# Integrating biodiversity into natural capital impact pathways

*Supporting corporate natural capital assessment and management accounting practices*

Align

Aligning accounting approaches for nature

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# 1 Introduction

This technical report (*Integrating biodiversity into natural capital impact pathways. Supporting corporate natural capital assessment and management accounting practices*) is especially relevant to the EU-Life funded Transparent project, as it aims to address the biodiversity component of its Natural Capital Management Accounting (NCMA) methodology based on the Align project.

The Align recommendations focus primarily on how to measure and value biodiversity-related impacts and dependencies[1] to assess organization's performance, to complement the Transparent method which looked mainly at climate, air, water, and land-related impacts (and some dependencies). Align provides a suggested approach on biodiversity metrics, structure of impact pathways, criteria for measurement approaches and valuation in order to support corporate natural capital assessment and accounting as developed in the Transparent project. Align thereby supports a wide array of business applications including external reporting and internal management decision-making; it considers project, site and supply chain assessments, and therefore is open to multiple approaches to assessing impacts and dependencies on biodiversity, it can support the work of Transparent by bringing biodiversity assessment into the natural capital accounting, specifically into environmental profit and loss accounts. Its recommendations outline two key approaches to screening and measuring biodiversity impacts and dependencies, encompassing different decision-making contexts:

1) Direct, ground-truthed measurement of ecosystem condition and biodiversity state, and collection of primary data on impact drivers - this is recommended for project, site, and- product related decision-making contexts where it is possible to define the geographical boundaries.
2) Inferred estimation of impacts through pressures – e.g. globally modelled pressure-state responses. This is recommended in a decision-making context where it not possible to use observed outcomes on the ground or track losses and gains in specific natural capital stocks.

Other factors of good and best practice highlighted in the Align Recommendations include:

- Spatial precision – primary survey data captured at a fine local scale provides the best precision but is not always feasible or scalable across an entire company.
- Accuracy - The level of accuracy achievable differs among approaches as does the ability to verify impacts or provide assurance on the outcomes of your activity and any mitigation measures.

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[1] The 1992 Convention on Biological Diversity defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species, and of ecosystems.

- Responsiveness to change – Are the chosen approaches and indicators used responsive to the pressure(s) and able to detect change in biodiversity.
- Feasibility to apply at scale – globally-modelled pressure-state responses can produce scalable measurements across value chains,

There was a particular need to deepen the understanding and guidance around impact pathways leading to biodiversity losses, starting from those set out in the Transparant project for climate, air, water, and land related impacts, albeit that objective could not be met.[2]

This technical report therefore seeks to define how such specific impact drivers lead to changes in the state of biodiversity whilst detailing what approaches and tools can be used to measure and value the impact on biodiversity in the context of Transparent. Eventually, eight impact drivers are detailed as follows: greenhouse gas emissions (GHG), non-GHG air emissions, water consumption, water pollution, land and seabed use, solid waste, resource use and exploitation and alien invasive species. This Report could not extend its analysis and recommendations to the final valuation stage for which many EU-funded (e.g. SELINA) and other projects CE Delft Handbook and peer-reviewed academic publications may provide guidance.

The Transparent project approach to NCMA centres around measuring impact drivers and assessing impacts through natural capital impact pathways. The specific objective of the Transparent NCMA[3][OBJ] is to guide the development of Environmental Profit and Loss (EP&L) accounts in order to support internal and strategic corporate decision-making (although the information gathered may also be applied to other objectives such as disclosure). EP&L accounts are typically compiled using Life Cycle Assessment (LCA) methods combined with environmentally extended input-output (EEIO) models. These approaches work well for the assessment of the environmental impact associated with a product's life phases. In particular, the impact is expressed in endpoints which can then be combined with monetary valuation which enables the organization to compare and consolidate different types of environmental impact and express it as a single monetary value. Note that the Transparent methodology also references the Organization / Product Environmental Footprint (OEF/PEF) methodology, albeit those methods consider mid-points rather than end-points. LCA models typically cover the following pressures: climate change, non-GHG emissions, eutrophication, acidification, ecotoxicity (freshwater and terrestrial), waste, land and resource use. However, the methods and data underpinning LCA are often not site specific and rely on sector-level aggregated data; they therefore do not represent well impacts on aspects of biodiversity which are location sensitive such as impacts on specific ecosystem types or locations of high biodiversity significance (which are not present equally all over the world).

It should be noted that the intended application of Transparent has a somewhat narrower scope than that of Align. While Align and Transparent both consider different organisational focus and value chain boundaries in their methodologies, such as project, product and corporate level assessments and

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[2] Impact pathways describe how, as result of a specific business activity, multiple impact drivers/pressures result in changes in natural capital stocks and flows and how these changes in natural capital affect human wellbeing. This understanding is also core to a number of other nature related frameworks, including the Taskforce for Nature-related Financial Disclosures (TNFD) and the Science-Based Targets Network (SBTN).

[3] https://capitalscoalition.org/publication/the-natural-capital-management-accounting-methodology/

full value chain approaches, both seek to be consistent with and reference concepts and definitions from key frameworks or standards including TNFD, SBTN, the United Nations System of Environmental Economic Accounting (UNSEEA) and the British Standard on Natural Capital Accounting (BS 8632).

Transparent recognizes a number of different methods for measuring changes in natural capital broadly including direct measurement approaches, generalized models (e.g. ReCiPe, GLOBIO), and detailed and bespoke models (e.g. ecotoxity models).

This Technical Report will encompass a similar methodological scope, mainly focusing on LCA-based approaches that support EP&L methodologies, and other more detailed, bespoke and site-specific approaches where relevant.

Setting out biodiversity impact pathways can support:

- Integration of biodiversity into LCA methods and EP&L accounts for high-level decision making (the focus of this report)
- Guiding the assessment of site impacts through identifying relevant pressures and priority elements of biodiversity to measure
- Providing context and guiding management of on-the-ground impacts tracked through more stock-based corporate biodiversity accounting approaches'

This technical report addresses the biodiversity gap in Transparent, providing an overview of the connections between impact drivers and the state of biodiversity, with example natural capital pathways that integrate biodiversity-specific components and considerations.

# 2 Elements of Impact Pathways

Measuring the state of biodiversity and/or changes thereof can then be conducted through direct measurement of biodiversity state or modelled based on pressure data (through impact pathways). Direct data, where available, should be used as best practice, however practical considerations such as cost and time can make this difficult in practice. This is why the Transparent methodology focusses on modelled data based on pressures, which despite its uncertainties can be managed and interpreted to create decision-useful information.

Impact pathways can be simple and direct (fishing removes fish species – both the targeted and bycatch) or complex with secondary impacts and feedback loops (run off from farms carrying high nutrient loads and pesticides leading to changes coastal water quality, reductions in fertility of species, disruptions in algal composition and blooms, fish and thus biodiversity loss).

Valuation focuses on the end impact on biodiversity state, regardless of how it eventuated.

The impact driver leads to **changes in natural capital**, in this case the atmosphere, climate and sea

This leads to **Changes in biodiversity**, e.g. desertification, loss of corals and movement of fish species

**Impact Driver**

Production process at a fossil fuel power plant release greenhouse gases

**Ecosystem services** such as food provisioning and recreation are affected

*Figure 1. Biodiversity-focused Impact Pathway*

Figure 1 illustrates the interaction between an *impact driver* (or pressure) and a *component of biodiversity* (via aspects of the environment such as air, water and land). The impact that arises can be measured using various *biodiversity impact metrics.* This change in biodiversity results in impacts on *ecosystem services* and finally *human wellbeing*. These components of the impact pathways are discussed in turn in the ensuing sections.

## 2.1 Impact Drivers

The Align Recommendations (Section 4.1.2) state that impact drivers (or pressures) should reflect those identified through the IPBES assessment and required by relevant policy. Below are six key impact drivers for developing practical assessments based on Transparent, supplemented by IPBES:

1. Land and Sea-Use Change
   Habitat destruction due to agriculture, urbanisation, deforestation, and infrastructure development.
2. Climate Change
   - CO2 Emissions (Transparent)
   - Non-CO2 GHG emissions (Transparent)
3. Pollution
   - Non-GHG Air Emissions (Transparent)
   - Water Pollution (Transparent)
   - Land degradation / Solid Waste (Transparent)
   - Land use (Transparent) including seabed use and soil pollution
4. Resource Use / Overexploitation of resources
   - Water Consumption (Transparent)
   - Resource use and exploitation (IPBES)
5. Invasive alien species (IPBES)

Although the impact driver framing in this report is based around the Transparent methodology, we consider also the IPBES elements currently not covered, such as soil pollution which we have placed soil pollution under Land use. Although impact drivers are presented here individually, they may combine across a company's operations, or with impact drivers of other organizations and other background pressures and trends to result in cumulative impacts.

