".

The biodiversity footprint is determined by other footprints, representing the most important drivers of biodiversity loss: greenhouse gas emissions, water use, pollution, land-use etc. Here we consider footprints relating to species, ecosystems and ecosystem services.

Why do we need to measure biodiversity footprints?

Footprint measures can be used to understand the biodiversity impact of specific sectors, products and organisations, supporting decision-making to mitigate negative and enhance positive impacts of public and private sectors on nature. Biodiversity footprint methods can therefore inform, implement and monitor various aspects of the post-2020 global biodiversity framework and sustainability agenda.

The following key needs for biodiversity footprints were identified within the current EU and global policy context:

- **Informing biodiversity targets**: clear, measurable indicators to monitor targets addressing biodiversity impacts of public and private decision making.

- **Natural capital accounting**: to calculate supply and demand of natural resources, including biodiversity, to implement ecosystem accounts.

- **Remaining within safe planetary boundaries**: to determine whether our demands on natural capital fit within long-term sustainable use.

- **Mainstreaming biodiversity into land-use sectors**: such as agriculture and food production, forestry, mining, and construction, to measure the biodiversity impacts of production and consumption along supply chains.

- **Addressing global biodiversity impacts**: to allow nations and other entities to determine the global impact of their consumption and policies.

- **Mainstreaming biodiversity into trade policies**: to measure the impact of trade policy on biodiversity to evaluate the total impact of a nation's trade, and the impact of specific trade relations. This can inform decisions on trade agreements e.g. to evaluate agreements as they are being negotiated.

- **Mainstreaming biodiversity into development cooperation policies**: to improve assessment of the biodiversity impact of development cooperation.

- **Mainstreaming biodiversity into financial and private sector policies:** to assess, monitor and report the biodiversity impact of private sector activities, to inform policies such as non-financial disclosure and due-diligence rules, circular economy policies, labelling and certification schemes, green claims.

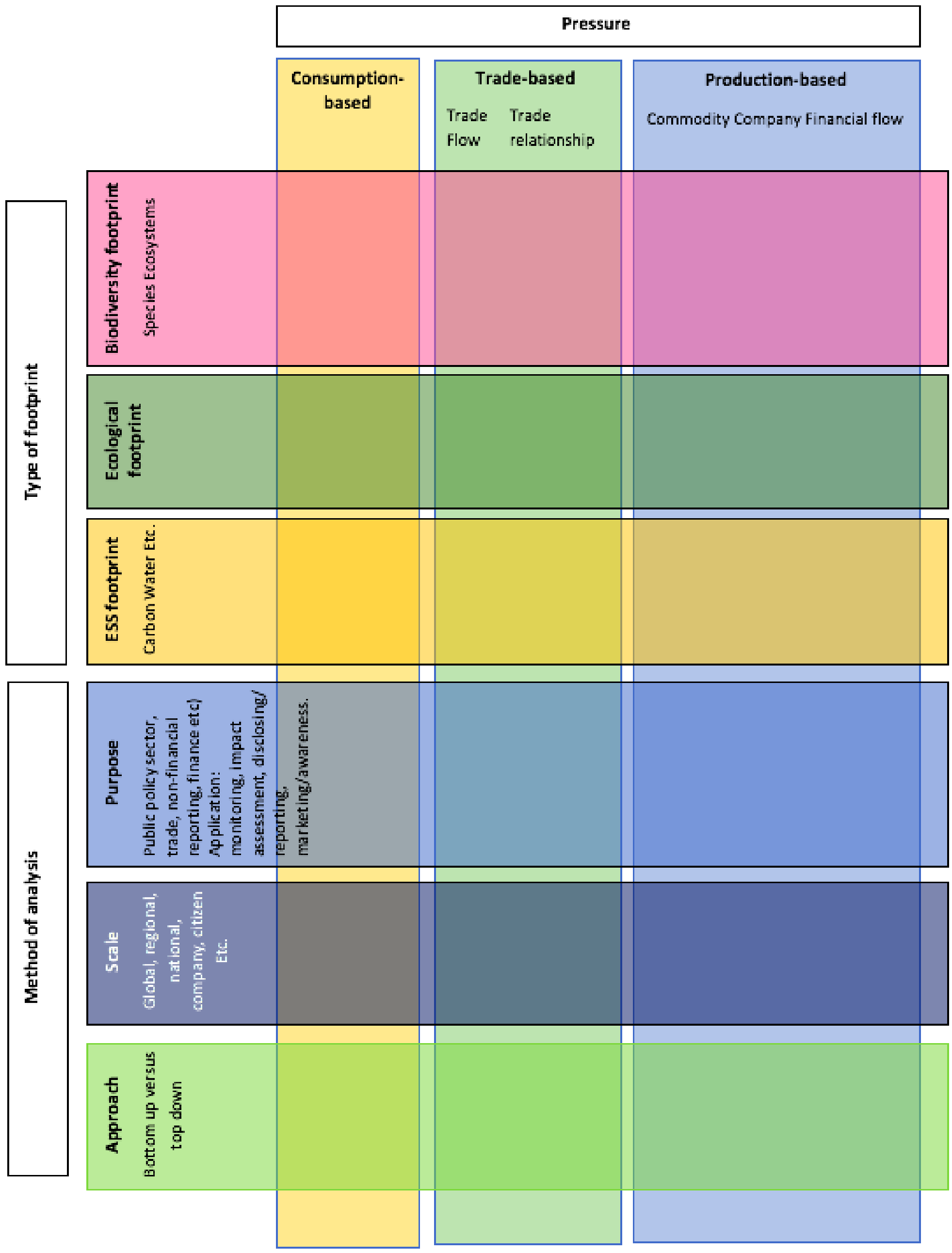
- **Reporting, monitoring and assessing progress on the 2030 agenda**: to inform and monitor SDGs linked to biodiversity goals, especially those aiming to reduce impacts from unsustainable production and consumption.

"Typology" of footprints: Mapping and navigating the existing biodiversity footprint landscape

To help navigate the complexity of available biodiversity footprint methodologies, we developed a typology which classifies them along three key dimensions:

1. **Driver of pressure**: footprints measure impacts associated with given pressures. Broadly, these pressures can be classified into consumption-based, trade-based or production-based.
2. **Type of footprint**: ecological, biodiversity or ecosystem service footprints.
3. **Method of analysis**: methods differ in their purpose, scale and approach. Bottom-up approaches typically measure impacts of individual products while top-down approaches start with higher-level aggregated impacts based on national accounts of input, output and trade, which can then be disaggregated.

These are illustrated in the diagram below.



Existing footprint methodologies and their applicability to address policy needs

We reviewed over 40 tools and categorised these against the typology. Data requirements emerged as a key factor to consider. We identified several types of footprint methods:

a) Foundational biodiversity data and tools supporting the measurement of footprints:

- **Tools synthesising and analysing data to identify risk to biodiversity and opportunity for mitigation**: using global datasets to identify levels of risk, mitigation and restoration opportunities and impacts of alternative scenarios.

- **Methodologies linking biodiversity pressures to impacts:** using global and regionalised datasets and data from scientific studies to design methods that predict the relationships between pressures and biodiversity impacts.

  b) Tools supporting the application of footprint information into decision-making:

- **General footprint frameworks**: combining a range of global datasets to provide a top-down estimate of the overall footprint for a product or a region.

- **Detailed methodologies for single sectors or ecosystem services**: some are aimed at particular sectors while others focus on ecosystem services like water quality and agrobiodiversity.

- **Rapid self-assessment systems**: a small number of bottom-up tools have been developed allowing for footprint assessments at the site-level.

- **Tools outlining general footprint frameworks**: describing the range of information to be collected but leaving it up to the user to access this.

The report provides further analysis in terms of types of pressures, types of footprints, approaches to calculating the footprint, scale and purpose. Each of the footprint methodologies described are summarised in a table.

Data availability and infrastructure underpinning footprints

The report identifies some key data sources, and assesses their usefulness, gaps and likely future developments including (not a complete list):

- Red Lists of Species

- Key Biodiversity Areas

- World Database of Protected and Conserved Areas

- Vegetation change mapping

Improving data

Lack of biodiversity data, particularly on trends in species, was identified as a key challenge for estimating biodiversity footprints, although not to the extent of preventing footprint analysis There are seven ways in which the EU and member states can help to address the provision and flow of data:

1. Support development of Red List data in data-poor, high biodiversity countries, including national Red Lists, and focusing on invertebrate groups and lower plants.
2. Support data collection from citizen science sources, as a cost-effective way of collecting such information.
3. Work with partners to coordinate the transfer of existing data to the IUCN Red List database and the Global Biodiversity Information Facility (GBIF).
4. Use EU funding to increase member states' capacity for biodiversity data collection and release for public use.
5. Support further research on automatic data collection options, such as camera traps, audio-analysis.
6. Support further research on satellite monitoring as applied to vegetation, particularly with respect to intactness and quality of non-forest vegetation.
7. Support work on the optimum units of measurement for biodiversity change: e.g., mean species abundance, potentially disappearing fraction of species.

The focus in the present paper is on biodiversity data. We acknowledge that other data sources, particularly relating to supply chain data connecting consumption to production sites, are also frequently missing and are of critical importance here.

Conclusions

A concluding section looks at strengths and weaknesses of the methodologies and concludes that there is no single tool that completely fits all the EU – and wider global – needs, partly due to the limitations in footprint methods and partly because of the inherent complications in measuring biodiversity impact. We matched some of the existing footprint tools against the policy needs identified in our analysis and found that the current application of existing tools can begin to address most needs. Moreover, the further development of these approaches could potentially better address needs thereby strengthening their policy relevance and uptake. To our knowledge, some needs have not been addressed by existing methodologies, such as the biodiversity impacts of a specific trade relationships. Crucially, as different tools suit different purposes and as biodiversity is a multifaceted concept, a suite of approaches is appropriate for the majority of needs.

Several staged processes could help increase the strength of footprint analysis within the EU:

- **A clear and agreed definition of a biodiversity footprint**, with additional emphasis on what such a footprint is supposed to reflect (i.e., the main indicators).
- **Agreement on the level of detail required** within EU footprint methodologies. Is this required at site level (suggesting in-depth life-cycle analysis) or at a more

general level (likely served with global or national-scale data)? Deciding on a minimum set of indicators – pressures on biodiversity and biodiversity status – is essential for the EU to assess progress towards its targets.

- **Further examination of available footprint tools** in light of the agreed definitions and level of detail needed to address the identified EU needs. It is important to be transparent about both the strengths and the limitations of tools available and under development.
- **If necessary, further development of existing footprint approaches, or development of novel approaches**: if it is found that existing tools do not match with all the EU needs.

1. INTRODUCTION

This briefing has two objectives:

1. To review the state of knowledge and current application of biodiversity footprints and assemble relevant experience among governments, NGOs and academics around the world in footprint methodologies for biodiversity, ecosystems and ecosystem services
2. To identify key future needs and opportunities for using biodiversity footprint information to support more sustainable policy- and decision making, including identifying key stakeholders that can function as change agents in this space

The footprint concept, as applied to environmental quality, emerged from recognition that actions to limit environmental degradation in one country were of only limited benefit if the causes of degradation were exported elsewhere. For example, forest conservation efforts in Europe have for long been known to lead to trade-offs by stimulating imports of timber, particularly from the tropics where deforestation is a major cause of biodiversity loss (Dudley *et al.*, 1995).[1]

Early footprint analyses were relatively crude, simply identifying impacts without attempting quantification (Stolton *et al.*, 2001).[2] More recently, footprint methodologies have become more sophisticated, data-driven processes that attempt to provide clear policy advice at the level of governments, industry, trade-flows and individual consumers.

The European Union's Green New Deal highlights the need to measure footprint as a key component of measuring the success or failure of its policies (E.C., 2020)[3].

[1] Dudley, N., Jeanrenaud, J.P. and Sullivan, F. 1995. *Bad Harvest: The timber trade and the degradation of the world's forests*. Earthscan, London.
[2] For instance, Stolton, S., Dudley, N. and Toyne, P. 2001. *The UK's Forest Footprint*. WWWF UK, Godalming, UK.
[3] European Commission. 2020. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: EU Strategy for 2030: *Bringing back nature into our lives*. COM (2020) 380 Final. Brussels.

This briefing aims to review and assemble relevant experience among governments, NGOs and academics around the world with regard to footprint methodologies for biodiversity, ecosystems and ecosystem services. Building on these insights, it aims to identify key future needs and opportunities for using biodiversity footprint information to support more sustainable policy- and decision-making. This includes identifying key stakeholders who can function as change agents in this space. Furthermore, the briefing aims to identify key synergies between the uptake and use of biodiversity related footprints and other emerging sustainability footprints, including underpinning data infrastructure.

Given the plethora of approaches the briefing starts by looking at types of footprints, provides definitions for those that are of most interest and policy relevance, and analyses the needs within the European Union and globally. Through literature review and interviews with key stakeholders, the briefing then attempts to provide an overview of the strengths and weaknesses of the most prominent existing methods, identifying the scale at which they operate, how long methods currently under development are likely to need before they become usable and whether or not they are likely to be useful within the context of the implementation of the Biodiversity Policy for 2030, both within the EU and globally.

This is a scoping study, and consequently the briefing makes some broad judgements that need to be further interrogated before any final decisions about methods are made. To this end, it identifies some of the key gaps, in both methodologies and in the data needed to drive them and make some recommendation for how the EU could help to address these, with the view to support assessment of biodiversity footprint within its territory and globally.

2. WHAT IS A BIODIVERSITY FOOTPRINT?

There is no commonly agreed definition of biodiversity footprint. For the purposes of this briefing, biodiversity footprint is defined as "*The impact of a commodity, company, person or community on global biodiversity, measured in terms of biodiversity change as a result of production and consumption of particular goods and services.*"

Footprints are, in an environmental context, measures of humans' direct and indirect impact on the natural world: usually by adding or subtracting something that has a quantifiable effect on the ecosystem. The Cambridge Dictionary defines footprint as: "*the effect that a person, company, activity, etc. has on the environment, for example the amount of natural resources that they use and the amount of harmful gases that they produce*". Footprints vary in focus, units of measurement, scale, and methods of calculation. Some have agreed definitions; others are still defined differently among users. Some can be measured precisely, like the concentrations of certain chemicals in the air, others are approximate, based on a range of assumptions. Footprint definitions and methodologies proliferate and overlap, and some are subsumed in others. A recent summary (Vanham *et al*., 2019),[4] linked to nine planetary boundaries (Rockstrom *et al*., 2009),[5] is already out of date. A partial list is given in Figure 1 below, with some (not all) linkages indicated. The link to planetary boundaries is important as some footprints go one step further by accounting the extent to which measured human impacts on nature stay within the regenerative capacity of the planet (Wackernagel et al., 2019)[6].