This report does not address other impact drivers such as disturbance (e.g. from noise, light or physical contact), and use of freshwater areas (e.g. for floating solar energy, hydropower infrastructure or reclamation).

## 2.2 Change in the state of biodiversity

The components of biodiversity were presented in the Align Recommendations (Figure 2) and comprise genes, species (population size and global extinction risk) and ecosystems (extent and condition).



*Figure 2. Components of biodiversity (Source: Align Recommendations)*

The focus of this deep dive is mainly on species, their habitats, and the biotic component of ecosystems, and will depend on the impact drivers addressed. Although genetic diversity is a key aspect of biodiversity, the application of genetic diversity metrics and tools for measuring business impacts is under-developed. However, some species level metrics may capture aspects of genetic diversity.

In comparison to climate change impacts, and similar to other natural capital assets and flows, the components of biodiversity potentially affected by impact drivers are site specific, local and spatially explicit.  It may be possible to model and simulate these impacts. The habitats and species affected will

be those most sensitive to the impact driver and these may often be useful indicators of impact to the wider ecosystem. Such examples will be indicated where possible although not exhaustive of the entire range of sensitive species.

The extent or size of species populations and habitats and ecosystem condition are main elements to characteristics changes in biodiversity. Impact indicators include change in species abundance, change in species composition and evenness, habitat loss and degradation. Ecosystem condition was explored in a separate study under the Align project.[4] However, there are also metrics for species health, including age and sex-ratio indicators and fecundity measures.

Biodiversity indicators for business applications cover different spatial and temporal scales of application. The Align Recommendations considered factors affecting the materiality (or significance) of an impact on biodiversity. They include:

- Relative distinctness - ecosystems that are threatened, rare or declining may be more material than ecosystems that are more common and widespread.
- Connectivity – ecosystems that are isolated may be more at risk than those that are better connected for the movement of gametes (e.g. seeds or larvae) and adults (e.g. through migration).
- Strategic and cultural significance - ecosystems may have high cultural significance or be in an area designated as strategically important for nature (e.g. a wetland), or an area managed for conservation (such as a legally designated Protected Area).

Global-level biodiversity information exists in databases such as the World Database on Protected Areas (WDPA), the World Database of Key Biodiversity Areas (WDKBA) and the IUCN Red List of Threatened Species. Some of this is incorporated into measurement and assessment tools (see Section 2.3). These sources will not have local accuracy or context but can provide information and modelling where otherwise there would be none.

## 2.3  Measurement of Biodiversity Impact

Biodiversity measurement metrics and approaches were recently reviewed by Lammerant et al (2021 and 2022). Examples are given in this technical report for their application in specific natural capital impact pathways relevant to the EP&L approach of Transparent.

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[4] UNEP-WCMC, Capitals Coalition, Arcadis, ICF, WCMC Europe (2023) Measuring Ecosystem Condition – A primer for business, Aligning accounting approaches for nature.

### 2.3.1  Measurement Approaches

**High-level models** for measuring changes in biodiversity at EP&L level are based on global-level, or sectoral-level averaged data. They are useful for high-level assessments of the company's activities, product level assessments or supply chain analysis where obtaining site-level data across the entire chain is not feasible. Examples include:

- The [GLOBIO model](#)[5] developed and hosted by PBL Netherlands Environmental Assessment Agency.
  - In version 4, impact on biodiversity is assessed for six human pressures: land use, road disturbance, fragmentation, hunting, atmospheric nitrogen deposition and climate change (version 3.6 that is used for several footprinting methods cover different pressures).
  - For each pressure factor, a dose-response relationships is developed based on scientific studies on biodiversity impacts. In general, a greater pressure means a greater loss of biodiversity.
  - GLOBIO uses a relative biodiversity indicator; the Mean Species Abundance (MSA) describes biodiversity changes with reference to the undisturbed state of ecosystems defined as the average abundances of originally occurring species relative to their abundance in the undisturbed ecosystem (equivalent to a pristine state, intact and undisturbed by human activity). MSA varies between 0% and 100% (or a score from 0 to 1). The MSA has a low value in areas where the pressure on biodiversity is high.
  - Many 'packaged' biodiversity methodologies and tools have incorporated GLOBIO into their approach including the Global Biodiversity Score (GBS) and the Corporate Biodiversity Footprint (CBF).
- [ReCiPe](#) (version 2016): is a model for life cycle impact assessment (LCIA) that includes 18 midpoint indicators and 3 endpoint indicators
  - The unit for ecosystem quality, 'the Potential Disappeared Fraction' is local relative species loss in terrestrial, freshwater and marine ecosystems, respectively, integrated over space and time (Huijbregts et al., 2016). A meta-study was used (Thomas et al., 2004) to assess the link to biodiversity.
  - Many 'packaged' Life Cycle Assessment and biodiversity footprinting methodologies and tools draw from the ReCiPe model, including Biodiversity Footprint for Financial Institutions (BFFI)
- Product Biodiversity Footprint (PBF)[6] specifically aims to quantify the impacts of a product on biodiversity, all along the product's life cycle stages, and uses a mix of LCIA and qualitative methodology. It covers land use (habitat change), pollution, climate change, invasive species, and overexploitation of species.
- Global Impact Database (GID).

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[5] https://www.globio.info/what-is-globio

[6] http://www.productbiodiversityfootprint.com/

It should be noted that assessing potential impacts on biodiversity may also require a consideration of potential tipping points where an accumulation of external pressures (both natural and anthropogenic), reaches a threshold that triggers an abrupt and possibly irreversible shift between alternative ecosystem states (see overviews by e.g. Sheffer, 2009; Lenton et al., 2013; Dakos et al., 2019; Duke, G. 2020). Currently, most tools available do not properly take into account tipping points. Businesses should be aware of any factors such as highly sensitive ecosystems or cumulative pressures that may influence a tipping point within their organisational boundary and adopt a precautionary approach where there is high uncertainty and risk[7].

## 2.4 Ecosystem Services

Some impact pathways explored in Transparent consider impacts on abiotic features (e.g. non-living physical and chemical aspects) without being mediated through biodiversity. For example, water consumption directly impacts on water supply ecosystem services and water pollution directly impacts soil quality regulation.

This section provides examples of the ecosystem services affected by the change in biodiversity. The ecosystem service tables in each impact driver below only detail those ecosystem services impacted by changes in biodiversity. A non-exhaustive list of ecosystem services measurement and valuation tools include:

- ENCORE database[8] - details the impacts to ecosystem services from different drivers of environmental change. The knowledge base underpinning ENCORE is currently undergoing redevelopment and review under the EU-led SUSTAIN project.
- Mapping and Assessment of Ecosystems and their Services (MAES) – outputs include indicators to map and assess biodiversity, ecosystem condition and ecosystem services (https://www.eea.europa.eu/themes/biodiversity/mapping-europes-ecosystems).
- Nature Value Explorer – assists land managers to map and value the ecosystem services at a site level (https://www.natuurwaardeverkenner.be/).
- ECOPLAN-SE – the project develops a range of tools enabling a company to quantify the effects of spatial scenarios on 18 different ecosystem services (https://www.uantwerpen.be/en/research-groups/ecoplan/).
- TESSA – a toolkit which provides practical guidance on how to identify which services may be significant at a site of interest, what data are needed to measure them, what methods or sources can be used to obtain the data and how to communicate the results. (https://tessa.tools/).

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[7] "The precautionary principle is an approach to risk management, where, if it is possible that a given policy or action might cause harm to the public or the environment and if there is still no scientific agreement on the issue, the policy or action in question should not be carried out" (Article 191 of the Treaty on the Functioning of the European Union (TFEU).

[8] https://encore.naturalcapital.finance/en

- INVEST - a suite of free, open-source software models used to map and value the goods and services (https://naturalcapitalproject.stanford.edu/software/invest).
- Ecosystem Services Identification and Inventory Tool (ESII) - an iPad app and web interface that lets people understand the benefits that nature provides and incorporate the value of nature into decision making (https://www.esiitool.com/).

## 2.5 Valuation

Valuation of the changes in biodiversity is applied to the change in ecosystem services. To give an example for context, the loss of mature forest vegetation may have consequences for water retention ecosystem services. This could result in increased flood risk for assets and people in the area. The valuation process would identify the components at risk and their value, e.g. property values. This is not unique to biodiversity-related impact pathways. and therefore the same general methods and considerations outlined in the Transparent NCMA are applicable (see section 4.1.3 in the NCMA methodology). As a result, this technical report does not extend into the approaches for valuation.

When considering the value of changes in biodiversity specifically, some types of value are particularly relevant to consider, including the relational and intrinsic values of nature, which are non-human centred and focus on the values of biodiversity independent on human use of the goods and services it provides. Whilst these values can be assessed and acknowledged cannot be capture methods that attempt to quantify economic values.

# 3 Biodiversity-focused impact pathways

Sections 3.1 to 3.8 discuss Impact pathways for eight different impact driver categories. These sections present the following information:

1. **Introduction** explaining the impact drivers, any relevant policy instruments governing its regulation and measurement, how it is characterised and measured and, where relevant, which sectoral activities it is primarily associated with.
2. **Biodiversity Impact and Measurement**. This section explores different approaches to biodiversity measurement such as site-based approaches with bespoke models or global models such as those employed by LCA. A table summarises the relevant biodiversity-focused impact pathways with examples of the changes in biodiversity.
3. **Ecosystem services affected.** This follows the UNSEEA classification with examples provided of the impacts on ecosystem services.

## 3.1 GHG Emissions

### 3.1.1 Introduction

GHG listed by the IPCC include carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$).[9]

GHG emissions arise from transport, energy and heating, and industrial process emissions as well as emissions from agriculture and land use. Activities may also contribute in a positive way to GHG Emissions, for example, carbon capture and storage activities, though these should not be used to justify emissions and netting of benefits should be avoided.

Greenhouse gas emissions contribute to climate change and in turn biodiversity loss from local to global level. Defining local impacts of GHG emissions is challenging.

Businesses can measure their specific GHG emissions in several ways such as:

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[9] $N_2O$ is a natural component of the earth nitrogen cycle with both natural (65%) and anthropogenic (35%) sources. Its abundance in the atmosphere has been growing in recent decades (Tian et al., 2020). $N_2O$ has furthermore become the largest ozone depleting substance not regulated by the Montreal Protocol, unlike CFCs and HCFCs.

- Multi-regional Environmentally Extended Supply and Use / Input-Output databases (e.g. EXIOBASE)
- Remote sensing of emissions using:
    - Multispectral satellite systems (this works best for companies with methane emissions over large areas).
    - Optical cameras and optical gas imaging (OGI) operated from satellites, airplanes, drones and handheld devices (useful for a wide range of spatial scales).
      Air sensors (or 'sniffers' – useful on-site and where a high level of accuracy is required; can also work over large scales with multiple sensors).
- Sectoral programmes (e.g. Oil and Gas Methane Partnership 2.0 (OGMP) which aims to improve the accuracy and transparency of methane emissions reporting in the sector through a comprehensive, measurement-based reporting framework).

## 3.1.2 GHG-related Biodiversity Impact Pathway and Measurement

The impact pathway of greenhouse gas (GHG) emissions involves multiple impacts of both regional and global nature and extends from short to long term change

Global-level changes to natural capital arise from the increased concentration of GHGs in the atmosphere leading to rising mean temperatures, shifting climate patterns, sea level change, ocean acidification and desertification. These changes in the climate impact biodiversity through changing habitats (including degradation and losses), changes in movement (e.g. migration) of species, and/or changes in species composition. Increased migration of species into biomes that they previously could not occupy could see a rise in invasive species pressures on local species. Species that can't adapt or migrate, such as some plant and insect species, are at risk of becoming locally or globally extinct.

Table 1 provides changes in biodiversity and examples from the impacts of priority greenhouse gases.

Once an estimate has been made of the business' GHG emissions, they can calculate their share in global climate change-related impacts using EEMRIO models (such as EXIOBASE, GLOBIO, or others) or LCA methodologies (and for example the endpoint models EPS2000 and ReCiPe) to infer the biodiversity impact from GHG emissions.

The climate-related dose-response relationship used in GLOBIO3[10] shows the decrease in biodiversity (Mean species abundance - MSA) versus the increase in mean global temperature (see Arets et al., 2014[11]).

Thus, the contribution of greenhouse gas emissions to the mean global temperature has first to be determined. This requires input of the greenhouse gas emissions of the company and its products for which the biodiversity footprint is to be determined. Because climate change has not only a local but also worldwide impact on biodiversity, the climate impact on MSA occurs worldwide in natural and semi-natural ecosystems. Thus, the MSA impact is multiplied by the total global land area for ecosystems in natural and semi-natural state.

ReCiPe (version 2016) uses GWP as the midpoint impact indicator which quantifies the integrated infrared radiative forcing increase of a GHG, expressed in kg CO2-eq (Huijbregts et al, 2017). It also calculates the ozone depleting potential (ODP) on the midpoint level, expressed in kg CFC-11 equivalents. This information is then used in the damage pathway assessment where terrestrial species loss due to changing the changing distribution of ecosystem biomes can be estimated and fish species loss due to decreased river water discharge. This makes assumptions on the speed at which species can migrate or adapt to change; some species may respond positively and others negatively and these responses can be very location specific (see e.g. De Schryver and Goedkoop, 2009). Note that marine biodiversity impacts are not covered by ReCiPe.

Overall, the uncertainty in LCA endpoint estimates is likely significant, as the long impact pathway link between radiative climate forcing and damages to ecosystems is difficult to establish (JRC, 2011). Uncertainly can be managed where quantification of this uncertainty is possible, this will help decision makers make business decisions. Characterisation factors (CF) for climate change impacts on biodiversity are highly simplified and do not consider spatial and taxonomic differentiation of species or local climate variability.

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[10] https://www.globio.info/globio3-framework-to-investigate-options-for-reducing-global-terrestrial-biodiversity-loss

[11] Arets, E.J.M.M., C. Verwer en R. Alkemade. (2014). Meta-analysis of the effect of global warming on local species richness WOt paper 34. Wettelijke Onderzoekstaken Natuur & Milieu, Wageningen UR, Wageningen, Nederland.

*Table 1. Biodiversity-focused impact pathways from GHG emissions*

| Impact Driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Carbon dioxide emissions | Change in species population size and extinction risk. | GHGs can cause shifts in climate patterns with heavy rainfall or desertification as a result and increased risk for e.g. wildfires, soil erosion and salinization which in turn results in loss and degradation of habitat. |
| Methane emissions | Changes in ecosystem extent and condition | Global warming is causing sea level rise with loss of coastal and island habitats and changes in species distribution patterns and migration routes. Loss of coastal land results in the displacement of people, sometimes from entire islands. |
| Nitrous oxide emissions | | As oceans absorb carbon dioxide, they become more acidic. This affects the ability of reef building corals to grow their skeleton. These weaker skeletons make corals more vulnerable to disease and mortality<br>Depletion of atmospheric ozone by $NO_2$ means less protection from the sun's rays and more exposure to UVB radiation at the Earth's surface. This in turn affects plant and phytoplankton growth[12]. |

## 3.1.3  Change in Ecosystem services driven by climate change

While climate change occurs at a global level, the impacts to biodiversity occur at regional or local levels and, therefore, so do consequent changes in ecosystem services and impacts to human well-being.

Widespread changes in the distribution of species and condition of habitats can ultimately impact all ecosystem services (see Table 2).

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[12] https://csl.noaa.gov/assessments/ozone/2014/preface.html

*Table 2. Ecosystem services affected by GHG-emission impacts on biodiversity.*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Crop yields are impacted by changes in the growth and productivity of crop species as well as changes in the distribution of crop pests. |
| **Regulating services:** | |
| Soil quality regulation services | Impacts on these services largely arise from general changes in the distribution of species |
| Soil and sediment retention services | |
| Water purification services | |
| Water flow regulation services | |
| Flood mitigation services | Coral reefs often act as a first line of defence against coastal flooding and erosion from storms. The loss of coral reefs results in decreased coastal protection from storms and floodings |
| Coastal storm protection | |
| Pollination services | Climate change will result in changes in the distribution and abundance of pollinator species |
| Biological control services | Climate change will result in changes in the distribution and abundance of species that provide biological control as well as pests and diseases. |
| Nursery population and habitat maintenance services | Climate change may alter species populations and habitat extent affecting connections between sources of pollen/gametes and adult populations. |
| **Cultural services:** | |
| Recreation-related services | Recreational fish species may change their distribution due to climate change, thereby affecting local activities. |
| Visual amenity services | Cultural services are likely to be affected by any changes in species or habitats. |
| Education, scientific and research services | |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.2 Non-GHG Air Emissions

### 3.2.1 Introduction

Air pollution is both a global and local phenomenon (pollution travels the world) albeit the impacts of air pollution are principally local or regional

Non-GHG air pollutants can be subdivided into "primary pollutants", which directly cause negative impacts, and "secondary pollutants", which originate from the reaction between primary pollutants and other gases in the atmosphere under certain conditions, and which subsequently also have negative impacts.