[4] Vanham, D., Leip, A., Galli, A., Kastner, T., *et al*. 2019. Environmental footprint family to address planetary sustainability and deliver on the SDGs. *Science of the Total Environment* 693: 133642. https://www.sciencedirect.com/science/article/pii/S0048969719335673

[5] Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., *et al*. 2009. A safe operating space for humanity. *Nature* 461: 472–475. https://www.nature.com/articles/461472a

[6] Wackernagel, M., Lin, D., Hanscom, L., Galli, A. and Iha, K., 2019. Ecological Footprint. Encyclopedia of Ecology, pp.270-282.

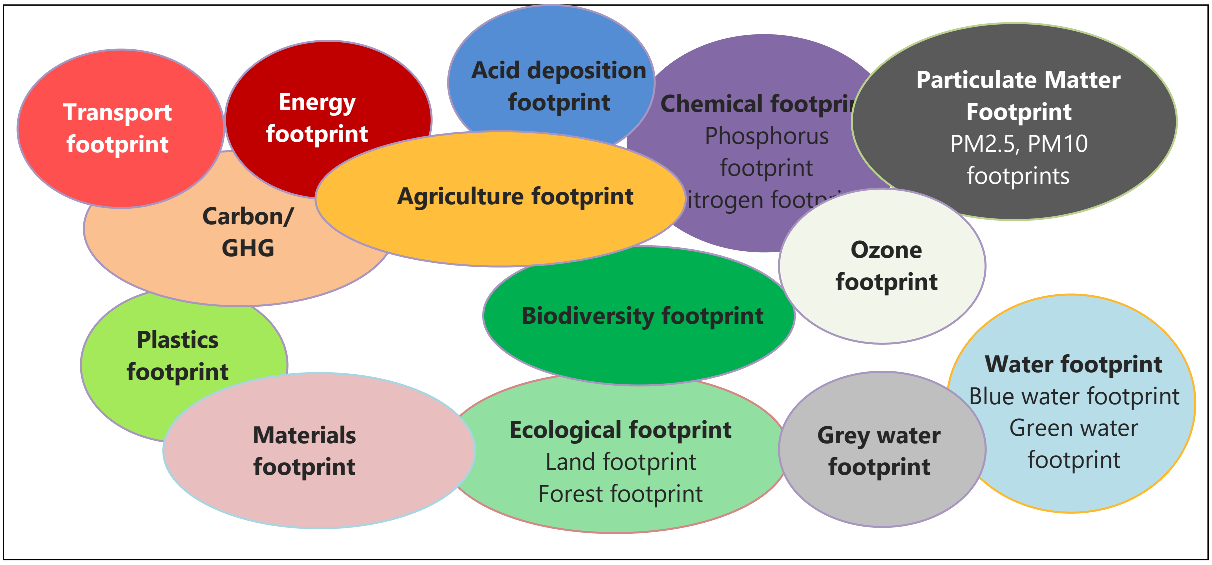


Figure 1: Commonly used measures of environmental footprint

Figure 1: Created by author

Putting the biodiversity footprint in the centre emphasises that, in this context, biodiversity is affected by all the other footprints shown. Here we consider footprints relating to:

- Species
- Ecosystems
- Ecosystem services

Table 1 summarises some key footprint approaches. Although generally measured in negative terms, footprints can be positive, e.g., if a production process increases a threatened species or ecosystem service: this could be an element in the EU restoration objectives. Care is needed to ensure that gains for one place do not result in leakage, e.g., displacing deforestation elsewhere.

Table 1: Key footprint methodologies important to this survey

Footprint	Definition	Method of calculation
Biodiversity footprint	No agreed definition. Often taken as equivalent to biodiversity loss,[7] Usually as relative biodiversity intactness (e.g., change in Mean Species Abundance, MSA)[8] or loss of "priority" species (e.g., Red List species).[9] Building on the above, the following definition is proposed to be used for the purposes of this briefing: "The impact of a commodity, company, person or community on global biodiversity, measured in terms of biodiversity change, as a result of production and consumption of particular goods and services."	Most current methods tend to use a combination of land use change (e.g., ecological footprint) and drivers (e.g., nitrogen and phosphorus levels in rivers);[10] Multi-Regional Input Output (MRIO) data;[11] and other Life Cycle Analysis methods.[12] There is consensus that more robust definitions and methods of measurement are needed.[13]

[7] Vanham, D., Leip, A., Galli, A., Kastner, T., Bruckner, M. *et al*. 2019. *Op cit*.
[8] For instance, Wilting, H.C., Schipper, A.M., Bakkenes, M., Meijer, J.R. & Huijbregts, M.A.J. 2017. Quantifying biodiversity losses due to human consumption: A global-scale footprint analysis. *Environmental Science and Technology* 51: 3298-3306.
[9] For instance, Moran, D. and Kanemoto, K. 2017. Identifying species threat hotspots from global supply chains. *Nature Ecology and Evolution* 1: 0023. https://www.nature.com/articles/s41559-016-0023
[10] Van Rooij, W. & Arets, E. 2016. *Biodiversity Footprint Assessment of Leading Companies*. Plansup & Alterra, Wageningen.
[11] Koslowski, M., Moran, D.D., Tisserant, A., Verones, F. and Wood, R. 2020. Quantifying Europe's biodiversity footprints and the role of urbanization and income. *Global Sustainability* **3**: e1, 1–12.
[12] CREM & PRé Consultants. 2016. *Towards ASN Bank's Biodiversity Footprint. A Pilot Project*. Amsterdam and Amersfoort.
[13] Marques, A., Robuchon, M., Hellweg, S., Newbold, T. & Beher, J. 2021. A research perspective: towards a more complete biodiversity footprint: a report from the World Biodiversity Forum. *International Journal of Life Cycle Analysis* 26: 238-243.

Footprint	Definition	Method of calculation
Ecological footprint (Area-based footprint)	The commonly accepted definition (from the Oxford dictionary) is "the impact of a person or community on the environment, expressed as the amount of land with a global average yield required to sustain their use of natural resources". For this analysis, company and commodity should be added to sources.	Most methods sum different footprints. The Global Footprint Network uses biocapacity.[14] Ecological footprints are criticised as simplistic,[15] in measuring land degradation, resource depletion and carbon.[16] Land footprints[17] are a subset.
Ecosystem services footprint	No general definition. These are largely disaggregated elements of an ecological footprint. One definition of a carbon footprint is: "the amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organization, or community".	Some mapping methods are available (Co$ting Nature)[18] or being developed.[19] Footprints for individual ecosystem services include particularly carbon[20] and water.[21] Some services do not lend themselves to footprint assessment (e.g., cultural and spiritual values).

[14] https://www.footprintnetwork.org/
[15] Fiala, N. 2008. Measuring sustainability: why the ecological footprint is bad economics and bad environmental science. *Ecological Economics* 67: 519-525.
[16] Zhang, L., Dzakpasu, M., Chen, R. & Wang, X.C. 2017. Validity and utility of ecological footprint accounting: a state-of-the-art review. *Sustainable Cities and Societies* 32: 411-416. https://www.sciencedirect.com/science/article/abs/pii/S2210670716303602
[17] Fischer, G., Tramberend, S., van Velthuizen, H. *et al.* 2017: *Extending land footprints towards characterizing sustainability of land use*. Federal Environment Agency, Dessau. http://pure.iiasa.ac.at/id/eprint/14807/1/2017-09-06_TEXTE_79-2017_Extended-land-footprint.pdf
[18] http://www.policysupport.org/costingnature.
[19] Long, P.R., *et al.* 2017. LEFT – A web-based tool for the remote measurement and estimation of ecological value across landscapes. *Methods in Ecology and Evolution* 9: 571-579. https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12924
[20] Mulrow, J., Machaj, K., Deanes, J. and Derrible, S. 2019. The state of carbon footprint calculators: A evaluation of calculator design and user interaction features. *Sustainable Production and Consumption* 18: 33-40.
[21] Hoekstra, A., Chapagain, A.K., Aldaya, M.M. & Mekonnen, M.M. 2011. *The Water Footprint Assessment Manual*. Earthscan, London.

3. WHY DO WE NEED TO MEASURE BIODIVERSITY FOOTPRINT?

Biodiversity, ecological and ecosystem service footprint methods are needed to inform, implement and monitor various dimensions of the post-2020 global biodiversity framework and the broader global sustainability agenda. This section explores present and future needs of biodiversity footprint indicators for public policy and decision-making in both the global and EU policy context. The needs for biodiversity footprints within private decision making are also considered from the perspective of public policy designed to address their environmental impacts.

The following key needs have been identified:

1. Informing biodiversity targets
2. Ensuring we remain within safe planetary boundaries
3. Advancing conservation by mainstreaming biodiversity into sectoral policies for land- and resource use
4. Identifying and addressing countries' biodiversity impacts
5. Mainstreaming biodiversity into trade policies with direct global impacts
6. Mainstreaming biodiversity into financial and private sector policies
7. Reporting, monitoring and assessing progress on the 2030 Sustainable Development Agenda

Biodiversity, ecological and ecosystem service footprint methods can contribute to assessing and raising awareness on the impacts of public and private decision-making on biodiversity worldwide. Understanding these can help mitigate the negative and, ideally, enhance the positive impacts of public and private sectors thereby addressing important drivers of global biodiversity loss. In this context, effective footprint methodologies can help inform, implement and monitor important dimensions of the post-2020 global biodiversity framework and broader sustainability goals.

Specifically, footprints are needed to (1) inform public policy on biodiversity loss and its drivers, (2) mainstream biodiversity into policy areas with important biodiversity impacts, (3) ensure national policies do not simply export biodiversity pressures, (4) mitigate and monitor the biodiversity impacts of trade and (5) development cooperation policies, (6) mainstream biodiversity considerations into policies addressing finance and private sectors which shape production and consumption patterns, and (7) monitor progress towards the global sustainability agenda. These key footprint needs are explored below both in the global and the EU policy context.

Crucially, when showing effects of concrete policies, and progress with actions towards CBD targets, a different set of indicators providing complementary information may be required alongside footprints: for example, the use of efficient techniques such as drip irrigation, or the share of resources produced, traded and consumed according to environmental standards. These aspects do not necessarily reduce the footprint, in terms of land, but make clear that what is used is produced in a responsible way (SDG12). Reducing our footprint to zero is not the aim as it is, by definition, impossible, as we will always consume. Therefore, it is important to ensure footprint measures also acknowledge the need to ensure that our necessary footprint on the planet is within planetary boundaries (i.e. acceptable), fair and responsible.

3.1 Informing biodiversity targets

Suitable biodiversity footprint methodologies are needed to inform and monitor progress towards targets and policies addressing biodiversity. In the global biodiversity policy context, several of the CBD's Aichi targets to 2020 need a clear understanding of the impact of decision making on biodiversity. Progress towards targets has been linked to their measurability (Green *et al.*, 2019).[22] Targets that have clear indicators, such as target 11 on the spatial extent of protected areas, are more easily measurable allowing them to be better understood, implemented and assessed. Consequently, better footprint indicators to measure the impact of public and private sector activities on biodiversity will help achieve the post-2020 biodiversity framework targets.

Strategic goal A of the global 2020 targets aims to tackle the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society. Calculating footprints can help achieve this by pinpointing activities that impose the largest pressures on biodiversity, identifying avenues to minimise their impact and determining the underlying consumption and production patterns driving them. Target 4 under goal A specifically called for stakeholders at all levels to implement plans for sustainable consumption and production.

[22] Green, E.J., Buchanan, G.M., Butchart, S.H.M., Chandler, G.M., Burgess, N.D., *et al.* 2019. Relating characteristics of global biodiversity targets to reported progress. *Conservation Biology* https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/cobi.13322

Indicators suggested to measure progress towards this included footprints such as the ecological footprint, water footprint, and human appropriation of net primary productivity. However, biodiversity footprint measures that causally link these area-based impacts to biodiversity impacts are lacking (Marques *et al*., 2017).[23] By calculating the biodiversity impact of activities in different sectors and traditional policy areas, these measures can help mainstream biodiversity considerations across society. Similarly, footprints are needed to address strategic goal B which aims to reduce direct pressures on biodiversity and promote sustainable use. They can help measure the impact of activities which directly drive biodiversity loss such as deforestation, overfishing, unsustainable agriculture and polluting processes. Strategic goal D, which aims to enhance the benefits to all from biodiversity and the services it delivers, would especially benefit from footprint methodologies evaluating ecosystem services, here in particular measured also as a positive impact. By measuring the impacts of activities on ecosystem services, they can be enhanced and safeguarded. Moreover, positive footprints that reflect biodiversity gains can help track action towards restoration.

Assessments show that, despite positive progress in some areas, the targets for 2020 set out in the Aichi targets have been missed and drivers of biodiversity loss continue (GBO, 2020).[24] In fact, none of the targets under strategic goal A have been achieved. Simply setting another set of ambitious targets for the future will therefore be pointless unless steps are taken towards achieving more effective and transformative action towards the conservation of biodiversity and ecosystem services beyond 2020. Finding effective ways to measure progress will be an important part of this process. The updated Zero Draft of the post 2020 Biodiversity framework (CBD, 2021),[25] building on the Aichi targets, highlights the need for tools and solutions for the implementation and mainstreaming of biodiversity policies. For example, drawing from the revised Zero Draft from the CBD: Target 3 "...active management actions to enable wild species of fauna and flora recovery and conservation..."; Target 9 "...support the productivity, sustainability and resilience of biodiversity in agricultural and other managed ecosystems..."; Target 14 "...achieve reduction of at least [50%] in negative impacts on biodiversity by ensuring production practices and supply chains are sustainable..."; Target 15 "...eliminate unsustainable consumption

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[23] Marques *et al*. 2017. *Op cit*. https://www.sciencedirect.com/science/article/pii/S1877343518300058

[24] Secretariat of the Convention on Biological Diversity (2020) *Global Biodiversity Outlook 5*. Montreal. https://www.cbd.int/gbo/gbo5/publication/gbo-5-en.pdf

[25] Convention on Biological Diversity. Updated Zero Draft of the Post-2020 Global Biodiversity Framework. https://www.cbd.int/doc/c/3064/749a/0f65ac7f9def86707f4eaefa/post2020-prep-02-01-en.pdf

patterns…" and several more. As outlined, footprints will be a key tool by aiding the implementation, monitoring, review and evaluation of future targets.

In Europe, the CBD targets are reflected in the new EU Biodiversity Strategy for 2030 highlighting *"biodiversity considerations need to be better integrated into public and business decision making at all levels"* to enable transformative change. To achieve this, a set of key actions are identified such as the development in 2021 of methods, criteria and standards to better consider biodiversity and its services and measure the environmental footprint of products and organisations including through life cycle approaches and natural capital accounting.