The non-GHG air pollutants covered here are nitrogen oxides (NOx), ammonia ($NH_3$), sulphur oxides ($SO_x$), ground-level ozone (O3), other non-methane volatile organic compounds (NMVOC), particulate matter (both PM10 and PM2.5?), carbon monoxide (CO) and heavy metals.

Nitrogen is present in the air in the form of several key pollutants, including nitrogen monoxide (NO), nitrogen dioxide (NO2) and ammonia (NH3).

The Transparent NCMA methodology discusses how to measure non-GHG air emissions and the relevant indicators.

### 3.2.2 Air Pollution-Related Biodiversity Impacts and Metrics

Data on air quality that is usually collected include particulate matter (PM) ground-level ozone ($O_3$), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), and carbon monoxide (CO).  These are linked to thresholds for impacts on human health, vegetation, etc. A key resource is the European Environment Agency 2022 review of air pollution impacts[13].

Linking emissions (pressures or drivers) to air quality (state) requires air dispersion and deposition models at the appropriate spatial and temporal scale. Dose-response functions can be used to determine the effects of air pollutants on e.g. loss of crop production.  (Cf models developed and used at IIASA.)

An alternative method to bespoke modelling is to use existing LCA models (e.g. ReCiPe) and comprehensive datasets for air emissions such as EXIOBASE. The EU Joint Research Centre provided a review of different modelling approaches and their limitations (JRC, 2011) covering photochemical ozone (e.g. smog and impacts on crop and wood production) and acidifying emissions (impacts include loss of terrestrial species and changes to net primary production).

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[13] https://www.eea.europa.eu//publications/europes-air-quality-status-2023

In ReCiPe (Huijbregts et al., 2017), for the midpoint characterisation factors of acidifying emissions, the fate of a pollutant in the atmosphere and the soil, as calculated by Roy et al. (2014), can be estimated. Acidification potentials (AP) are expressed in kg SO2-equivalents. Changes in acid deposition, following changes in air emission of NOx, NH3 and SO2, are calculated with the GEOS-Chem model (Roy et al. 2012a). Subsequently, the change in acidity in the soil due to a change in acid deposition is derived with the geochemical steady-state model PROFILE (Roy et al. 2012b). ReCiPe also models loss of plant species due to increase in ozone exposure following van Zelm et al. (2016).

In GLOBIO, an Atmospheric Nitrogen Deposition dose-response relationship is built based on a meta-analysis linking yearly amount of added nitrogen in exceedance of the critical-load and the relative local species richness (considered as a proxy for MSA).

Table 3 provides changes in biodiversity and examples due to impacts from the priority non-greenhouse gases.

*Table 3. Biodiversity focused impact pathway from non-GHG emissions*

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Ammonia and nitrogen oxides air emissions | Altered species composition | The deposition of nitrogen oxides and ammonia leads to changes in the chemical composition of soils, lakes, rivers and marine waters through a process known as acidification, which disrupts ecosystems and leads to biodiversity loss (EEA, 2022). Deposition of nitrogen in terrestrial ecosystems can cause eutrophication of waterways when critical loads are exceeded. Nitrogen is high in nutrients and fast -growing species adapted to high nutrient availability thrive in a nitrogen-rich environment. These will outcompete smaller and more sensitive species adapted to nutrient-poor ecosystems. |
| Sulphur oxide air emissions | Acid rain causing habitat change | Acid rain causes minerals and nutrients to leach from the soil making it inaccessible to trees and plants. Acidification of soil and (ground)water creates pressure on plants and animals. |
| Ozone (O$_3$) | Change in ecosystem extent and quality | Ground-level or tropospheric ozone damages vegetation and reduces biodiversity. Ozone damages agricultural crops and reduces yields. From 2000 to 2020, there was an overall reduction in the percentage of agricultural land exposed to levels above the target value for the protection of vegetation in EEA member countries (EEA, 2022) |
| Other VOC (volatile organic compounds) emissions | Change in ecosystem extent and condition | Aside from tropospheric ozone, very little is known about the effects of other VOCs (such as benzene and its derivatives) on biodiversity. The largest source of VOC emissions to air is oil and gas production (US EPA, 2014). Impacts to humans include effects on respiratory and neurological systems |

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Particulate matter emissions | Impacts to species functioning and ultimately habitat condition | Suboptimal photosynthesis by plants because of a dust layer on the leaves blocking sunlight, and particles blocking stomata. Particulate matter can interfere with breathing and feeding ability. Particulate matter can affect visibility and therefore hunting and predator avoidance abilities. |
| Carbon monoxide (CO) | Impacts to species condition and ultimately abundance and extinction risk | CO is poisonous to all animals that use haemoglobin to transport oxygen from the lungs to the cells of the body. This gas prevents the uptake of oxygen by the blood leading to a significant reduction in the supply of oxygen to the heart ultimately causing death through asphyxiation. |
| Heavy metals | Impacts to species condition and ultimately abundance and extinction risk | Heavy metals are toxic pollutants that travel long distances in the atmosphere and are deposited into ecosystems, leading to the build-up of these contaminants in soils and their subsequent bioaccumulation and biomagnification in the food chain (EEA, 2022). Heavy metals can lead to changes in fecundity and survival. |

### 3.2.3 Change in Ecosystem services

As air emissions impact air quality over local to regional-level scales, the impacts to biodiversity also occur at local to regional scales and, therefore, so do consequent changes in ecosystem services. Regional changes in the distribution of species and condition of habitats can ultimately impact a range of ecosystem services (see Table 4).

*Table 4. Ecosystem services affected by non-GHG emission impacts on biodiversity.*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Acid rain from $SO_2$ has the potential to cause forest dieback which could have an influence on the timber industry. It can also cause stress for agricultural plants and thus impact the agricultural sector. |
| **Regulating services:** | |
| Pollination services | Many pollinators are vulnerable to air pollutants. As well as affecting their health, air pollution may also degrade the scent that pollinators use to find flowers. |
| Nursery population and habitat maintenance services | Air quality may affect vegetation and species that support the maintenance of forest and agricultural crops. |
| **Cultural services:** | |
| Recreation-related services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Visual amenity services | |
| Education, scientific and research services | |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.3 Water Consumption

### 3.3.1 Introduction

There is global concern regarding the state of water resources, which are subject to significant pressure from increasing water demand, with pressures projected to be exacerbated by climate change. Unmet water demand within ecosystems can lead to a loss of habitat, with further impacts on biodiversity and loss of ecosystem services.

WRI (2013) defines water consumption as "the portion of water use[14] that is not returned to the original water source after being withdrawn. Consumption occurs when water is lost into the atmosphere through evaporation or incorporated into a product or plant (such as a corn stalk) and is no longer available for reuse." There are other water 'withdrawals' which are returned to the original water source but may no longer be in their original state due to the inclusion of pollutants or thermal heat – these are discussed under water pollution in Section 3.4.

The Transparent NCMA methodology discusses how to measure water consumption and the relevant indicators.

### 3.3.2 Biodiversity Impact and Measurement

The extent to which water use contributes to water stress or scarcity may vary by location and season. Water stress or scarcity is highly dependent on the specific context, including the local hydrology situation, human activities, climatic conditions / seasonal variations in precipitation, as well as the state of the local environment. Depleting groundwater at an unsustainable rate may also lead to inflow of saline water, indirectly affecting the quality of soil systems and biodiversity. Water consumption usually involves a deviation from the natural flow (which can be measured with the Amended Annual Proportional Flow Deviation (AAPFD) for example) which then impacts biodiversity.

Companies measure and disclose their water consumption and therefore have direct records of this. For larger areas, surface water consumption can be estimated via arial photography/remote sensing assessment of size of surface waters. At a site level these consumption estimates could be assessed against sensitivity criteria for species and habitats.

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[14] Water use "describes the total amount of water withdrawn from its source to be used" (WRI, 2013).