3.1.1 Natural capital accounting

A method to facilitate the integration of biodiversity into policy decision-making identified by the Aichi target 2 is national accounting of natural capital. Natural capital accounting refers to any framework which aims to measure and report on stocks and flows of natural capital to integrate them into accounting and reporting systems at international, regional and national levels. This complements traditional national economic accounts. In 2021, the UN adopted a revised statistical framework for natural capital accounting which better integrates ecosystems and their services: the System of Environmental Economics Accounting (SEEA) Ecosystem accounting.[26] The system aims to help integrate biodiversity and ecosystem services into macro-economic policies, sectoral policies, and can promote sustainable practices in the private sector. The European Commission supported the development of this framework and will propose a revision of its Regulation on European Environmental Economic Accounts (EEEA) to include natural capital accounting consistent with it.[27] Another key example is the Natural Capital Project, from Stanford University and Partners, which has been supporting the implementation of natural capital accounting in over 60 countries worldwide since 2006. Through their open-source software tool called InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) they help a range of decision makers integrate ecosystem services into their management choices.[28]

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[26] https://seea.un.org/content/frequently-asked-questions#What%20is%20natural%20capital%20accounting
[27] European Commission. Natural Capital Accounting. https://ec.europa.eu/environment/nature/capital_accounting/index_en.htm
[28] Natural Capital Project. https://naturalcapitalproject.stanford.edu/who-we-are/natural-capital-project

Natural capital accounts require detailed measurements of supply and demand of natural resources, including biodiversity. Some footprint methods and related models can help provide this information, as the impact of activities on biodiversity can also be conceptualised as their demand for biodiversity (Monfreda *et al*., 2004).[29] The InVEST tool, for example, is a package of models that map and value different ecosystem services and how their delivery might be impacted by different management scenarios. These include models looking at ecosystem footprints (including habitat quality, pollination, carbon storage and nutrient delivery), and a model directly measuring biodiversity footprint (using the InVEST GLOBIO model). There is therefore a clear need to develop these footprint methods and related models as more signatories to the CBD implement ecosystem accounts in their national accounts.

Footprint methods can also inform natural capital accounting for private sector decision making. Several initiatives are developing tools and guidance to help organisations measure, value and manage natural capital to improve their environmental performance. The Capitals Coalition has developed the Natural Capital Protocol; a decision-making framework for organisations of all sizes and sectors to identify their impacts and dependencies on nature[30]. Businesses can use this to integrate nature into internal business processes and external disclosure and stakeholder engagement. In line with the ambition of the EU's Green Deal, there is an ongoing effort in the EU to standardise natural capital accounting and valuation practices. Through the EU LIFE funded "Transparent" project, the Value Balancing Alliance (VBA), the Capitals Coalition and the World Business Council for Sustainable Development (WBCSD), have joined forces to develop a standardised natural capital accounting methodology building on existing methodologies such as the Natural Capital Protocol. The European Commission funded "Align" project also aims to develop standardised natural accounting practices with a focus on developing standardised biodiversity measurement methods. It does so by maximising synergies between a range of initiatives including the "Transparent" project. A key step to achieve this might be to develop a set of common biodiversity footprint methods and to identify best practices and potential synergies amongst them.

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[29] Monfreda, C., Wackernagel, M. and Deumling, D. 2004. Establishing national natural capital accounting based on detailed ecological footprint and biological capacity assessments. *Land Use Policy* 21 (3): 231-246. https://www.researchgate.net/publication/222424582_Establishing_National_Natural_Capital_Accounts_Based_on_Detailed_Ecological_Footprint_and_Biological_Capacity_Assessments

[30] https://capitalscoalition.org/capitals-approach/natural-capital-protocol/?fwp_filter_tabs=training_material

3.2 Remaining within safe planetary boundaries:

Some footprint tools and methods can be used to determine whether our demands on natural capital fit within long-term sustainable use. The first developed indicator, the ecological footprint, was designed for this purpose as it compares the impact of human products and activities on the environment to the natural regenerative capacity of our planet (biocapacity) (Fang et al, 2015).[31] These measures have received some criticism for being over simplistic and they do not provide detailed information on how to ensure we remain within planetary boundaries (Blomkvist et al, 2013).[32] However, they have undoubtedly raised awareness on the finite capacity of our planet's natural capital and the need to ensure that our demands do not exceed nature's ability to replenish itself. For example, the Global Footprint's Network Earth overshoot day has increased citizen's awareness of this concept. Awareness raising on the indirect effects of consumption is an important aspect of why the footprint concept was developed,

3.3 Advancing conservation by mainstreaming biodiversity into sectoral policies for land- and resource use

The food sector has a high biodiversity impact making it an especially important area to mainstream biodiversity management and conservation. Food production has become increasingly global with complex supply chains linking agriculture, production, trade, distribution and consumption. Footprint methodologies can be used to measure the direct and indirect biodiversity impacts of agricultural commodity production and consumption along supply chains: from the farmer to food producers and retailers (Crenna *et al.*, 2019).[33] This can then be used to identify areas of improvement to make food systems more biodiversity friendly (Sala *et al.*, 2017).[34]

[31] Fang, K., Heijungs, R. and De Snoo, G., 2015. Understanding the complementary linkages between environmental footprints and planetary boundaries in a footprint–boundary environmental sustainability assessment framework. *Ecological Economics* 114: 218-226.

[32] Blomqvist L, Brook BW, Ellis EC, Kareiva PM, Nordhaus T, Shellenberger M (2013) Does the Shoe Fit? Real versus Imagined Ecological Footprints. *PLoS Biol* 11(11): e1001700.
https://doi.org/10.1371/journal.pbio.1001700

[33] Crenna *et al*. 2019. *Op cit*.
https://www.sciencedirect.com/science/article/pii/S095965261931131X?via%3Dihub

[34] Sala, S., Anton, A., McLaren, S.J., Notarnicola, B., Saouter, E. and Sonesson, U. 2017. In quest of reducing the environmental impacts of food production and consumption. *Journal of Cleaner Production* 140 (2): 387-398.
https://www.sciencedirect.com/science/article/pii/S0959652616313956

In Europe, the new EU Farm to Fork Strategy, which aims to make European food systems more sustainable, acknowledges Europe's role as the biggest food importer and exporter and highlights the need to address this. The need to ensure sustainable trade policy (discussed below), is highlighted as an essential step towards achieving sustainability in food systems. A number of studies have calculated the biodiversity footprint of European food consumption using the EU Consumer Footprint 'basket of products' of food (e.g., Notarnicola *et al.*, 2017),[35] and recently a WWF report measured the EU consumption's impact on global deforestation from the expansion of agro-commodity production.[36] These can be used to compare the impacts of different products. For example, Crenna *et al.* (2019)[37] measured the biodiversity impact of EU food consumption by looking at the footprint of 19 different food commodities. The study found meat and dairy products have the highest biodiversity impact and identified the key impacts of other products (e.g., water use and ecotoxicity related to wine).[38] These footprint methods can also be used to model different scenarios to help decision making in the agricultural and wider food sector.[39] For example, the Cool Farm Tool helps farmers quantify the biodiversity footprint of their management decisions[40] and the agrobiodiversity index measures the biodiversity footprint of food systems to inform public and private decision making.[41]

Other policy areas and sectors with large biodiversity impacts can also use footprint methodologies to mainstream biodiversity into their decision-making. This includes sectors linked to direct land use changes such as forestry, mining and indirect land use change such as construction. Results from footprint methods can feed into environmental impact assessment methods to compare the different biodiversity impacts of different policy options or economic activities and understand the trade-offs with other impacts. In addition,

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[35] Notarnicola, B., Tassielli, G., Renzuli, P.A., Castellani, V. and Sala, S. 2017. Environmental impacts of food consumption in Europe. *Journal of Cleaner Production* 140 (2): 753-765. https://scholar.google.com/scholar_lookup?title=Environmental%20impacts%20of%20food%20consumption%20in%20Europe&publication_year=2017&author=B.%20Notarnicola&author=G.%20Tassielli&author=P.A.%20Renzulli&author=V.%20Castellani&author=S.%20Sala

[36] Wedeux, B. and Schulmeister-Oldenhove, A. 2021.*Stepping Up: The continuing impact of EU consumption on nature*. WWF, Brussels.

[37] Crenna *et al.* 2019. *Op cit.* https://www.sciencedirect.com/science/article/pii/S095965261931131X?via%3Dihub

[38] Crenna *et al.* 2019. *Op cit.* https://www.sciencedirect.com/science/article/pii/S095965261931131X

[39] European Commission. Consumer Footprint. Basket of products indicator on food. https://ec.europa.eu/jrc/en/publication/consumer-footprint-basket-products-indicator-food

[40] Cool Farm Alliance. Biodiversity. https://coolfarmtool.org/coolfarmtool/biodiversity/

[41] https://www.agrobiodiversityindex.org/index.php/about/

footprint measures can be used to compare the biodiversity impacts of different economic sectors within a country or region (Wilting & Oorschor, 2017).[42]

3.4 Identifying and addressing countries' global biodiversity impacts

Footprint methods can allow nations and other entities to determine the global impact of their consumption and policies (sometimes known as spillovers). In today's globalised world, the impacts of decision-making extend beyond borders and global cooperation is needed in addressing the drivers of biodiversity loss. Considering these global dimensions is particularly important for many countries in the global north, including the EU, which import a lot of their production and, consequently, export many of their impacts on biodiversity. Footprint measures can link biodiversity impacts anywhere in the world to a region's or nation's aggregate consumption, by looking at impacts along supply chains, or to a region's or nation's trade, by looking at impacts along trade flows. Examining global impacts from a consumption perspective can also be used to attribute biodiversity impacts to specific organisations, products, activities and even individuals (Koslowski *et al*., 2020).[43] For example, Green *et al*., 2019[44] examined the biodiversity impacts of soy production in the highly biodiverse Brazilian Cerrado and found European consumption is driving recent losses in the habitat including to many endemic species of the region.

In the outgoing 2020 EU Biodiversity Strategy, target 6 aimed to address the global biodiversity crisis, acknowledging the biodiversity impacts of EU consumption and production beyond its borders. Under this target, action 17 aimed to reduce the biodiversity impacts of EU consumption and enhance the positive and minimise the negative biodiversity impacts of trade policy. The mid-term review revealed insufficient progress towards reducing the impacts of EU consumption on global biodiversity.[45] The new strategy to 2030 builds on the old strategy, with a proposed action to reduce the deforestation impact of EU consumption. The Commission will propose a legal framework to stop

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[42] Wilting, H. and Oorschot, M.. 2017. Quantifying Biodiversity Footprints of Dutch Economic Sectors: A Global Supply-Chain Analysis. *Journal of Cleaner Production* 156: 10.1016/j.jclepro.2017.04.066.

[43] Koslowski, M., Moran, D.B., Tisserant, A., Verones, F. and Wood, R. 2020. Quantifying Europe's biodiversity footprints and the role of urbanization and income. *Global Sustainability* 3: e1, 1–12. https://www.cambridge.org/core/journals/global-sustainability/article/quantifying-europes-biodiversity-footprints-and-the-role-of-urbanization-and-income/243D1A4EE934A9129AF01AFE0AA1DFF1

[44] Green, J.M.H., Croft, S.A., Durán, A.P., Balmford, A.P., Burgess, N.D., *et al.* 2019. Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity. *PNAS* 116 (46): 23202-23208. https://www.pnas.org/content/116/46/23202

[45] European Commission. Undated. Mid-term review of the EU biodiversity strategy to 2020. https://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/mid_term_review_summary.pdf

products linked to deforestation being sold in the EU in 2021. Other countries, such as the UK, are moving in a similar direction. To achieve this, methods to calculate the deforestation footprint of products necessary.

3.5 Mainstreaming biodiversity into policies with direct global impact

3.5.1 Trade policy

Footprint methods are needed to better evaluate the impact of trade policy on biodiversity. International trade is responsible for an estimated 30% of global species threats (Lenzen *et al.*, 2012).[46] Understanding the biodiversity impact associated with trade flows can help countries make their trade more sustainable. Footprints can be used to evaluate the aggregated impact of trade flows, as discussed, or to evaluate the impact of specific trade agreements.

As the world's largest trading block, the EU has a considerable impact on the countries it trades with. The EU has made substantial efforts to integrate sustainable development in its trade policy including those linked to biodiversity. However, these have so far not delivered their full potential to protect global biodiversity.[47] The European Green Deal promises to strengthen the sustainability of EU trade. Sustainability Impact Assessments (SIAs) are used in the EU to evaluate the potential social, environmental and economic impact of proposed trade agreements while they are being negotiated. After they enter into force, an ex-post evaluation on these impacts is conducted. Although this framework is considered to be one of the most advanced globally to mainstream sustainability in trade, it falls short in integrating biodiversity considerations Kuik et al, 2018).[48] Therefore, there is a need for the EU to create and improve methodologies to assess the biodiversity impact of trade and support their development globally.

3.5.2 Development cooperation

Development cooperation action is another policy area which needs better consideration of biodiversity impacts. The EU is the largest development aid

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[46] Lenzen, M., *et al*. 2012. *Op cit*. https://www.nature.com/articles/nature11145

[47] European Commission. Undated. Mid-term review of the EU biodiversity strategy to 2020. https://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/mid_term_review_summary.pdf

[48] Kuik, O., Kettunen, M., van Vliet, J., Colsa, A. and Illes, A. 2018 *Trade Liberalisation and Biodiversity Scoping Study on Methodologies and Indicators to Assess the Impact of Trade Liberalisation on Biodiversity (Ecosystems and Ecosystem Services)*. Final report for the European Commission (DG ENV) (ENV.F.1/FRA/2014/0063), Institute for Environmental Studies (IVM/Vrije Universiteit), Amsterdam & Institute for European Policy (IEEP), Brussels/ London. https://ec.europa.eu/environment/nature/pdf/scoping_study.pdf

donor.[49] Action 19 of the EU biodiversity strategy to 2020 aims to "systematically screen the EU's development cooperation action to minimise any negative impact on biodiversity and undertake Strategic Environmental Assessments and/or Environmental Impact Assessments for actions likely to have significant effects on biodiversity". This links to the broader objective of "biodiversity proofing" the EU budget to avoid spending which harms biodiversity. For biodiversity proofing development cooperation policies, one of the key measures introduced to meet the biodiversity strategy goal was a compulsory environmental screening of any new development cooperation policy. The process identifies policies that require impact assessments. A mid-term review found biodiversity is not explicitly addressed in these screenings.[50] Therefore, there might be a need for better assessment of the biodiversity impact of development cooperation actions.

3.6 Mainstreaming biodiversity into financial and private sector policies

Biodiversity footprint methodologies are needed to assess the impact of private sector activities and products on biodiversity. Businesses can calculate impacts along their supply chains and product's life cycle stages to identify areas for improvement. To do this, information is needed on the pressures their activities place on ecosystems and their services and the effectiveness of their responses to these.[51] This information can help decision making, reduce risk associated with natural resource use and secure supply. Similarly, financial institutions can use biodiversity footprint methods to calculate the impact of their investment portfolios. This can help better understand investment risks and opportunities relating to biodiversity. An example of such tool is ENCORE, developed by the Natural Capital Finance Alliance, which helps banks, investors and insurance companies assess their natural capital opportunities, risks and exposures.

Biodiversity footprints can also help with monitoring, reporting and disclosing biodiversity impacts. This is increasingly being demanded by governments and consumers who want to ensure the products they purchase are sustainable.

[49] https://eeas.europa.eu/topics/development-and-cooperation_en

[50] European Commission. 2015. Commission Staff Working Document: EU Assessment of Progress in Implementing the EU Biodiversity Strategy to 2020. https://eur-lex.europa.eu/resource.html?uri=cellar:5254559f-68eb-11e5-9317-01aa75ed71a1.0001.02/DOC_3&format=PDF

[51] Stephenson, P.J. and Carbone, G. 2021. *Guidelines for planning and monitoring corporate biodiversity performance*. Gland, Switzerland: IUCN. https://portals.iucn.org/library/sites/library/files/documents/2021-009-En.pdf

Indeed, some of the leading drivers for the increased interest of the private sector in biodiversity are to avoid reputational loss, adapt to changing consumer preferences, decrease risk of litigation and ensure they are in line with future regulatory action.[52,53] Current practices on corporate environmental disclosure do not systematically integrate biodiversity concerns and contributions. Improved regulatory frameworks promoting transparent supply chains and integration of biodiversity dimensions is needed. The French government are active in developing methods for these uses. In Europe, the Commission will propose mandatory due diligence legislation in 2021 under the EU non-financial disclosure directive. This move is being supported by the European parliament who highlight that the current voluntary approach to the directive has been ineffective.[54]

Several EU initiatives are currently aiming to improve the assessment of businesses' biodiversity impacts and dependencies. For example, the EU B@B Platform has developed decision-making approaches to help businesses and financial institutions select the appropriate biodiversity measurement approaches for their context (Zamfir, 2020).[55] In addition, the previously discussed efforts to standardise natural capital accounting methodologies in the private sector will also help mainstream biodiversity into private sector decision making and could include the development of common biodiversity footprint indicators.

In the EU, a number of strengthened policies that aim to increase environmental, including biodiversity considerations in private decision making have been emerging as part of the Green Deal. This includes initiatives under the new circular economy action plan (CEAP) which aims to address environmental impacts associated with production and consumption patterns of the EU. In the CEAP, the Commission commits to updating the monitoring framework including the development of consumption footprints by 2021. The current monitoring framework does not include biodiversity specific

[52] Credit Suisse. Undated. *Op cit.* https://www.credit-suisse.com/media/assets/microsite/docs/responsibleinvesting/unearthing-investor-action-on-biodiversity.pdf

[53] European Commission. 2019. *Assessment of Biodiversity Measurement Approaches for Businesses and Financial Institutions*. https://ec.europa.eu/environment/biodiversity/business/assets/pdf/European_B@B_platform_report_biodiversity_assessment_2019_FINAL_5Dec2019.pdf

[54] Zamfir. I. 2020. *European Parliament Briefing. Towards a mandatory EU system of due diligence for supply chains*. https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659299/EPRS_BRI(2020)659299_EN.pdf

[55] https://ec.europa.eu/environment/biodiversity/business/news/news-277_en.htm

parameters.[56] Consequently, there is a need to include biodiversity footprints to monitor circular economy policies in order to integrate both objectives (Buchmann-Duck *et al.*, 2020).[57]

Biodiversity footprints could also allow for the creation of labelling and certification schemes informing consumers on whether the products they purchase are biodiversity friendly. The CEAP proposes that companies substantiate these 'green claims' using Product and Organisation Environmental Footprint methods. Currently, these methods fall short in integrating biodiversity dimensions (European Commission, 2018).[58,59] Finally, another highly relevant development is under the EU's sustainable finance directive where criteria to define a taxonomy of sustainable investments are being developed. This includes screening criteria to ensure substantial contributions to biodiversity. This move towards better regulatory frameworks for biodiversity-friendly investments is reflected internationally with the launch of a Task Force on Nature-related Financial Disclosures in September 2020.

3.7 Reporting, monitoring and assessing progress on the 2030 Sustainable Development Agenda

There is a strong link between biodiversity and the 2030 agenda for sustainable development.[60] Biodiversity is directly targeted in SDGs 14 (Life below water) and 15 (Life on land) and underpins the delivery of many other SDGs.[61] Footprint methodologies can help achieve these goals, as outlined, and can be used as indicators to track progress towards them. Footprint indicators are especially relevant to SDG 12 aimed at responsible production and consumption and reducing spillovers (Vanham *et al.*, 2019),[62] but potentially relate to many other SDGs, such as SDG 2 (target 2.4 on sustainable food), SDG6 (target 6.4 on water-use efficiency) and SDG 11 (target 11.6 on per capita environmental

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[56] Eurostat. Circular economy indicators.
https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework
[57] Buchmann-Duck, J. and Beazley, K.F. 2020. An urgent call for circular economy advocates to acknowledge its limitations in conserving biodiversity. *Science of the Total Environment* 727: 138602.
https://www.sciencedirect.com/science/article/abs/pii/S0048969720321185
[58] European Commission. 2018. Product environmental footprint category rules guidance Version 6.3. https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf
[59] However, there are overviews of certification and impact studies. See ISEAL's EVIDENSIA platform
[60] Blicharska, M., Smithers, R.J., Mikusiński, G., Rönnbäck, P., Harrison, P.A. *et al.* 2019. Biodiversity's contribution to sustainable development. *Nature Sustainability* 2: 1083-1093.
https://www.nature.com/articles/s41893-019-0417-9?proof=t
[61] Kettunen, M. *et al.* 2021. *Building on Nature: Area-based conservation as a tool for delivering SDGs*. IEEP and partners.
[62] Vanham, D., *et al.* 2019. *Op cit*. https://www.sciencedirect.com/science/article/pii/S0048969719335673

impact of cities). However, the only footprint indicator already part of the SDG indicators proposed by the inter-agency expert group on SDG indicators is the material footprint. Independent reporting of the Global SDG Index by sustainable development solutions network (SDSN) reveals that national monitoring frameworks currently lack adequate monitoring of global impacts of production and consumption. Data on countries' negative and positive spillovers is currently sparse and incomplete. Therefore, there is a need to better integrate consumption-based accounting within SDG monitoring frameworks through footprint indicators.[63]

The SDSN Spillover index confirms that high income countries generate the highest negative spillovers.[64] In Europe, Eurostat recently started exploring options to include footprint indicators for spill-over impacts of EU consumption and production in the EU annual reporting framework for the SDGs.[65] Although they propose related indicators on material and other consumption footprints including water and land footprints, no biodiversity footprints are suggested.[66] The SDG spillover index considers marine and terrestrial biodiversity threats embodied in imports. However, this is based on a single study by Lenzen (2012)[67] which measured the biodiversity impact of international trade of more than 15,000 commodities. Consequently, there is scope for improving the use of biodiversity footprint indicators in monitoring the SDGs.

[63] Sachs, J., Schmidt-Traub, G., Kroll, C., Lafortune, G., Fuller, G., Woelm, F. 2020. *The Sustainable Development Goals and COVID-19. Sustainable Development Report 2020*. Cambridge: Cambridge University Press https://s3.amazonaws.com/sustainabledevelopment.report/2020/2020_sustainable_development_report.pdf
[64] *ibid*
[65] *ibid*
[66] European Commission. 2020. The EU SDG Indicator Set 2020.
https://ec.europa.eu/eurostat/documents/276524/10369740/SDG_indicator_2020.pdf
[67] Lenzen, M., *et al*. 2012. *Op cit*. https://www.nature.com/articles/nature11145

4. "TYPOLOGY" OF FOOTPRINTS: MAPPING AND NAVIGATING THE EXISTING BIODIVERSITY FOOTPRINT LANDSCAPE

Existing footprints can be classified along three key dimensions:

1. Driver of pressure: consumption-based, production-based or trade-based
2. Type of footprint: ecological, biodiversity or ecosystem service
3. Method of analysis: considering purpose, scale and approach.

Biodiversity is a multidimensional concept which needs several different indicators to capture its complexity. No common metric to measure biodiversity impact exists so biodiversity is commonly conceptualised through the choice of indicators within the different footprint types.

To navigate the complexity of the 'footprint' concept, Fang *et al*. (2016)[68] suggest mapping existing footprints onto a typology. Categorising different footprints can help understand the main attributes and approaches. We developed a typology as a tool to explore current uses of biodiversity footprint indicators. This builds on Fang *et al*., adapted to the objectives of the study. It classifies footprints along three key dimensions: driver of pressure, type of footprint and method of analysis (Figure 2).

[68] Fang, K., Song, S., Heijungs, R., de Groot, S., *et al*. 2016. The footprint's fingerprint: on the classification of the footprint family. *Current Opinions on Environmental Sustainability* 23: 54–62. https://www.sciencedirect.com/science/article/abs/pii/S1877343516301063

Figure 2: Biodiversity Footprint typology

Figure 2: Created by authors

4.1 Main focus of the footprint

This dimension classifies footprints according to the driver of pressure associated with the human impact they measure. In their typology, Fang *et al.* (2016)[69] identify two key types of pressures for footprint methodologies: consumption-based and production-based. Building on this, we add a third category: trade based.

- **Consumption-based** approaches measure biodiversity pressures driven by the final consumption of given products. Impacts from the production of goods are therefore measured regardless of where the product or its parts were produced. Through this, the biodiversity impacts linked to the consumption of a given region, country or even individual citizens can be calculated. Many well-known footprint methodologies such as the Global Footprint Network's ecological footprint follow this approach.[70]

- **Production-based** approaches measure the biodiversity pressures driven by a given production process regardless of whether the final products are exported or not. This covers the production of a given good, supply chain or company or the total production of a given country, region or economic sector activity. An important sector to highlight is the financial one. Investors need tools to measure and understand biodiversity pressures associated with financial flows to address their impact on biodiversity and reduce biodiversity-related financial risks (Credit Suisse, 2020).[71] Footprint indicators can therefore inform the environmental dimensions of environmental, social and corporate governance measures for investments. Typically, these indicators are production-based as they measure the impact of certain businesses, economic activities or projects within investor's portfolios.

- **Trade-based** approaches measure the impacts of pressures driven by trade flows. These can be further divided into two categories: trade flows and trade relationships. The trade-flows category refers to approaches measuring aggregated biodiversity impacts driven by global trade (e.g., Lenzen *et al.*, 2012)[72] or trade within a given region or nation. This is the bridge between consumption and production-based national footprint approaches as

[69] Fang, K., *et al.* 2016. *Op cit.* https://www.sciencedirect.com/science/article/abs/pii/S1877343516301063
[70] https://www.footprintnetwork.org/biodiversity/
[71] Credit Suisse. Undated. *Unearthing Investor Action on Biodiversity*. https://www.credit-suisse.com/media/assets/microsite/docs/responsibleinvesting/unearthing-investor-action-on-biodiversity.pdf
[72] Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L. and Geschke, A. 2012. International trade drives biodiversity threats in developing nations. *Nature* 486: 109-112. https://www.nature.com/articles/nature11145

consumption-based approaches include pressures from imported products and ignore those of exported products while production-based footprints exclude pressures from exported products. On the other hand, footprints can be evaluated for a specific bilateral and multilateral trade relationship by measuring the impacts associated with the flow of goods facilitated by a given trade agreement between specific countries.

It is important to note these different categories are not discrete and some footprint methods will fall between them as they combine different approaches. For example, some studies looking at impacts from consumption trace the origin of consumed goods along trade flows (Chaudhary & Kastner, 2016, Moran & Kanemoto, 2017)[73,74] and data from macroeconomic assessments have been used to assess the impacts of individual sectors, companies and products (Moran *et al*., 2015).[75] In fact, consumption-based footprints need information from production-based footprints as they measure the biodiversity impact of consumed products or activities. Consumption-based footprints simply frame these impacts from a final consumption perspective.

4.2 Type of footprint

This dimension refers to the type of biodiversity impact the footprint is measuring. Following from Chapter 2, the three main types of footprints relevant to this study are biodiversity, ecological and ecosystem service footprints. This dimension classifies footprints depending on their conceptualisation of biodiversity impacts.

The choice of biodiversity metrics is one of the most important considerations for biodiversity footprints (Marques *et al*., 2021).[76] Biodiversity is a multidimensional concept which needs several different indicators to capture its complexity (Marques *et al*., 2017). No common metric to measure biodiversity impact exists, so biodiversity needs to be further defined through the choice of indicators within the different footprint types (Vanham *et al*., 2019).

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[73] Chaudhary, A. and Kastner, T. 2016. Land use biodiversity impacts embodied in international food trade. *Global Environmental Change* 38: 195-204.
https://www.sciencedirect.com/science/article/abs/pii/S0959378016300346
[74] Moran, D. and Kanemoto, K. 2017. *Op cit*. https://www.nature.com/articles/s41559-016-0023.
[75] Moran, D., Petersone, M. and Verones, F. 2016. On the suitability of input-output analysis for calculating product-specific biodiversity footprints. *Ecological Indicators* 60: 192-201.
https://www.sciencedirect.com/science/article/abs/pii/S1470160X15003404
[76] Marques, A., *et al*. 2021. *Op cit*. https://link.springer.com/article/10.1007/s11367-020-01846-1

- **Ecological footprints** measure impacts on biodiversity through measuring the virtual land needed for a given good or activity. Land use change is one of the biggest biodiversity pressures so assessing land use impacts will indirectly measure biodiversity impact. Other related footprints measure impact through different pressures such as acidification, climate change and eutrophication (Crenna *et al.*, 2019).[77] These footprints typically use mid-point indicators measuring how given products and activities drive these pressures.

- **Biodiversity footprints** measure impacts on biodiversity by directly calculating the biodiversity loss caused by the pressures driven by a given product or activity. End-point indicators are typically used to link midpoint impacts to the biodiversity loss they cause. To do this, models are used such as phenomenological models, process-based models, and species area relationships which predict biodiversity loss from land use change. A variety of different biodiversity indicators are used to calculate biodiversity footprints. These include alpha type diversity indicators which measure local diversity within a site (e.g., mean species abundance, relative abundance and relative richness), beta type indicators which measure differences in diversity between two communities or ecosystems, and gamma type indicators which measure diversity at a landscape scale (the sum of beta and alpha diversity)(Marquardt et al 2019).[78] The most commonly used biodiversity indicators are potentially disappearing fraction of species (PDF), local biodiversity intactness index (LBII) and mean species abundance (MSA) (Marques *et al.*, 2021).[79][80] Studies tend to focus on vertebrate taxonomic groups for which robust data is available e.g., wild birds (Kitzes *et al.*, 2016),[81] mammals (Di Marco *et al.*, 2018),[82] and mammals, birds, amphibians and

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[77] Crenna, E., Sinkko, T. and Sala, S. 2019. Biodiversity impacts due to food consumption in Europe. *Journal of Cleaner Production* 227 (1): 378-391.
https://www.sciencedirect.com/science/article/pii/S095965261931131X?via%3Dihub

[78] Marquardt, S., Guindon, M., Wilting, H., Steinmann, Z., Sim, S., Kulak, M. and Huijbregts, M., 2019. Consumption-based biodiversity footprints – Do different indicators yield different results? Ecological Indicators 103: 461-470.