Alternative sources of sectoral data and pre-existing global models include AQUASTAT by FAO, WaterStat by the Water Footprint Network (WFN)), AWARE (Available WAter REmaining), WSI (Water Scarcity Index) and LCA/LCIA databases such as Ecoinvent[15]. Indicators include the PDF potentially Disappeared Fraction of Species per $m^3$ water or per hectare or the decrease in net primary productivity as a proxy for total species loss (ReCiPe). The indicators available in EXIOBASE provide sectoral information on this pressure. However, there is a lack of data for several sectors (i.e. mining, certain manufacturing activities, construction, etc).

Water footprint including environmental sustainability can be measured using for example the Water Footprint Assessment calculator WFA including sustainability assessment, Water Calculation Tool developed for the Textile Wet Processing Sector to evaluate a product life cycle, and the Global Water Tool by WBCSD.

Screening of impacts and dependencies is available via ENCORE and GLOBIO through the AAPFD. Screening of vulnerabilities is available via, for example, the WWF Water Risk Filter and Aqueduct Water Risk Atlas by the World Resources Institute. Table 5 provides examples of changes in biodiversity due to the impacts of water consumption.

*Table 5. Biodiversity-focused impact pathways from water consumption*

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| **Surface water consumption (e.g. rivers and lakes)** | Change in freshwater species population size and extinction risk. | Surface water depletion can lead to drying out of ponds and lakes, and therefore loss of aquatic habitats and wetlands (loss of foraging grounds, breeding sites, resting places, etc.). Even a decline in water levels may cause loss of critical habitats, which can impact species survival and reproductivity (less dispersion, loss of genetic diversity due to inbreeding, increased competition). |
| | Changes in freshwater habitat extent and condition | Surface water depletion can alter the quality of the remaining water. Less water means less dilution and thus a higher concentration of pollutants and other harmful substances. |

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[15] https://ecoinvent.org/database/

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| **Groundwater consumption** | Change in species population size and extinction risk.<br><br>Changes in habitat extent and condition | Depletion of groundwater can cause drought stress and a shift in the balance of species within an ecosystem. The loss of groundwater can reduce the flow of water in surface rivers and streams, which can lead to changes in water temperature and quality that can result in the loss of habitat and negatively impact species. Both terrestrial species dependent on groundwater and freshwater species downstream may be impacted. |

### 3.3.3 Change in Ecosystem services

Over-consumption of water will reduce the resilience of wetlands, rivers, lakes and estuary ecosystems and also their ability to directly provide flood attenuation, waste assimilation and food provisioning. The key ecosystem services affected are described in Table 6.

*Table 6. Ecosystem services affected by water consumption impacts on biodiversity*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Changes in groundwater and surface water levels has the potential to affect forestry and freshwater fish stocks. |
| Genetic material | May have high impacts on local populations and genetic stock. |
| **Regulating services:** | |
| Global climate regulation | May occur at a local scale due to impacts on vegetation from water level changes. At cumulative or larger scales there may be impacts at a global level. |
| Rainfall pattern regulation | |
| Local climate regulation | |
| Air filtration services | |
| Soil quality regulation services | Changes in groundwater levels and vegetation has the potential to affect soil quality and retention. Less vegetation and dry soils will lead to increased soil erosion. |
| Soil and sediment retention services | |
| Water purification services | Over consumption of water can lead to loss of purifying water habitats such as reedbeds |

| Water flow regulation services | Extraction of water and loss of terrestrial and freshwater vegetation will affect the flow of water |
|---|---|
| Flood mitigation services | Extraction of water and loss of terrestrial and freshwater vegetation may reduce flood mitigation services |
| Pollinator services | Due to loss of pollinator species |
| Biological control services | Due to loss of biological control species |
| Nursery population and habitat maintenance services | Due to loss of species and habitats |
| **Cultural services:** | |
| Recreation-related services | Due to loss of recreation-related species and habitats, e.g. wetlands and birdwatching activities |
| Visual amenity services | Due to loss in habitat quality and species abundance |
| Education, scientific and research services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.4  Water Pollution

### 3.4.1  Introduction

This impact driver specifies aspects of water pollution resulting in changes to key water quality parameters from emissions to water. Introduction of plastics and litter to water is covered by the solid waste section and introduction of invasive species to water is covered under the invasive species section. Change in key water quality parameters will influence species and habitats living in or interacting with the affected waterbody. They may affect an animal's ability to feed and reproduce and a plant's ability to photosynthesise. In extreme cases, organisms may die and the site may no longer be able to support life.

Businesses may also undertake activities that have a positive impact on water pollution metrics. An example of a positive impact pathway includes the introduction of oysters or other filter-feeding shellfish to a waterbody to improve water characteristics such as suspended solids.

Most water pollutants are measured in mg/L or ug/L to allow comparison against internationally established criteria and reference values. Solids like suspended sediments may use ppm. In LCA, to assess the comparative toxic unit, the mass of the chemical emitted (kg) is used, but this is related to the volume of water that it is emitted with in $m^3$, which then converts to a weight/volume. The Transparent NCMA methodology discusses how to measure water pollution and the relevant indicators.

### 3.4.2  Biodiversity Impact and Measurement

High-level screening of water pollution impacts can be provided via Bioscope and ENCORE to identify where the most important impacts on biodiversity are in a company or sector's supply chain. However, there are few global datasets on water pollution. In EXIOBASE, the data on nutrient emissions pollutants is only available for agriculture and waste sectors.

With impacts from water pollution often being located downstream from point sources, precise site-level measurement of pollutants may require water dispersion models at the appropriate spatial and temporal scale. This is particularly the case in the marine environment where tides and currents can carry pollutants far from their source and towards sensitive habitats such as seagrass beds or coral reefs. Water clarity or turbidity can occasionally be used as a proxy for water pollution. Sediment particle size, hydrological energy (current speed & direction) and tidal excursion are all influencing factors on the spatial extent and temporal duration of water pollution. Salinity, turbulence, pH and temperature may result in flocculation of suspended organic matter.

Determining the presence and condition of potentially vulnerable habitats is needed at a site level as well as criteria defining the point at which likely acute and/or chronic impacts arise. The distribution and quality of habitats and/or indicator species can be based on monitoring surveys, eDNA surveys, traps (e.g. for insects), remote sensing and extrapolation from existing databases. Tissue samples of species may be needed to assess condition.

An alternative method to bespoke modelling is to use existing models. The EU Joint Research Centre provided a review of different modelling approaches and their limitations (JRC, 2011) covering eutrophication and ecotoxicity. The GLOBIO-Aquatic model for freshwater ecosystems covers nitrogen and phosphorus discharge to surface water and may also take into account water temperature for some ecosystems.

ReCiPe 2016 models the loss of aquatic species due to increased phosphorus concentration; it also has pressure-impact relationships for heavy metals. Freshwater eutrophication potentials (FEP) are expressed in kg P to freshwater-equivalents. Global fate factors for phosphorus emissions to freshwater are taken from Helmes et al. (2012). For freshwater ecotoxicity and marine ecotoxicity, the model follows that of van Zelm et al (2016) where the ecotoxicological effect factor represents the change in PDF of species due to a change in the environmental concentration of a chemical.

Furthermore, it's possible that assessments based on land-use change at a catchment level could be used as a proxy for risk to aquatic ecosystems, especially for sediments or nutrient impacts (e.g. Morant et al., 2020). Table 7 provides changes in biodiversity and examples due to the impacts of the main water pollutants.