[79] Marques, A., *et al*. 2021. *Op cit*. https://link.springer.com/article/10.1007/s11367-020-01846-1

[80] For an evaluation of some of the different existing biodiversity indicators please see Leclère, D., Obersteiner, M., Barrett, M. et al. Bending the curve of terrestrial biodiversity needs an integrated strategy. Nature 585, 551–556 (2020). https://doi.org/10.1038/s41586-020-2705-y

[81] Kitzes, J., Berlow, E., Conlisk, E., Erb, K., Iha, K. *et al*. 2016. Consumption-based conservation targeting: linking biodiversity loss to upstream demand through a global wildlife footprint. *Conservation Letters* 10 (5): 531-538. https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/con4.12321

[82] Di Marco, M., Venter, O., Possingham, H.P. and Watson, J.E.M. 2018. Changes in human footprint drive changes in species extinction risk. *Nature Communications* 9: 4261. https://www.nature.com/articles/s41467-018-07049-5

reptiles (Chaudhary & Kastner, 2016).[83] The impact on invertebrates and plants is often not accounted for. However, there are some exceptions as, for example, the MSA impact database used to derive MSA values includes some plant studies.

- **Ecosystem service footprints** measure impacts on biodiversity by calculating the effects given goods or products have on the provision of the different benefits nature delivers. These services include water regulation, carbon sequestration, pollination, habitat provision, health benefits, recreational values and many others. Whereas biodiversity footprints tend to focus on quantitative assessments of biodiversity loss, ecosystem service footprints assess impacts on human wellbeing of degraded ecosystems, as healthy ecosystems are needed to deliver their full potential benefits.

Again, the 'footprint types' categories are not discrete. Some footprint methods will measure ecological, biodiversity and ecosystem service impacts or combinations of the three. Moreover, these different types rely on each other as biodiversity footprints rely on indicators of biodiversity pressures to calculate biodiversity loss and ecosystem service indicators need information on biodiversity loss to assess impacts on services. Biodiversity is multidimensional and, therefore, a combination of mid-point and end-point indicators are often needed to capture biodiversity impacts. All footprints can in theory be positive or negative; ecosystem footprints are perhaps particularly likely to reveal both states.

4.3 Method of analysis

While the previous two dimensions aim to classify footprints according to their conceptualisations of pressures and impacts, this dimension focuses on the specific characteristics of the method. Three main aspects are considered: purpose, scale and approach.

- **Purpose**: classifies footprints according to their intended application. This includes the different sectors they are applied to and their concrete application within them. For example, footprint indicators can be used to inform decision-making in either the public or private sector. In the public sector this can include uses within policies related to biodiversity, trade and production and consumption. In the private sector, footprint uses include

[83] Chaudhary, A. and Kastner, T. 2016. *Op cit.* https://www.sciencedirect.com/science/article/abs/pii/S0959378016300346

non-financial reporting and disclosure responsibilities and risk mitigation. Within these uses, footprints can have different applications such as impact assessments, monitoring, reporting, and awareness raising. Mapping out current footprint purpose and comparing it to the present and future footprint needs identified in the following section will allow for an assessment of whether ongoing footprint initiatives match their intended uses.

- **Scale**: classifies footprints according to the scale of analysis used when evaluating impacts. This covers different geographical scales including global, regional and local assessments, as well as different entities, activities and communities from companies, specific supply chains and economic sectors, down to specific products and individual consumers. This is relevant to the purpose for which the footprint can be used, as large-scale approaches cannot be used to make small scale decisions, and vice versa.

- **Approach**: Footprint methods have been generally classified into two main approaches: bottom-up and top-down. Bottom-up approaches typically measure the impacts of individual products and then add these up to calculate the total impact. Top-down approaches start with higher-level aggregated impacts typically based on national accounts of input, output and trade, which can then be analysed to determine biodiversity impacts, typically those of nations or regions. Top-down approaches are often based on extended multi-regional input-output analysis (EMRIO) while bottom-up approaches typically use process life cycle assessment (LCA) methods (Crena *et al.*, 2019). EMRIOs are based on environmental extensions of input output models of yearly economic flows across different sectors in a country which link these flows to the global environmental impacts of their associated economic activities. LCA methodologies measure the impact associated with all stages of the production of a given product or activity from the extraction of its raw materials to its disposal. Both methods are well established within the field of industrial ecology and have been widely used to measure the impacts of consumption and production patterns on the environment (Marques *et al.*, 2018).[84] However, few methods currently account for biodiversity (Marques *et al.*, 2021).[85] Although both approaches can be used for any footprint pressure and scale, bottom-up LCA methods are more

[84] Marques, A., Verones, F., Kok, M.T.J., Huijbregts, M.A.J. and Pereira, H.M. 2017. How to quantify biodiversity footprints of consumption? A review of multi-regional input-output analysis and life cycle assessment. *Current Opinion in Environmental Sustainability* 29: 75-81.
https://www.sciencedirect.com/science/article/pii/S1877343518300058#fig0010

[85] Marques, A., *et al.* 2021. *Op cit*. https://link.springer.com/article/10.1007/s11367-020-01846-1

commonly used for consumption or production-based footprints at the product and organisation scale while EMRIOs are more commonly used for national and global trade-based footprints. A new top-down method uses biophysical accounting methods to calculate biodiversity footprints where impacts are based on official statistical datasets on physical trade flows (e.g., FAOSTAT) rather than on economic data or LCA inventory data. This method builds on frameworks such as material flow analysis (MFA) and physical supply use tables (PSUT) which measure the biophysical dimensions of socio-economic activities overcoming some of the limitations associated with MRIO-based calculations of product flows (Bruckner *et al.*, 2019).[86] A good example of such a method is the Food and Agriculture Biomass Input Output Model (FABIO). Bottom-up and top-down approaches are not completely distinct. Hybrid approaches combining both methods exist and are often used when assessing impacts at intermediate scales, such as sectoral footprints, (Boucher *et al.*, 2019).[87]

- **Tier**: Drawing inspiration from the IPCC Guidelines for greenhouse gas (GHG) accounting, accounting for the biodiversity impacts of products and activities can also be distinguished by their different levels of methodological complexity. Broadly, we can think of 'Tier 1' methods as more general top-down methodologies using global data and sector averages to show general patterns. These can be used to scan for and identify potential biodiversity risks and raise awareness and can be applied at larger scales (e.g., sectors and national economies). 'Tier 2' methods could be those which need more specific information on specific supply chains where risk has been identified. These can be used for risk assessment and management and are applied to smaller scales (e.g., company and product level). For these methods, more supply-chain specific and context sensitive information is required. Due to their different complexities and scales, the data needs and subsequent potential uses of these different methodological 'tiers' are quite different.

Almost all footprint analyses currently suffer from lack of data, with criteria and indicators often being chosen more on the basis of the availability of particular kinds of information. Methods are forced to draw on rather large generalisations, rather than what would be ideal in terms of decision-making. In

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[86] Bruckner, M., Wood, R., Moran, D., Kuschnig, N., Wieland, H., Maus, V. and Börner, J. 2019. *Environmental Science and Technology* 53 (19): 11302-11312. DOI: 10.1021/acs.est.9b03554

[87] Boucher, J., Dubois, C. Kounina, A. and Puydarrieux, P. 2019. *Review of plastic footprint methodologies: Laying the foundation for the development of a standardised plastic footprint measurement tool*. IUCN, Gland, Switzerland. https://portals.iucn.org/library/node/48510

the following analysis we consider both what is available now and what might be aspired to in the future given more comprehensive access to information.

5. EXISTING FOOTPRINT METHODOLOGIES AND THEIR APPLICABILITY TO ADDRESS POLICY NEEDS

The existing footprint methods can be divided into the following categories:

- Global data analysis to identify risk to biodiversity and opportunity for mitigation
- Global data analysis to identify footprint
- General footprint frameworks
- Hybrid systems
- Detailed methodologies for single sectors
- Rapid self-assessment systems.

5.1 The range of footprint tools available

As described in Chapter 2, there is still some confusion about what constitutes a footprint, and a plethora of tools and approaches that claim to provide a level of footprint analysis.

This briefing has reviewed over 40 of these tools and approaches (see Table 2) and categorised these against the typology developed above. Through our analysis, data requirements emerged as a key factor to consider - as these often dictate the potential applications, strengths, limitations and future needs of these methods. We evaluated these for the reviewed methods as reflected in our synthesis below.

Although the following analysis is necessarily simplified, the reviewed footprint tools divide broadly into five main groups. The first two groups are **foundational biodiversity data and tools** which support the measurement of biodiversity footprints and can be divided into:

1. **Tools synthesising and analysing data to identify risk to biodiversity and opportunity for mitigation**: Drawing on global datasets to identify levels of risk to biodiversity, mitigation and restoration opportunities and the impacts of alternative development scenarios, for example, IBAT, InVEST, OPAL, STAR, PREDICTS and others. These are not strictly speaking footprint methodologies but can play an important role in helping to

identify footprints and react to threats and pressures that emerge from the analysis.

2. **Methodologies providing data and models to link biodiversity pressures to potential biodiversity impacts**: Drawing on global and regionalised data sets on key biodiversity pressures, global and regionalised biodiversity datasets and a wide range of data from studies to determine the relationships between pressures and biodiversity impacts. These methods and models can then be applied to calculate production-based, consumption-based and trade-based footprints. This includes LCIA methods (e.g., ReCiPe, LC-IMPACT, Impactworld+), which use life cycle inventories and can be applied to different scales (from global to product) and methods such as GLOBIO which have been applied to EEMRIOs to calculate consumption-based footprints at global and regionalised scales.

The rest of the groups are tools that **support the application of biodiversity footprint information into decision-making** and can be divided into:

3. **Tools applying global and regional data analysis to assess footprints**: Combining a range of global datasets to provide an estimate of overall footprint for a product or a region, for example, Co$ting Nature, Bioscope). These methods have the advantage of being quick, accessible, fairly easy to use and provide a broad overview – but inevitably draw on a limited range of indicators (and often do not particularly prioritise biodiversity).
4. **Detailed methodologies for single sectors**: Providing detailed guidance on indicators (and sometimes also sources of information) to build a footprint, for example, the Agrobiodiversity Index and Hortifootprint. Some aim at particular sectors, such as horticulture or cement and aggregates, others at defined ecosystems services or values like water quality and agrobiodiversity. Further footprint methods of this type can be predicted to proliferate in the coming years.
5. **Rapid self-assessment systems**: Contrasting with the generally top-down approaches of many methods relying on global databases, a small number of bottom-up footprint tools have developed, mainly aimed at ecosystem services rather than biodiversity, which use site specific data to calculate impacts. For example, TESSA and the PA-BAT.
6. **Tools outlining general footprint frameworks**: Describing the range of information that needs to be collected but leaving it up to the user to access this, for example, Biological Diversity Protocol, Kering's Environmental Profit and Loss Account. These approaches are useful as background but in effect just describe what is needed for a footprint.

These groups are not a perfect reflection of the purpose and full scope of each of the methods, but they give an indication of the wide variety of potential biodiversity footprint tools that are currently available or being developed. **Many methods interlink**; one approach drawing on one or more of the others. For example, many of the tools in the Natural Capital approaches (InVEST, OPAL etc) interlink as might be expected, while foundational tools such as GLOBIO/IMAGE and ReCIPe are also used by other systems.

5.2 The topology of footprints available

In terms of **"drivers of pressures"** the majority of methods reviewed focused on measuring the impact of production. This reflects the large recent interest from the private sector to measure their impacts on biodiversity in a similar way to what has been achieved for climate change impacts. Moreover, in order to measure the impacts of consumption, the impacts of production have to be understood first. This is reflected by the considerable number of methods which were applied to measure the impacts of both production and consumption (e.g., LC-Impact, ReCiPe, ENCORE). Some methods (e.g., ecological footprint) are explicitly designed for evaluating consumption-based biodiversity footprints but, again, trade and production information is needed to calculate them. Few methods take an explicit trade perspective. However, the biodiversity impact of trade flows was implicitly measured in a methods focusing on production and consumption impacts (e.g., TRASE, BioScope, Biodiversity monitoring system). Trade flows can be used for production-based footprints to understand impacts along supply chains and are needed to calculate consumption-based footprints as they link the impacts associated with goods to the regions where they are consumed. In addition, the type of trade data used varies between different footprint methods as, typically, Tier 1 methods use general global yield averages while Tier 2 methods use specific regional values.

Tools differ in the biodiversity pressures they assess, with the most common being land use and land use change. Several approaches also assess pressures of climate change and aspects of pollution (e.g., nitrogen, phosphorus, eutrophication, freshwater ecotoxicity, acidification). Less widespread pressures evaluated include invasive alien species, water stress, marine plastic pollution and the overexploitation of species. No tool had a perfect overview of all pressures that impact biodiversity as this would be unfeasible. Moreover, measuring each pressure comes with unique challenges and limitations. For example, land use cannot be adequately assessed down to management type level and pollution does not cover all substances. However, initiatives are actively expanding the pressures they consider (e.g., LC-impact is exploring noise pollution and salinisation).

Types of footprints: around half of the reviewed footprint tools were biodiversity footprints (e.g., biodiversity footprint method, biodiversity impact metric), which directly measured impacts on biodiversity. Within this group, there were different approaches regarding what aspects of biodiversity were considered. Two quantitative indicators stand out: mean species abundance (MSA) (e.g., GLOBIO/IMAGE, Global biodiversity score) and potentially disappearing fraction of species (PDF) (the most popularly used biodiversity indicator in LCAs). Both measure intactness of biodiversity by comparing two different ways of considering biodiversity (species abundance or number of species committed to global extinction) before and after human intervention (Marques *et al*., 2017)[88]. Other indicators measuring other facets of biodiversity were used such as the local biodiversity intactness index (e.g., PREDICTS), simple species loss in species/year (e.g., PREDICTS), habitat condition (e.g., BIRS) and some initiatives used their own (e.g., biodiversity impact metric). Indicators such as the biodiversity habitats index have been proposed elsewhere (Marques *et al*., 2021)[89]. All of these indicators attempt to capture biodiversity, a multidimensional and complex concept, into one measure and as such they inevitably come with limitations. For example, none of these measures capture impacts on important aspects of biodiversity such as functional diversity and interactions between species. Moreover, tools have measured indicators using only a subset of taxonomic groups where data is readily available meaning impacts on invertebrate groups associated with specific ecosystem services, such as pollinators and soil biodiversity, are often excluded. Similarly, some ecosystems are better covered than others with significant gaps for marine and freshwater. These limitations are well-recognised in the biodiversity footprint literature. Several avenues to overcome and manage them are being explored.

A number of tools were classified as ecological tools which evaluated impacts through mid-point indicators such as land-use change without explicitly translating this to biodiversity impact. All biodiversity footprint tools also use measures of pressures to evaluate final biodiversity impact. A few ecosystem service tools were also identified. The most commonly assessed services were **regulating services** such as carbon sequestration and storage, control of soil erosion and **provisioning services** such as crop production. Several initiatives also looked at other services such as pollination, soil protection and recreation

[88] Marques, A., Verones, F., Kok, M., Huijbregts, M. and Pereira, H., 2017. How to quantify biodiversity footprints of consumption? A review of multi-regional input–output analysis and life cycle assessment. Current Opinion in Environmental Sustainability 29: 75-81.

[89] Marques, A., Robuchon, M., Hellweg, S. *et al.* 2021. A research perspective towards a more complete biodiversity footprint: a report from the World Biodiversity Forum. International Journal of Life Cycle Assessment 26: 238–243. https://doi.org/10.1007/s11367-020-01846-1.

(e.g., GLOBIO-ES, InVESt). Finally, a handful of methods were applied to assess more than one footprint type showing the strong links between them as they capture different facets of biodiversity.

Approach: Many of the tools used LCA approaches to calculate footprints, taking a bottom-up approach. We note that a lot of work is being done in the LCA expert community to better integrate biodiversity into assessments as biodiversity is still rarely considered (e.g., world biodiversity forum discussion on biodiversity footprints, the GLAM initiative, national initiatives e.g., Germany).[90] Covering and discussing different approaches within these methods is outside the scope of this study (for an overview see Winter *et al*., 2017).[91] However, ongoing work and discussions on common approaches and best practice to include biodiversity in LCAs is vital to the biodiversity footprint question. A number of tools rely on or could be applied to top-down approaches to calculate footprints. The majority of these used economic MRIO data (e.g., GLOBIO/EMRIO) and few used biophysical accounting approaches (e.g., TRASE).

Scales: Methods varied widely in the scales they can and have been applied to. Many use global, national and more regionalised data and could be applied to several scales and some could be applied down to the product level. It is important to understand the different implications, data needs and limitations of analysing impacts at different scales. Moreover, some methods are designed for or are most effective at specific scales (e.g., EEMRIO based footprints work well at the sectoral level and LCAs typically have well-defined boundaries).

Purpose and use: is outlined in more detail in the tables. In section 7, we apply this information to consider how they can respond to the identified global and EU footprint needs.

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[90] https://www.ibp.fraunhofer.de/en/projects-references/biodiversity.html

[91] Winter, L., Lehmann, A., Finogenova, N. and Finkbeiner, M. 2017. Including biodiversity in life cycle assessment – State of the art, gaps and research needs. *Environmental Impact Assessment Review* 67: 88–100. doi:10.1016/j.eiar.2017.08.006

Table 2: Summary of some significant footprint methodologies

Footprint initiative	Organisation	Pressure	Type of footprint	Purpose/ use	Data required
Agrobiodivesity index	Biodiversity International	Production based	Biodiversity, albeit of only one aspect	Policy and business levers, good practices and improvements, risks and opportunities, for agrobiodiversity	
ARIES	IPBES	Production or consumption	Ecosystem services	Open-source technology capable to select and run models to quantify and map all aspects of ecosystem services.	Data are provided with the tools. Already applicable but still being developed.
Aqueduct tools to assess water risk	World Resources Institute	Production, consumption, trade flows	Ecological	To provide free and accessible information on key aspects of water use and risk	Data are provided with the tools
Benchmark for Nature frameworks	Interdisciplinary Centre for Conservation Science			(1) assessing impacts of investments (2) drafting Preliminary Standard for Nature-related Financial Disclosures,	*System in preparation*
Biodiversity Footprint	Lenzen at al 2012	Trade-based (global)	Biodiversity	Academic study	
Biodiversity Footprint Financial Institutions (BFFI)	ASN Bank (NL)	Value chain of investments of the bank	Biodiversity	Establishing insights into biodiversity impacts of the investments of ASN Bank	Quantitative analysis using the Bioscope database, plus qualitative analysis
Biodiversity Footprint method and calculator	Plansup, Wageningen ER (Alterra), PBL, CREM and JSScience	Production-, along supply chains	Biodiversity	Private sector assessment to measure biodiversity footprint	Data from companies in production chain, peer literature on cause-effect, MSA values from GLOBIO3, etc
Biodiversity Impact Metric	CISL. Natural Capital Impact Group at the U. of Cambridge		Biodiversity	To assess the impact of a particular business on the natural world	1) commodity type; 2) sourcing country; and 3) quantity purchased at minimum
Biodiversity Indicator and Reporting System (BIRS)	IUCN	Production	Biodiversity footprint	To guide companies in the cement and aggregates sector in monitoring biodiversity at their operations	Habitat area and condition, Site Biodiversity Condition Class

Footprint initiative	Organisation	Pressure	Type of footprint	Purpose/ use	Data required
Biodiversity Indicators for Extractives	UNEP WCMC, CI and FFI	Production	Biodiversity	So far initial guidance has been produced, the system is under development	
Biodiversity Monitoring System	Elaborated within the EU LIFE Initiative	Production-based, along supply chains	Ecological	Allows standards and food companies to monitor the biodiversity performance of certified farms	25 indicators covering agricultural issues, Biodiversity Action Plan
Biodiversity Performance Tool for the Food sector	Lake Constance Foundation, Germany	Production (on farms)	Biodiversity	Improvement and implementation of Biodiversity Action Plans on farms	
Biological Diversity Protocol	Biodiversity Disclosure Project of Endangered Wildlife Trust	Production	Biodiversity	Guidance on inventory and reporting	The BDP provides a framework, precise data requirements need to be developed by companies
Bioscope	Platform BEE, PRé Sustainability, Arcadis and CODE	Production, consumption, trade flows	Ecological	To calculate where an industry is having most impact, covering 170 commodities and 43 countries	Habitat area and condition, Site Biodiversity Condition Class
Cool Farm Tool	Cool Farm Alliance	Production	Biodiversity Ecosystem services	To calculate the impacts of an individual farm on greenhouse gases, biodiversity and water	Crop, livestock, biodiversity and water data
Co$ting Nature	Kings College, Ambiotek and UNEP-WCMC		Ecosystem service	Providing assessment of ecosystem services, global database applied through filters (PAs, KBAs, etc)	Uses global datasets
Ecological footprint	Global footprint network	Consumption	Ecological	"to help end ecological overshoot by making ecological limits central to decision-making".	National Footprint and Biocapacity Accounts based on UN or affiliated data sets.
Ex-ACT tool project – biodiversity indicator B-Intact	FAO & AFD	Production	Biodiversity for Agric., Forestry & Other Land Use	Quantify the biodiversity impact of various investments at project and policy-level.	Biodiversity quantified by MSAc. Non-quantifiable impacts assessed with a qualitative appraisal.

Footprint initiative	Organisation	Pressure	Type of footprint	Purpose/ use	Data required
Exploring natural capital opportunities risks and exposure (ENCORE)	UNEP	Production, consumption, trade flows	Biodiversity, ecological, ecosystem service	Finance	Online tool drawing on existing databases
Financial disclosures reporting frameworks	Task Force on Nature related financial disclosures	Production, consumption, trade flows			*Informal working group still developing this approach*
Global Biodiversity Model for Policy Support (GLOBIO)	PBL Netherlands Environmental Assessment Agency	Production and consumption	Biodiversity (GLOBIO) & ecosystem service (GLOBIO-ES)	Can be used to quantify ecosystem services, impacts of humans on biodiversity and ES, calculating global biodiversity impacts, etc	Data on land use patterns, road maps, GHG emissions, nitrogen deposition, hunter access points, pressure-impact relationships, GLOBIO species
Global Biodiversity Score	CDC Biodiversité and Mission Économie de la Biodiversité	Production (company)	Biodiversity	The GLOBIO/IMAGE model is a worldwide biodiversity impact calculation model developed for scenario analyses to inform the CBD convention. The GLOBIO/EMRIO Biodiversity Model is based on GLOBIO information to make a supply-chain and footprint analysis to assess the impact of a particular business on biodiversity.	Observed species and expected species for that ecosystem, along with the area being converted
Global Life Cycle Impact Assessment Method (GLAM)	UNEP	Consumption bottom-up, production by LCA	Biodiversity, ecosystem services	To create a consistent and global environmental life cycle IA method	Species specific data to calculate extinction probabilities, inventory data on location land use intensity and management practices
Hortifootprint tool	Wageningen University	Production (horticultural products)	Ecological	Food sector.	
IBAT	IUCN, Birdlife Int., UNEP WCMC & Conservation Int.	Production based; trade based	Biodiversity	To identify level of risk to biodiversity at a site scale.	Draws from: (1) IUCN Red List of Ecosystems; (2) WDPA; (3) WDKBA.

Footprint initiative	Organisation	Pressure	Type of footprint	Purpose/ use	Data required
Impact World +	CIRAIG, EPFL, DTU, Poly. Montréal, Ann Arbor Michigan etc	Production (LCA), consumption	Biodiversity, ecosystem service	Supports LCAI part of LCA. Can be used for decision-making.	Inventory data of emissions and extractions, water consumption, land use data from FAO map, etc.
Kering's Environmental Profit & Loss Approach	Kering's	Value chain	Ecological	Designed to measure the company's own impacts; made available for use by other similar companies.	Requires both primary and secondary data on all major components.
InVEST	Natural Capital Project		Ecosystem service	Enables decision makers to assess quantified trade-offs associated with alternative management choices.	Draws on existing databases. A mapping software such as QGIS or ArcGIS is needed to view results.
LC-IMPACT methodology: Development and application of environmental Life Cycle Impact assessment Methods for imProved sustAinability Characterisation of Technologies	LC Impact / ETH Zurich. Part of the EU FP7 project in collaboration with 14 partners.	Production	Biological footprint	LCIA methodology quantifying impacts from LC inventories. Used for preventing, reducing and remediating potential negative environmental impacts of products and activities	Inventory data for the different pressures e.g. emissions. Occupation and transformation of all terrestrical ecoregions. Existing data from literature to calculate effect factors e.g. species sensitivity to chemicals. Vulnerability factor based on red list status and species range data. Information on the current state if using marginal characterisation factors.
Local Environmental Footprint Tool (LEFT)	University of Oxford	Production based; trade based	Ecological	Assembles relevant environmental data from global databases and produces a map of ecological risk.	Draws on existing data
LIFE Key	LIFE Institute, Brazil	Production	Ecological and ecosystem services	Measures positive and negative business impacts, strategic reporting of environmental performance.	

Footprint initiative	Organisation	Pressure	Type of footprint	Purpose/ use	Data required
NatCap Map	Natural Capital Research Ltd.	Production	Natural capital assets, ecosystem service, biodiversity	Enables landowners and corporates to map natural capital provided by landholdings at fine spatial scale (5-25m), including carbon storage and sequestration, soil erosion protection, flood risk management, biodiversity, water quality and recreation. Allows repeat measurements and monitoring through time.	Draws on existing data, updated regularly. Currently only used in mainland GB but whole of EU in next 6-8 months and global by end of 2022.
Offset Portfolio analyzer and locator software tool (OPAL)	Natural Capital Project	Production	Ecological Ecosystem services	Identifies mitigation options that can restore ecosystem service benefits and meet mitigation targets.	Widely available ecological and social data along with data from InVEST.
Potential species loss from land and water use	LC Impact / ETH Zurich			A method for quantifying global species extinctions from land use	
Product Biodiversity Footprint	I Care & Consult - Sayari (France)	Product based	Biodiversity	Impact of different products on biodiversity, through LCA focusing on areas of biodiversity importance	
Projecting Responses of Ecological Diversity In Changing Terrestrial Systems (PREDICTS)	Natural History Museum London, UNEP-WCMC, and UK universities	Production	Biodiversity	Predicting biodiversity losses across space and time. Outputs used for decision-making, scenario analysis for regional assessments, policy reports	Raw data from studies across a broad range on taxa and countries to understand responses to human pressures
Protected area benefits assessment tool (PA-BAT+)	WWF	Production and consumption	Biodiversity and ecosystem services	Bottom-up methodology, working with stakeholders to identify ecosystem services (including nature conservation benefits) from protected and conserved areas.	Data provided by stakeholders on site.
ReCiPe methodology	RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability	Production (LCA) and consumption	Biodiversity	Supports LCIA parts of LCAs. Can be used to support tools looking at biodiversity footprints of supply chains e.g., BioScope	Scientific literature to inform cause-effect pathway models, life-cycle inventory data, data on mid-point indicators.

Footprint initiative	Organisation	Pressure	Type of footprint	Purpose/ use	Data required
Restoration Opps. Assessment Methodology (ROAM)	IUCN and World Resources Institute		Ecosystem service (carbon)	(1) priority areas; (2) interventions; (3) costs and benefits; (4) extra C seq.; (5) finance and investment; (6) "restoration readiness"	Many indicators covering physical and ecological: social and economic: policy, legal and institutional issues:
Restoration Opportunities Optimization Tool (ROOT)	IUCN and the Natural Capital Project		Ecosystem services	To optimise trade-offs among different ecosystem services to help decision-makers visualise best investments in restoration	
Species Threat Abatement and Recovery Metric (STAR)	IUCN	Production, consumption, trade flows	Biodiversity	Put Red List data into a standardised form to measure the potential contribution of conservation actions to any conservation target	Draws data directly from the Red List
Toolkit for Ecosystem Service Site-based assessments (TESSA)	UNEP WCMC, BirdLife International, etc		Ecosystem services	Rapid, low-cost, participatory valuation tool used to assess ecosystem services.	
Transparency for Sustainable Economics (TRASE) Earth tool	SEI and global canopy, with multiple partners	Production, consumption, trade flows - supply chains	Biodiversity, ecological	Following trade flows to identify sourcing regions, profile supply chain risks and assess opportunities for sustainable production.	

6. DATA AVAILABILITY AND INFRASTRUCTURE UNDERPINNING FOOTPRINTS

6.1 Overview of data availability

Data availability underpins all footprint methodologies. The accessibility to relevant data has increased dramatically in the last two decades, due both to increased sophistication of satellite imagery and greater effort to assemble information, particularly on topics such as biodiversity, carbon, water flows and vegetation change. Those working close to data sources are often most keenly aware of the remaining gaps, and there is certainly an urgent need for more data, but there is already enough information available globally to make meaningful analyses of biodiversity change, ecosystem change and many of the most important ecosystem services.