*Table 7. Biodiversity focused Impact pathway from the introduction of various pollutants to water*

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Nutrients (mainly nitrogen and phosphorus). May be introduced through point-source discharges or diffuse sources such as run off. | Ecosystem change. Specifically, algal growth (leading to lack of oxygen in the water) Algal blooms can further lead to fish death for example and their toxins can accumulate in shellfish | Introduction of nutrients can lead to a chain reaction of events termed eutrophication: the nutrients encourage increased growth of phytoplankton and algae. The excess algal and plant matter eventually decompose, producing large amounts of carbon dioxide and reducing the oxygen levels in the water and lowering the pH. This creates hypoxic "dead zones" where marine life cannot be sustained and dies. The acidification of waterbodies slows the growth of fish and shellfish and can prevent shell formation in bivalve molluscs.<br><br>In particular, algal blooms can occur under high nutrient conditions and some of these species may be harmful to aquatic life and human health. Their toxins can lead to fish death and accumulate in shellfish. Fast-growing algal species (e.g. coontail - Ceratophyllum demersum) may be favoured changing the existing habitat conditions, such as increased shading.<br><br>Other water parameters can also change including turbidity which can alter the photosynthetic ability of algal plants and affect the feeding of predators that rely on vision (e.g. northern pike - Esox lucius) |
| Organic pollutants (petroleum, dyes, pesticides, surfactants and pharmaceuticals) | Changes in biology (e.g. reproductive rates/fecundity), species health and ultimately changes in abundance and species composition | This includes priority substances listed in Annex II of Directive 2008/105/EC and Persistent Organic Pollutants (POPs) governed by the 2001 Stockholm Convention. Many organic pollutants act as 'endocrine disruptors' interfering with reproductive hormones, increasing the risk of cancerous growths and deformations, and disturbing the immune and nervous system functions. |
| Inorganic pollutants (Heavy metals, persistent chemical compounds) | Changes to species condition ultimately causing species loss and changes to composition | Bioaccumulation through the food chain impacting on fecundity and survival. The accumulation of harmful pollutants in prey species can carry the toxins further in the food chain and have cascading effects. |
| Pathogens | May impact on species health | Mass mortality of populations due to disease. Pathogens may include viruses, bacteria, protozoa and helminths. |
| Thermal pollution | Species extinction Habitat degradation | Water used as a cooling agent may be pumped back into streams and coastal waters above the ambient temperature of natural water bodies. This can affect oxygen levels in the water, the survival and fertility of species, and the ecosystem in general. |

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Salinity changes | Loss of saline sensitive species and habitats | The salinity of water bodies can increase for example due to brine discharges from salt caverns; and may decrease due to freshwater discharges into saline environments. |
| Suspended solids | Smothering of organisms and interference of feeding mechanisms | Activities in water bodies may introduce or resuspend fine silts into the water causing a plume which disperses and may settle onto reefs, smothering organisms and interfering with their feeding mechanisms. These sediments may also carry other toxins such as heavy metals. Activities includes maritime dredging of harbours and construction but also relates to runoff from land. |
| Radioactive pollutants | Radioactive elements can be absorbed by small organisms and transmitted up the food chain, to fish, and marine mammals, potentially causing death, cancer, or genetic damage. | Under the London Convention the dumping of radioactive waste at sea is prohibited unless it fulfils exemption criteria developed by the International Atomic Energy Agency (IAEA). However, such waste finds its way into waterbodies from nuclear installation discharges, historic dumping sites, atmospheric fallout, leaching through contaminated soils as well as damage to power plants from natural environmental disasters, human error and war. |

### 3.4.3 Change in Ecosystem services

Table 8 presents the changes in ecosystem services as a consequence of biodiversity impacts from water pollution. Contaminants in groundwater may also contaminate surface soils but this is a direct impact, rather than being mediated by biodiversity.

*Table 8. Ecosystem services affected by water pollution impacts on biodiversity*

| Ecosystem service affected | Examples |
| --- | --- |
| **Provisioning services** | |
| Biomass provisioning | Impacts to populations of commercial fish species.<br>Pathogens contaminating fresh water sources that are used as drink water supplies for agricultural livestock present a risk to their wellbeing |
| **Regulating services:** | |
| Water purification services | Water pollution may impact on vegetation that would otherwise assist in the purification of water |
| Water flow regulation services | Increased influx of nutrients can cause plants (such as the invasive weed *Phragmites australis*) to grow rapidly and obstruct the flow of waterways. |
| Flood mitigation services | Clogging of waterways from excess nutrients and vegetation can reduce mitigation of flood waters. |
| Coastal storm protection | Water pollution can reduce the abundance of vegetation such as mangroves, coral reefs and seagrass beds that provide protection from coastal storms. |
| Biological control services | Water pollution can result in losses of biological control species, e.g. a decline in fish species can cause more issues with e.g. mosquitos. |
| Nursery population and habitat maintenance services | Due to loss of species and habitats from water pollution |
| **Cultural services:** | |
| Recreation-related services | Contaminated water bodies will be closed to recreational activities (e.g. blue-green algae toxins) |
| Visual amenity services | Due to loss in habitat quality and species abundance |
| Education, scientific and research services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.5 Land and seabed use

### 3.5.1 Introduction

Land (and by extension, seabed) use change is defined by IPBES as "the change in the use or management of land by humans, which may lead to a change in land cover." Business activities that result in changes to land use are for example residential and industrial development, agri- and aqua- culture, mining (e.g. open cast and seabed) and forestry (Salafsky et al., 2007).

Land or seabed use can be defined by the area and type of land or seabed used or converted. The Transparent NCMA methodology discusses how to measure land use change and the relevant indicators.

However, different land/seabed uses can result in secondary impact drivers and consequent changes in the quality of the land or seabed, such as the introduction of pollutants directly to the soil and soil erosion. As Transparent doesn't have a separate category for soil pollutants, these are considered here as secondary impacts within the impact pathway linked to land use. Changes to water flow patterns are also included here as land development within waterbodies can redirect streams and change coastlines. An example is the drainage of wetlands which can change natural water levels. Note that air and water pollution linked to different land uses are captured in a different impact driver category, as is the introduction of invasive alien species (IAS) via land uses such as agriculture for example. The impact on biodiversity can be considered under land use. However, the oxidation and decomposition of the organic matter in the wetland leads to emissions of $CO_2$ and $N_2O$. This part of the impact pathway would be considered under Section 3.1 with the indicator being the quantity of gas emitted per hectare and per year per unit of activity data associated with the loss of these gases following the drainage for agriculture. Relevant impact pathways are explored in Table 9.

Some forms of land use, such as biomass production (the introduction and growth of a species) can alter the species and/or habitat composition of an area. For example, monocultural forest production changes the pre-existing soil structure, and reduces the plant and animal life that the forest and its soils supported. Other forms of land use can introduce pollutants as secondary impact drivers, e.g. landfilling (a form of land use) can result in leachates and gases from the decay of waste. Acid rain may then be caused by gases released from landfills, which can affect the acidification of soils and ecosystems.

Businesses may also undertake land or seabed use activities that have a positive impact on biodiversity. Examples of positive impact pathways include restoring ecological habitats, rewilding and nature-based solutions. The growing of oyster and other filter feeding shellfish that filter water pollutants can help to improve water quality for other organisms.

### 3.5.2 Biodiversity Impact and Measurement

The main metric for direct land use is the measurement of the area of land used or converted (km$^2$), by type of ecosystem type (before and after change) and business activity. The TNFD recommendations give sector-specific examples such as the area of a forest plantation, the area of a dam and it's associated waterbody, or the area of seabed mining.

An assessment of impact should consider what land cover was there in the past. At a site level, biodiversity monitoring can be upgraded through the use of modern technologies such as drones, Artificial Intelligence algorithms, and remote sensing.

Impacts from soil pollution can be measured through soil biodiversity indices which refer to measures of richness (bacterial richness, fungal richness) and the relative abundance of guilds of soil.

Changes in water movement as a result of reclamation projects for example can be estimated via hydrodynamic modelling. Infiltration capacity, measured in mm/hour, is linked to the function of soil to store water and can be used to identify environmentally sensitive areas. Water storage capacity to calculate soil water balance, expressed in depth (mm) or volume.[16]

There are many global level models for land use change which have been reviewed by Vidal-Legaz et al, 2016, Sala et al. 2019 and Lammerant et al. 2021, 2022. EXIOBASE provides data on land use by sector for 15 different land use types and 163 industries. The Ecoinvent database is a life cycle inventory covering a range of sectors and providing impact scores for "land use" throughout the supply chain.

Many LCA methodologies assess the impact of land use on biodiversity (endpoints) with midpoint indicators being the area of land being occupied and/or transformed. Models include ReCiPe and LANCA.

In ReCiPe, the midpoint characterisation factors (in PDF.m$^2$/m$^2$·yr annual crop equivalents) refer to the relative species loss caused by a specific land use type (annual crops, permanent crops, mosaic agriculture, forestry, urban land, pasture). Relative species loss is determined by comparing field data on local species richness in specific types of natural and human-made land covers (De Baan et al. 2013; Elshout et al. 2014). For land conversion, passive recovery towards a (semi-)natural, old growth habitat is assumed, based on average recovery times from Curran et al. (2014).

LANCA is a multi-indicator model specifically developed for soil quality assessment within a LCA. Country average characterisation factors express the alteration of soil quality of the current land use type with respect to a reference situation (Bos et al, 2016).

Other approaches used for measuring biodiversity loss, impact and risk with a focus on ecosystems, habitats and land cover include: GLOBIO, Biodiversity Impact Metric (BIM), and Global Biodiversity Score (GBS). The Agrobiodiversity Index can explore indicators such as changes in "landscape complexity" and

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[16] https://esdac.jrc.ec.europa.eu/public_path/shared_folder/projects/DIS4ME/indicator_descriptions/water_storage_capacity.htm

its impact on biodiversity and improved ecosystem service provisioning (Jones et al., 2021). GLOBIO additionally has a 'fragmentation pressure' to estimate the impact of land use change on the movement of species.

*Table 9. Biodiversity-focused impact pathways (examples) from land and seabed use*

| Impact driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Area of land / seabed used or converted | Direct loss of habitats and species through destruction or conversion.<br><br>Change to other types of habitats. | Permanent physical change to another substratum or habitat type |
| Soil / sediment pollutants | Changes in species composition and abundance, especially of soil sensitive species<br><br>Changes in ecosystem functions, e.g. from changes in soil biodiversity (Wagg et al., 2014). | Introduction of pollutants to land or the seabed (e.g. fertilisers, pesticides) can result in changes to soil quality. |
| Creation of physical barriers | Fragmentation of habitats resulting in changes in species movement and collision (and ultimately on populations). | Physical barriers can obstruct species movements (e.g. within & between roosting, breeding, feeding areas) and regional/global migrations (e.g. birds, eels, salmon, and whales). Ultimately this can impact species populations and viability. Both include river movements (where tidal barrages & devices or dams could obstruct movements) or movements across open waters (offshore wind farm, wave or tidal device arrays, mariculture infrastructure). |

### 3.5.3 Change in Ecosystem services

As land use change can affect many different aspects of the environment and ultimately impact all habitats and species in a location, it potentially impacts all ecosystem services (Table 10).

*Table 10. Ecosystem services affected by land use change impacts on biodiversity*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Some land uses may impact natural habitats used for wild foraging.<br>Seabed uses may impact benthic habitats that are important nursery habitats for commercial fish species. |
| Genetic material | Local land use changes may have high impacts on local populations and genetic stocks. |
| **Regulating services:** | |
| Global climate regulation | Large scale land use changes, e.g. loss of vegetation through deforestation, can impact on global and local climate regulation. |
| Rainfall pattern regulation | |
| Local climate regulation | |
| Soil quality regulation services | Soil quality and retention will be affected by the removal of vegetation. |
| Soil and sediment retention services | |
| Water purification services | Water quality and flow will be affected by the removal of vegetation as well as morphological changes to waterbodies such as the redirection of streams. This may lead to reduced flood mitigation and increased risk on inundation. |
| Water flow regulation services | |
| Flood mitigation services | |
| Coastal storm protection | Redevelopment of coastlines and removal of dampening coastal vegetation and habitats (such as mangroves and saltmarshes) may reduce the protection of coastal assets from storms. |
| Pollination services | Changes in habitats and environmental quality may result in impacts on pollinator, biological control and nursery species. |
| Biological control services | |
| Nursery population and habitat maintenance services | |
| **Cultural services:** | |
| Recreation-related services | Impacted due to loss of recreation-related species and habitats, e.g. wetlands and birdwatching activities |
| Visual amenity services | Visual aesthetics may be impacted due to change in habitat type and loss in habitat quality |
| Education, scientific and research services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.6  Solid Waste

### 3.6.1  Introduction

Solid waste (such as plastics and litter) is defined as materials which can be deposited on land or the seabed but also make its way into waterways. An example is derelict fishing gear, one of the most abundant types of marine litter. Solid waste emissions in the form of suspended particulate matter in air is covered under non-GHG emissions and suspended particulate matter (sediments) in water is covered under Water Pollution. For those that follow the Transparent Methodology, you will also note that this section instead focuses on inputs of solid waste to the environment as an impact driver; Transparent focussed on Waste Management which is an activity that includes a range of different impact drivers, e.g. emissions of non-GHGs from incineration of waste. The structure here is considered more consistent with the approach to other impact drivers above.

### 3.6.2  Biodiversity Impact and Measurement

From solid waste in landfills, pollutants can be released into soil, water and air. Leachate will occur when surface water, such as rain, runs through the waste and extracts toxic solutes. These leachates can be toxic for animals and plants, especially if they pollute water sources used as drinking water. Ecotoxicologic research in China discovered the leachates from landfills contributed to damage in roots of crops (Sang & Li, 2006). There is a risk for plants surrounding landfill sites.

For solid wastes in waterbodies, direct measurements and agent-based modelling can be used to determine the concentration and spatial extent of solid wastes from point sources such as rivers which can then be assessed against sensitivity criteria for species and habitats. For larger areas of dispersal, such as litter in the ocean, remote sensing can be used to follow the extent of the 'plastic soup'.

Global models and LCA models examine the impact of waste streams from different sectors. Some may be estimated from agricultural yields for example. Source-pathway-receptor relationships can be used to assess the likelihood and severity of agricultural impacts from leachates in landfills.

LCA software SimaPro can be used to conduct contribution, sensitivity and uncertainty analysis and ReCiPe as the impact methodology in studies to compare waste treatment scenarios for products (e.g. derelict fishing gear, Schneider et al., 2023).

IMPACT 2002+ is a life cycle impact assessment methodology. It is especially useful for comparative assessment of human toxicity and ecotoxicity for which effect factors are based on mean responses rather than on conservative assumptions (Jolliet et al., 2003).

*Table 11. Biodiversity-focused impact pathway from solid waste*

| Impact Driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Introduction of solid waste (e.g. plastics and litter) | Reduced species condition and ultimately abundance | Accumulation of various types of plastics, risking physical entanglement of species (drowning and strangulation) and disruption of natural food patterns (e.g. accumulation of waste in the intestines of aquatic species and birds), leading to malnutrition |
| Introduction of pollutants due to decay of solid waste | Habitat degradation and reduced condition and extent. | Leachates from solid waste (heavy metals, organic compounds, etc.) can pass through waterbodies (rivers, estuaries, sea) and terrestrial soils or marine sediments and degrade it, making it unfavourable for organisms. For example, when plastic is exposed to ultraviolet radiation, it will slowly degrade and leach chemicals into surrounding waters (Gewert et al., 2021) |

### 3.6.3  Change in Ecosystem services

Many impacts from litter have a direct impact on ecosystem services without being mediated by changes in biodiversity, such as odour nuisance, reduced visual amenity and contamination of drinking water sources. Those ecosystem services that are impacted via changes in biodiversity are outlined in Table 12.

*Table 12. Ecosystem services affected by solid waste impacts on biodiversity*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Bioaccumulation of microplastics in filter-feeding farmed shellfish, reducing their condition and entering human food chains. |
| **Regulating services:** | |
| Soil quality regulation services | Toxic leachates leaking from waste, e.g. in landfills, can be released in the soil and form a toxic environment. |
| Soil and sediment retention services | Soil retention will be affected by loss of vegetation from toxic leachate. |
| Water purification services | Leachates can damage habitats in ponds and lakes, and damage plant communities that offer purification services. |
| Water flow regulation services | Large pieces of solid waste or litter clumped together can create blockages in canals, streams and rivers |
| Flood mitigation services | Clogging of waterways from (clumped) solid waste can reduce mitigation of flood waters. |
| Pollination services | Changes in habitats and environmental quality may result in impacts on pollinator, biological control and nursery species. |
| Biological control services | |
| Nursery population and habitat maintenance services | |
| **Cultural services:** | |
| Recreation-related services | Loss of biodiversity due to solid waste and litter will affect wildlife watching activities |
| Visual amenity services | Visual aesthetics may be impacted due to the litter and waste |
| Education, scientific and research services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.7 Resource use and exploitation

### 3.7.1 Introduction

There is some debate on what is included under the category of resource use (JRC, 2011). Primarily it covers the use of biological materials, i.e. the use of biodiversity directly. This would include wild fisheries, hunting and logging of naturally occurring vegetation, for example.

The impacts from farming biological resources (e.g. crops, forestry and aquaculture) are largely considered under land use, as well as many pressures that they present (e.g. water and soil pollution). However, relevant to this section at a biological level might be the impacts of introducing or extracting biodiversity from the local ecology.

The extraction of abiotic resources such as minerals, fossil fuels and aggregates, for example, tend to present a range of different pressures which are already represented under the other categories such as water pollution (see Section 3.4) and land use (see Section 3.5). However, there may be aspects of the physical extraction of these resources (abrasion or removal) that have an impact on biodiversity through unintentional physical damage. These biological impacts from the extraction of abiotic resources are considered here.

Water use as a resource has unique impact drivers and consequences for the environment and is treated as a separate category (see Section 3.3).

The main impact pathways are outlined in Table 13.