National and regional biodiversity data sources are usually more accurate, fine grained, and comprehensive than global data sources, but because footprint methods usually need to capture impacts at global or at least transboundary scales, they tend to have to rely on standardised global data sets.

Some important global information sources particularly relevant to biodiversity footprint include:

- **Red Lists of Species**: global coverage already for mammals, birds and amphibians. National coverage, of varying quality, for many other groups. This is a core data set for biodiversity footprints and is discussed in section 6.2 below.

- **Key Biodiversity Areas**: now mapped globally, although coverage changes between countries. Global data are available for birds but not for most other species, and while ecosystems with high biodiversity tend to have high bird diversity the relationship is not exact and becomes much less so in disturbed and culturally influenced ecosystems.

- **World Database of Protected and Conserved Areas**: global coverage, inaccuracies remain at national level in some cases and data are incomplete, but this remains a powerful and generally accurate, spatially defined tool.

- **Vegetation change mapping**: mapped by both international and NGO bodies, principally FAO, International Livestock Research Institute (produced an atlas of rangelands in May 2021)[92], Global Forest Watch and others.

For more details, see Table 4 following. It should be noted that some footprint methods are being much more thorough and innovative in their approach, including analysis of connectivity for example, drawing on data from the European Pesticides Action Network, and other sources.

Most footprint methods draw on **satellite imagery**, for example in tracking forest loss or locating protected and conserved areas, Key Biodiversity Areas and other important sites, drawing on global datasets set as Protected Planet, Aqueduct and Global Forest Watch. However, satellite imagery is still little used to identify and track more subtle changes to the condition of habitats and ecosystems or the location of species. GIS specialists still struggle to represent subtle changes accurately, e.g., changes in condition of grassland and savannah, decline in tree health, or tracking cetacean migration

Better coverage of land use data is needed and a better understanding of links between particular pressures and biodiversity change. Choice of indicators to be included in footprints is important, in that it influences the type of data required. From a practical perspective choice of indicators that are relatively easy to measure will help the rate of take-up, as long as these still tell a coherent story about impacts and rate of change.

Data sources will be improved by additional use of natural capital accounting. The EU already has some standardised, EU wide datasets on biodiversity, including the Farmland Bird Index, Grassland Butterfly Index, etc. Additionally, far more data, and therefore stronger footprint analyses, are available whenever a product or production unit goes through a certification system and encouragement of voluntary certification schemes is a clear option for improving the accuracy of footprint analyses.

6.2 Changes in data availability

Red List: Many of the systems analysed here rely to some extent or another on the IUCN Red List of Species, which remains incomplete, although IUCN claims it already has enough information to give useful information in most cases. There is comprehensive global coverage of mammals, birds and amphibians. European

[92]https://www.rangelandsdata.org/atlas/sites/default/files/2021-06/Rangelands_web%20%28144%20dpi%29.pdf

Red List data is also strong across many taxonomic groups, and data collection has been well supported in the past by the EU. Further developments needed, with estimated time required, are as follows:[93]

- **Reptiles**: global reptile coverage should be ready by September 2021.
- **Marine**: work is ongoing about what general conclusions can be drawn from data from groups already well represented, some fish (e.g., sharks), corals, marine cetaceans and seabirds. Spatial resolution remains a challenge although high spatial resolution is not needed for a proportion of marine pressures.
- **Freshwater**: IUCN is close to having a global dataset for all freshwater fish.
- **Plants**: work is ongoing. It is hoped to have a global assessment for the 60,000 trees within the next four years.
- **National Red Lists:** are available for many places but far from complete and sometimes within geographical data on range, which makes them of little use for global footprint analysis. Good national Red Lists that for instance include data on plants exist for China, South Africa, and Brazil.

There is an urgent need for greater coverage of invertebrates, particularly butterflies where there may be enough information already collected (but not assembled) to make a meaningful assessment, and for geographically specific national Red Lists for high biodiversity countries where these are currently missing.

There is also a Red List of Ecosystems, which when finished will be a valuable tool for footprints and much more besides, but this project is still many years from completion.

Key Biodiversity Areas: Country-level studies are being completed gradually (Turkey, Iraq) but there needs to be a focus on completion for countries with high biodiversity and rapid rates of vegetation change.

[93] Estimates from IUCN

Table 3: Some important global data sources for footprint analysis

Information source	Origin	Details	Link
Biodiversity			
Global Red List of Species	IUCN	Global database of species categories according to degree of extinction threat, there are currently over 128,500 species on The IUCN Red List, with more than 35,500 **threatened with extinction**	https://www.iucnredlist.org/
National Red Lists of Species	Zoological Society for London runs a database	Single source for all national and regional Red Lists, covering a huge range of material. Usefulness varies, those lists without range data are far less valuable for footprint exercises.	https://www.nationalredlist.org/
Global Red List of Ecosystems	IUCN	Aims to provide complete assessment of ecosystems, similar to the RL for species, still under development. Of limited applicability in the near future.	https://iucnrle.org/
Global Biodiversity Information Facility	GBIF	Global data-sharing facility on when and where species have been recorded, drawing on everything from museum	https://www.gbif.org/

Information source	Origin	Details	Link
		collections to geotagged smartphone photos	
Protected Planet: Protected area coverage	UNEP World Conservation Monitoring Centre	Online, regularly updated database and maps including name, location, area, IUCN management category and other data	https://www.protectedplanet.net/en
Key Biodiversity Areas	Consortium of NGOs, and the Global Environmental Facility	Areas identified through a standardised methodology as the most important for the survival of the world's biodiversity. Comprehensive for birds, less so for other animals and for plant	http://www.keybiodiversityareas.org/
Biodiversity Indicators Partnership	UNEP-WCMC	BIP promotes and coordinates the development and delivery of biodiversity indicators for use by the Convention on Biological Diversity and other biodiversity-related conventions, IPBES, the SDGs etc.	https://www.bipindicators.net/about
Ecosystem services			

Information source	Origin	Details	Link
Ecosystem Services Valuation Database	Ecosystem Services Partnership	Contains over 600 studies and more than 4000 value records distributed across all biomes, services and geographic regions.	https://www.es-partnership.org/esvd/
Global Forest Watch	Originally established by the World Resources Institute, many partners	Over 100 data sets, global and regional maps of forest cover and changes in forest cover	https://www.globalforestwatch.org/
Global Safety Net	RESOLVE and others	Maps a variety of layers including terrestrial protected areas, rare species sites, high biodiversity areas, intact wilderness, climate stabilisation areas, potential corridors etc., on a global scale	https://www.globalsafetynet.app/viewer/
Trade flows			
Exiobase	NTNU, TNO, SERI, Universiteit Leiden, WU, and 2.-0 LCA Consultants	A global, detailed Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT). It was developed by harmonizing and detailing supply-use tables for a large number of countries, estimating emissions and resource extractions by industry.	https://www.exiobase.eu/index.php

7. CONCLUSIONS AND RECOMMENDATIONS

Although much work remains to be done in terms of both improving footprint methodologies and building data, there are already enough tools and information to make a meaningful start at tracing a company's or nation's footprint and thus driving more sustainable policies. In the following conclusions and recommendations, we necessarily focus on what still needs to be done, but this should not give the impression that results from current approaches are meaningless or inaccurate.

So far there is no single tool that fits the needs of the EU exactly. Nor is there likely to be, because the EU has multiple needs from biodiversity footprints, and these necessarily require different approaches. We have however identified some of the most promising options. Different metrics illustrate different aspects of biodiversity so that this variety is not necessarily a negative thing. Table 2 starts to match existing tools with identified needs, but further work will be required to refine this.

Many actors are working in this field and approaches are developing fast; things will change substantially during the period of the Green New Deal and the EU may have to remain flexible in its approach to monitoring. Those involved in footprint analysis are typically enthusiastic about their own tools and it has sometimes proved difficult to pin down the precise opportunities and limitations provided by particular footprint methodologies.

In particular, the range of options open for monitoring from satellite imagery are likely to expand greatly in the next few years, as are the possibilities for use of automatic monitoring tools and the inclusion of citizen science and traditional ecological knowledge (TEK) into monitoring systems.

It is also noticeable in our conversations with experts, that a proportion of the tools described in Table 3 have not been developed explicitly with the footprint approach in mind, but rather with a more general monitoring or analytic function. Some short-term work is needed to improve the fit of these to the needs of a biodiversity footprint.

7.1 Key shortcomings hindering wider uptake

Many of the commercial footprint tools are rather simplistic and will only provide limited information, at least to the level required by the EU, although they may be useful for raising awareness. Others, including some of the better-known footprint approaches, rely on global data sets that will not usually show up meaningful changes on a site or even a national scale; whilst theoretically useful they will be difficult to put into action in the medium term.

As biodiversity impacts are highly geographically variable, accurate applications of biodiversity footprints at the level of specific companies or products must be spatially explicit. This can be challenging as it relies on site-level data that may be missing, or only obtainable through individual and expensive surveys. Several footprint methodologies rely on global datasets, such as the Red List of Species, which may not be sufficiently spatially explicit and may need to be supplemented with field verifications (Lammerant, 2021).[94] Clearly, the degree and quality of spatially explicit data needed to calculate biodiversity footprints depends on its intended purpose and on the scale its applied to. Therefore, data gaps and opportunities for improvement regarding spatialisation should be assessed for different footprint uses.

Furthermore, some limitations exist regarding the indicators used in certain methodologies to capture impacts on biodiversity. Most indicators measure changes in biodiversity intactness or status by looking at species abundance, richness, or extinction risk (e.g. PDF, MSA) (Mace et al 2018)[95]. Focusing on the number of species is not a wholly accurate measure of biodiversity importance. Ecosystem disturbance due to human interference can, not infrequently, lead to an increase in the number of species – with an influx of weed or generalist species, while losing less common species that are tied to a particular set of ecological conditions. Some measures, such as MSA, account for this to some extent by taking species composition before human intervention as a baseline for abundance (Alkemande et al, 2009)[96]. Despite this, important dimensions of biodiversity are still overlooked by the indicators used at present such as functional and genetic diversity. In other words, by focusing on species richness, the loss of rare species with important ecosystem functions is not captured. As a

[94] Lammerant, J. (2021) Assessment of Biodiversity measurement approaches for businesses and financial institutions. Updated report 3. EU Business @ Biodiversity Platform. Available at: https://ec.europa.eu/environment/biodiversity/business/assets/pdf/EU%20B@B%20Platform%20Update%20Report%203_FINAL_1March2021.pdf

[95] Mace, G.M., Barrett, M., Burgess, N.D. et al. Aiming higher to bend the curve of biodiversity loss. Nat Sustain 1, 448–451 (2018). https://doi.org/10.1038/s41893-018-0130-0

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

result, some researchers are suggesting a move from abundance-based to functional-based species indicators Ricotta et al. 2020).[97]

Ultimately, no single indicator will be able to capture all the different facets of biodiversity, or claims to do so, and a set of complementary indicators is needed. This is reflected in the CBD framework where 5 different indicator categories are identified to monitor progress to global biodiversity targets. Existing indicator metrics used in biodiversity footprints consider different categories of the CBD biodiversity indicators list. By combining different indicators, all of these can be represented (Netherlands Environmental Assessment Agency, 2010; Mace et al., 2018)[98][99].

Lack of data, particularly on trends in species, is currently probably a larger challenge than lack of approaches, although not to the extent of preventing footprint analysis. All or almost all systems rely heavily on the IUCN Red List, which has weaknesses in terms of both lack of data on the large majority of the world's species and challenges in keeping information updated. National Red Lists are far more useful, particularly for lesser-known species, but are only very sporadically available, do not always provide details of the species' range, and are often not available for those countries richest in biodiversity and most under pressure. And they are not necessarily comparable because they use different approaches and standards.

In particular, Red List data are strongest for mammals, birds and amphibians, and most footprint systems confine analysis to these groups. These groups tend to receive the most attention from conservationists but are not necessarily the most sensitive indicators of change, as they respond at larger scales and over longer time periods than invertebrates and plants. MSA for birds will not necessarily be equivalent to MSA for Lepidoptera.

This also provides the EU with some clear policy directions, both for coordinated research and data collection and by providing a framework to increase knowledge. These issues are examined in greater detail in the final section below.

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[97] Ricotta, C., Acosta, A.T.R., Caccianga, M., Cerabolini, B.E.L., Godfried, S. & Carboni, M. 2020. From abundance-based to functional-based indicator species. Ecological Indicators 118: 106761.

[98] Netherlands Environmental Assessment Agency (2010) Rethinking Global Biodiversity Strategies: Exploring structural changes in production and consumption to reduce biodiversity loss.

[99] Mace, G.M., Barrett, M., Burgess, N.D. et al. Aiming higher to bend the curve of biodiversity loss. Nat Sustain 1, 448–451 (2018). https://doi.org/10.1038/s41893-018-0130-0.

7.2 Which of the existing tools are likely to be useful to address policy needs?

There is no single tool that completely fits all the EU – and wider global – needs identified in Chapter 3. In part this is because of the limitations in footprint methods and partly because of the inherent complications in measuring biodiversity impact.

With respect to the latter, measuring biodiversity footprint is inherently difficult because it is *location specific*. Some of the most important ecosystem services have generalised, global impacts. e.g., a tonne of carbon emitted in China has roughly the same effect on greenhouse gas emissions as a tonne of carbon in Germany, so every tonne of carbon emitted is equally important. But clearing a forest in one place might have negligible biodiversity impacts, while in an area with many endemic species, such as Western Australia or Cape Province South Africa, it could result in several species extinctions. This means that coarse filters, such as "area of natural vegetation cleared", will be relatively meaningless without an understanding of the existing biodiversity and pressures.

Identifying useful footprint methods also depends to a large extent on what the tool is being used for. In Table 4 below, some of the existing methodologies are matched against the six needs identified in chapter 3 above.

Table 4: Matching footprint tools to needs

Policy needs	Available tools
Informing biodiversity targets	Several tools could inform biodiversity targets by identifying hotspots for action (both in terms of pressure and biodiversity) and some compare management and policy scenarios. A tool to highlight is the STAR system, recently developed to quantify contributions of actions in particular regions to the post-2020 biodiversity framework. It identifies roles of a variety of actors, which could strengthen multi-stakeholder action. STAR also identifies restoration potential, which fits the EU restoration target and aspects of both the SDGs and CBD Biodiversity Framework. Tools identifying areas with vulnerable biodiversity will be aided by tools identifying high biodiversity areas such as IBAT.
Advancing conservation by mainstreaming biodiversity into sectoral policies for land- and	Some more specialised approaches can help here, which focus on particular issues, commodities or

Policy needs	Available tools
resource use	sectors. The agricultural sector is especially important. The Biodiversity performance tool (which can be used with the Agrobiodiversity index) will be useful here. Tools vary in their assessment scale, often looking at the farm level (e.g., CoolFarm) or supply chains for specific products using LCAs or trade data (e.g., TRASE). Some initiatives (e.g., AKRIBI in Germany) also look at the regional level. Sector specific tools include Aqueduct to assess water risk, BIRS for cement and aggregates, and others being developed for the extractive sector. Methods such as Bioscope, and others that aggregate impacts from companies and products at the sectoral scale, are useful. All these can help mainstream biodiversity by identifying priority areas, creating standards for good biodiversity management and monitoring (e.g., BPT). Other tools such as InVEST can enable national decision-makers to compare different options. Tools that can be applied to MRIO and other sector-disaggregated data can identify hotspots and provide overviews of the biodiversity impact of sectors. It is noted that although some methods can help inform policies and identify priorities, such as GLOBIO/IMAGE which can be linked to the IMAGE model to assess the effectiveness of large-scale policy options, they have not been designed to provide the level of detail needed for many decisions.
Identifying and addressing countries' biodiversity impacts	A number of tools have already been applied to assess the biodiversity impact created by different countries' consumption. Another promising advance is the exploration of how to adapt STAR values to reflect countries' total biodiversity impact, including consumption. However, it is important to consider how exactly biodiversity is being conceptualised and what pressures are assessed. No one tool can be recommended to capture countries' total biodiversity impacts at this stage. Different tools suit different purposes and as biodiversity is a multifaceted concept, a suite of approaches might be best. All tools with a consumption-focus can inform impacts beyond countries' borders including those tools that focus on specific commodities, sectors or activities.

Policy needs	Available tools
Mainstreaming biodiversity into trade policies with direct global impacts	Tools like TRASE and those applied to EEMRIOs were identified which directly measure impact along trade flows. Many tools rely on trade data and could therefore be applied to understand the impacts of total trade in a region and to identify hotspots. Methods that use life cycle inventory databases and integrate biodiversity into existing LCA analyses are useful to provide increased granularity and understanding on the impacts of specific goods. Hybrid approaches combining information from MRIO and LCAs could be explored. Although, to our knowledge, no method identified has been used to assess the biodiversity impacts of a specific trade relationship, methods that can be used to assess biodiversity impacts from EEMRIOs and other trade data could be developed to fit this need.
Mainstreaming biodiversity into financial and private sector policies	For private sector policies, LCA methodologies that integrate biodiversity are most relevant. Methodologies allowing for the measurement of impacts of specific sectors, products and organisations (including farms), as discussed under the mainstreaming need, will help identify priority areas to improve biodiversity performance. Furthermore, some of these methodologies can be further developed for monitoring, reporting and disclosing the biodiversity impacts of organisations and products. Several tools are explicitly aimed at the financial sector, including those for banks, such as BFFI, ENCORE and, once it is developed, the Financial disclosures reporting frameworks. Tools such as STAR can be helpful in communicating to the the private sector, to show their contributions to biodiversity goals, as has been done for the Paris Agreement.
Reporting, monitoring and assessing progress on the wider 2030 Sustainable Development Agenda	Such a wide remit virtually ensures that a range of tools will be needed. Therefore, a large number of the analysed methodologies could help inform progress to relevant SDGs in different ways. Exploring this further is necessary. Natural Capital accounting (e.g., the NatCap methodology) will be important here. In addition, some of the identified methodologies simultaneously look at impacts on other SDG relevant areas like resource availability

Policy needs	Available tools
	and human health which can help strengthen synergies.

It should be stressed that many methods remain under development and options will develop quickly. Some standard way of measuring biodiversity change – such as Mean Species Abundance MSA and the Potentially Disappearing Fraction (PDF) are constantly being updated and improved. It is likely that they will be further developed over time, and for instance distinguish more land-use type categories. Simultaneously, other types of biodiversity indicators will emerge on other aspects of the biodiversity concept. For the near future, it is relevant to take the IPBES values assessment into account, where different perspectives on the values of biodiversity are distinguished.

Recommendations and next steps

The lack of a single tool, and the inherent complications in measuring biodiversity impacts, means that measuring a biodiversity footprint is necessarily at least a two-stage process, usually three, even when analysis has identified the areas being impacted by a given company, commodity or trade flow. A suggested process is outlined in Figure 3.

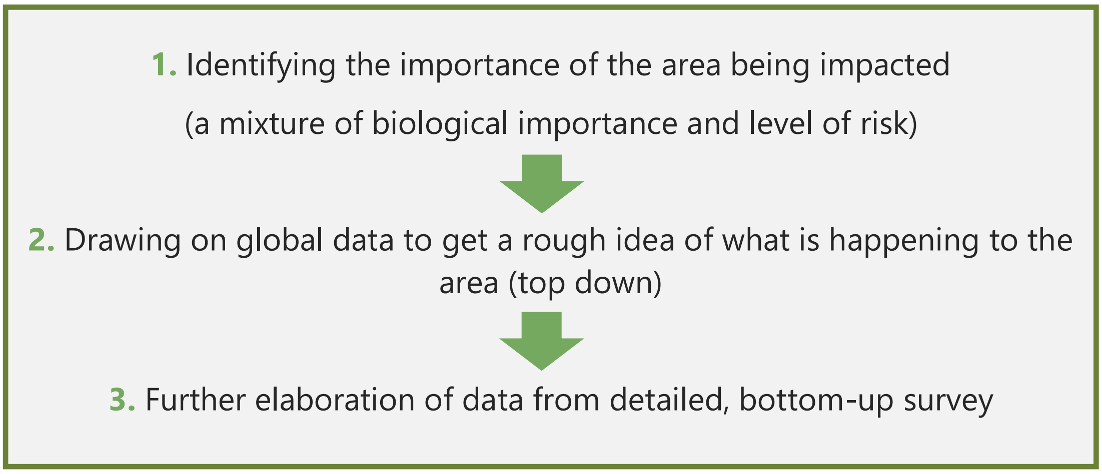

Figure 3: Stages in development of a biodiversity footprint

Figure 3: Created by author

There are increasingly sophisticated tools and databases available to measure level of importance and risk, and increasingly for measuring the options for mitigation and potential for recovery. It is still more difficult to get an accurate picture of the impacts of a process on biodiversity in the immediate or medium term. In other words, step 1 is increasingly well covered, step 2 can be done to some extent, step 3 still needs groundwork and also some methodological development (standardisation etc).

7.2.1 Footprint methodologies

A number of staged processes could help increase the strength of footprint analysis within the EU:

- **A clear and agreed definition of a biodiversity footprint**, with additional emphasis on what such a footprint is supposed to reflect (i.e., the main indicators). At the moment many footprint methods necessarily focus on information currently available, the EU has the opportunity to say now what information *should* be available.

- **Agreement on the level of detail required** within EU footprint methodologies. In terms of the stages laid out in figure 3, is this required at site level (suggesting some kind of in-depth life-cycle analysis) or at a more general level likely to be served with global or national-scale data? Deciding on a minimum set of indicators – those as aspects of both pressures on biodiversity and biodiversity status that are essential for the EU to feel comfortable about assessing progress towards its targets – will be an important stage in this process.

- **Further examination of available footprint tools** in light of these decisions, ideally in a workshop format with key players so that strengths and weaknesses of different tools can be examined and compared, and tools aimed at particular EU needs. It is important to be transparent about both the strengths and the limitations of tools available and under development.

- **If necessary, further development of footprint approaches**: if it is found that existing tools do not match with all the EU needs.

Several of the experts interviewed in the study stressed the need for more standardisation of approaches, along with sharing and transparency regarding data and this is an area where the EU could play a positive role in both establishing a framework and encouraging collaborative approaches.

7.2.2 Underpinning data sources and infrastructure

As noted in section 8, the usefulness of any of the footprint methods will currently be hampered by lack of data, particularly in tropical countries where this analysis is particularly needed. The EU therefore needs simultaneously to identify a useful portfolio of methods and also act to support data collection. This is politically challenging because biodiversity monitoring is often the first casualty of any budget cuts in both government conservation divisions and academia. There are, nonetheless, ways in which the EU and member states can help to address this:

1. Support development of Red List data in data-poor, high biodiversity countries, including national Red Lists and focusing on invertebrate and lower plant groups.
2. Support data collection from citizen science sources, as providing a cost-effective way of collecting such information. Increasing work is being done on the role and opportunities of citizen science and ways in which this approach can be strengthened.[100]
3. Work with partners to help coordinate the transfer of existing data to the Red List and the Global Biodiversity Information Facility (GBIF).
4. Use EU funding to increase member states' capacity for biodiversity data collection and release for public use.
5. Support further research on automatic data collection options, such as camera traps, audio-analysis
6. Support further research on satellite monitoring as applied to vegetation analysis
7. Supporting work on the optimum units of measurement for biodiversity change: e.g., MAS.

7.2.3 Policy windows of opportunity

Under the EU Green Deal, a number of parallel policy initiatives are taking place that can provide impetus for the future development and application of biodiversity footprint and/or their underpinning data sources and infrastructure. These include the following:

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[100] Chandler, M., See, L., Copas, K., Bonde, A.M.Z., Claramunt López, B. *et al*. 2017. Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation* 213 B: 280-294. https://www.sciencedirect.com/science/article/pii/S0006320716303639

- **Deforestation free value chains**: Adopted as part of the EU Biodiversity Strategy for 2030, the EU deforestation free value chains initiatives[101] aims to minimise the EU's contribution to deforestation and forest degradation worldwide through promoting sustainable production and consumption patterns in the EU. Footprint methodologies are likely to play a key role in supporting the monitoring of outcomes in the future, including linked to different commodity chains. Here footprint methods following whole trade flows will be important, to trace deforestation back to source. These need to be linked with data sources that track forest loss, such as those from Global Forest Watch and national systems as in Brazil. *The Commission proposal due in summer 2021 has been delayed to autumn 2021.*

- **Framework for due diligence**: In parallel to the above, the EU is working on developing an improved framework for due diligence on environmental and social sustainability for business operators.[102] This initiative foresees a more comprehensive and stringent framework to be put in place to require operators that place a commodity or a product on the EU market to exercise due diligence to ascertain that these are not associated with supply chains with negative impacts, including deforestation and/or forest degradation. Approaches and methodologies assessing footprints of key value chains will play a key role in helping the operators (e.g., businesses) to assess and monitor this. *The Parliament adopted a legislative report in March 2021*[103] *and the Commission proposal due in summer 2021 has been delayed to autumn 2021.*

- **Integration of biodiversity into EU trade**: EU Biodiversity Strategy for 2030 reaffirms the EU's commitment to improve the role of trade in delivering biodiversity conservation. As one of the key elements the Commission is intending to improve the methodological approach used to assess biodiversity impacts as part of the EU trade impact assessments (ex-ante and ex post).[104] Footprint methodologies looking at the biodiversity impacts of trade flows within EU trade partnerships will form a key element of this development. Decisions will be needed about whether to employ sector

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[101] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12137-Deforestation-and-forest-degradation-reducing-the-impact-of-products-placed-on-the-EU-market
[102] https://ec.europa.eu/growth/sectors/raw-materials/due-diligence-ready/explained_en
[103] https://www.europarl.europa.eu/news/en/press-room/20210304IPR99216/meps-companies-must-no-longer-cause-harm-to-people-and-planet-with-impunity
[104] Rayment M., Arroyo A., Baldock D., Becerra G., Gerritsen E., Kettunen M., Meredith S., Underwood E., and Tucker G. 2018. *Valuing biodiversity and reversing its decline by 2030*. IEEP policy paper. https://ieep.eu/uploads/articles/attachments/947eb8aa-1694-41b1-8037-a4f16a7d2ace/Think%202030%20Biodiversity.pdf?v=63710011292

specific methodologies, such as those developed for cement and aggregates,[105] or to rely on more generalised footprint approaches. *The guidance for assessing biodiversity impacts of EU trade agreements was released in May 2021[106]*.

- **Sustainable finance taxonomy**: The taxonomy aims to define and identify environmentally sustainable opportunities for companies, investors and policy makers to invest in, providing a concrete list of activities and a screening criterion for investment. Defining sustainable investment activities in relation to the protection and restoration of biodiversity and ecosystems is one of the upcoming areas for guidance under the regulation. Furthermore, all investment under the regulation should not "do no significant harm" to biodiversity and ecosystems. Different footprint methodologies could be used in the future to complement or verify investment under this regulation, including its "do no significant harm" requirement. *The Commission proposal for first delegated act (climate mitigation and adaptation) was published in April 2021[107]. A second delegated act with the remaining objectives will be published in 2022*.

- **Corporate Sustainability Reporting Directive**: The European Commission has adopted a package of measures[108] to improve the flow of money towards sustainable activities across the European Union. This aims to assist in making Europe climate neutral by 2050. The package includes the EU Taxonomy Climate Delegated Act, to support sustainable investment by making it clearer which economic activities most contribute to meeting the EU's environmental objectives; a proposal for a Corporate Sustainability Reporting Directive to improve the flow of sustainability information in the corporate world; and six amending Delegated Acts to ensure that financial firms, e.g. advisers, asset managers or insurers, include sustainability in their procedures and their investment advice to clients. *The package was adopted in April 2021*.

- **EU data infrastructure**: The European Data Infrastructure (EUDAT)[109] aims to create a pan-European solution to the challenge of data proliferation in

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[105] IUCN 2014. *Biodiversity management in the cement and aggregates sector: Biodiversity Indicator and Reporting System (BIRS)*. IUCN, Gland, Switzerland. https://portals.iucn.org/library/sites/library/files/documents/2014-055.pdf

[106] https://ec.europa.eu/environment/publications/methodology-assessing-impacts-trade-agreements-biodiversity-and-ecosystems_en

[107] *https://ec.europa.eu/info/publications/210421-sustainable-finance-communication_en#taxonomy*

[108] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_1804

[109] https://eudat.eu/european-data-initiative

Europe's scientific and research communities. EUDAT’s mission is to design, develop, implement and offer “Common Data Services” to all interested researchers and research communities. These must be relevant to several communities, be available at European level and they need to be characterised by a high degree of openness: (1) Open Access should be the default principle; (2) Independent of specific technologies since these will change frequently and (3) Flexible to allow new communities to be integrated. **EUDAT itself aims to support sharing and reuse of open data through its services, while recognising that not all data will be completely unrestricted.** ***As the biodiversity footprint proposals become clearer, key data sources need to be recognised and integrated into the EUDAT process.***

It will be noted that many of these proposals have just been, or are about to be, published. There is therefore some urgency in identifying biodiversity footprint strategies to address these multiple EU policy initiatives.

7.2.4 Key stakeholders and change agents

We suggest a workshop to take these ideas forward would be most useful if it included representatives from four main groups:

- Academics working on the theoretical basis for footprint research
- Researchers who have developed practical footprint tools
- Practitioners who are charged with implementing this within the EU
- Holders of data sources


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