### 3.7.2 Biodiversity Impact and Measurement

The level at which extraction and related biodiversity impacts need to be modelled depend on the spatial scale of the resource itself. For forestry, this might be quite localised at a watershed level with data sourced through satellite data. For fisheries, modelling occurs at the level of the fish stock which is regional for pelagic fish, eg. The North-East Atlantic region or the Baltic Sea but at smaller waterbody scales for shellfish or freshwater fisheries.

LCA 'Resource use' methods are typically only concerned with energy or mineral use and apply scarcity models which are not relevant to biodiversity (although energy use may be relevant under the wider Transparent Methodology). An exception is the Product Biodiversity Footprint tool which incorporates a qualitative score for the overexploitation of species in an LCA framework[17].

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[17] http://www.productbiodiversityfootprint.com/

Rates of extraction can sometimes be used as a proxy for loss of biodiversity and sustainability, e.g. deforestation rates or fisheries catch rates. Abiotic and biotic extraction indicators are available in some global datasets such as EXIOBASE including quantitative data in kilo tonnes for crop residues, primary crops, fodder crops, grazing, fisheries, forestry, metal ores, non-metallic minerals and fossil fuels.

High-level screening of the impacts from resource extraction can be provided via ENCORE to identify where the most important impacts on biodiversity are in a company or sector's supply chain.

The Biodiversity Integrated Assessment and Computation Tool (B-INTACT) provides a quantitative assessment of the extent of forestry (extraction of timber) and a qualitative assessment of the over-exploitation of species. The tool relies on the MSA metric and is based on the GLOBIO model. However, it has been adapted for project-level assessments at a site-level (FAO, 2021).

*Table 13. Biodiversity-focused impact pathway from resource use and exploitation*

| Impact Driver | Change in biodiversity | Example of change in biodiversity |
|---|---|---|
| Extraction of biotic material (fishing, forestry, hunting) | Changes in population abundance and biodiversity composition. | The unsustainable loss of individuals of a species though overexploitation (e.g. through fishing or hunting) can severely alter the species composition in the area and therefore disrupt the overall ecological balance, e.g. population collapse and tropic level shifts. Extraction includes deforestation which can lead to habitat fragmentation and reduced habitat condition as well as impacts on dependent species, e.g. through loss of wildlife corridors. Removal of forests that mitigate climate change may have global secondary impacts. The extraction of biotic material may also have *secondary impacts* for other ecosystems. For example, bottom trawling not only extracts fish, but also destroys habitats on the seabed. |
| Extraction of abiotic materials | Destruction of biodiversity within the site | Examples of abiotic extraction include mining for minerals, marine aggregate extraction and salt extraction. The removal of such materials can cause damage and mortality to organisms living within or adjacent to the extraction site. |

### 3.7.3  Change in Ecosystem services

Resource use and exploitation has the potential to cause regional or local level change in habitats and species, which may be irreversible, thereby affecting a wide range of ecosystem services (Table 14).

*Table 14. Ecosystem services affected by resource use and exploitation impacts on biodiversity*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Habitat change from extraction activities may result in impacts to biomass used for food and materials. For example, the extraction of marine aggregates from the seabed could affect nursery grounds for commercial fish species. |
| Genetic material | Local changes due to exploitation may have high impacts on local populations and genetic stocks. |
| **Regulating services:** | |
| Global climate regulation | Large scale extraction, e.g. deforestation, can impact on global and local climate regulation. |
| Rainfall pattern regulation | |
| Local climate regulation | |
| Soil quality regulation services | Soil quality and retention will be affected by the removal of vegetation. |
| Soil and sediment retention services | |
| Water purification services | Water quality and flow will be affected by the removal of vegetation as well as morphological changes to waterbodies such as the redirection of streams. This may lead to reduced flood mitigation and increased risk on inundation. |
| Water flow regulation services | |
| Flood mitigation services | |
| Coastal storm protection | Mangroves forests are often harvested for wood. If this is unsustainable then the coastal protection service provided by the forest is lost. |
| Biological control services | Ecological shifts from resource extraction may result in the loss of species that provided a biological control service, such as the loss of keystone predators. |
| Nursery population and habitat maintenance services | Extraction activities can reduce or damage the habitats that provide nursery functions. |
| **Cultural services:** | |
| Recreation-related services | Sandeel fisheries impact on bird populations that are dependent on sand eels, thereby impacting bird watching activities. Recreational fishing may be impacted by commercial fisheries and other extractive activities such as mineral extraction. |
| Visual amenity services | Visual aesthetics may be impacted due to change in habitat type and loss in habitat quality |
| Education, scientific and research services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

## 3.8  Invasive alien species

### 3.8.1  Introduction

Invasive Alien Species (IAS) are species introduced into places outside their natural range that have negative impacts on native biodiversity. They have been identified by IPBES as one of the most important direct drivers of biodiversity loss and change in ecosystem services (IPBES, 2023). IAS are defined and governed by various legislation, including international conventions (e.g. Convention on Biological Diversity, Bern Convention and Ballast Water Management Convention), regional regulations (e.g. the EU Invasive Alien Species Regulation 1143/2014) and national regulations. National regulations are particularly important for defining what species are considered invasive for a particular country as they are not alien or invasive everywhere throughout their range. Information on invasive species is held in the Global Invasive Species Database and Global Register of Introduced and Invasive Species (GRIIS) managed by the IUCN[18] as well as the European Alien Species Information Network (EASIN).

The term "biological invasion" is used to describe the process involving the intentional or unintentional transport or movement of a species outside its natural range by human activities (IPBES, 2023). The most important pathway for the introduction of IAS is international trade, followed by other well recognised vectors including agriculture, aquaculture, horticulture, international travel and tourism, and retail sectors such gardens, aquaria and pets. Codes of conduct exist for some economic sectors[19].

At the same time, climate change is making areas more hospitable to new species as their distribution and migration patterns change. None of the impact drivers and pathways described in this report act in isolation and others such as land and seabed use and resource extraction, may combine to amplify the impacts from biological invasions (IPBES, 2023).

### 3.8.2  Biodiversity Impact and Measurement

Data are available for many invasive alien species, some of which have global coverage data at a coarse resolution. Sector-specific monitoring includes detection of escaped individuals from aquaculture and testing of ballast water tanks on ships. Therefore, some sectors will have reported monitoring data to base an assessment on. Other survey-based methods include eDNA, camera trapping, bioacoustic surveys and remote sensing.

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[18] http://www.iucngisd.org/gisd/

[19] https://easin.jrc.ec.europa.eu/easin/Documentation/Codesofconduct; https://www.glofouling.imo.org/publications-menu

Measures of the pressure include relative alien species richness and relative alien species abundance. The 'Rate of Invasive Alien Species Spread Indicator' measures the change in impact risk from IAS that are expected to have entered a new region.

The Product Biodiversity Footprint tool incorporates a qualitative score for the impact from invasive species on biodiversity in an LCA framework[20]. The Biodiversity Integrated Assessment and Computation Tool (B-INTACT) covers impacts from invasive species via user input. The tool relies on the MSA metric and is based on the GLOBIO model. However, it has been adapted for project-level assessments at a site-level (FAO, 2021). Table 15 provides the key impacts that arise from IAS.

*Table 15. Biodiversity-focused impact pathways from invasive alien species*

| Impact driver | Change in biodiversity | Examples of change in biodiversity |
|---|---|---|
| Introduction of Invasive Alien Species | Loss of native species and extinction from predation by IAS on native species | Chinese mitten crabs predate upon native fish, crustaceans, and invertebrates. The lionfish *Pterois* predates upon coral reef fish. |
| | Changes to species condition affecting abundance and extinction risk from competition with native species for food and space | Farmed non-native fish such as trout that escape can become invasive alien species. With the lack of natural predators and a high survival rate, the species can outcompete native species and degrade habitats and ecosystems. |
| | Changes to species condition from introduction of pathogens to native species | Introduction to Europe of north American crayfishes infected with the fungus *Aphanomyces astaci* caused economic losses to fisheries (Vrålstad et al., 2011) |

### 3.8.3 Change in Ecosystem services

Invasive alien species tend to express their impacts at a local level, e.g. on local habitats and species. However, because of their rapid invasive spread, their impact can end up covering entire regions. Therefore a wider range of affected ecosystem services are evidenced in the literature (Charles & Dukes, 2007; Pejchar & Mooney, 2009) (Table 16).

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[20] http://www.productbiodiversityfootprint.com/

*Table 16. Ecosystem services affected by invasive alien species impacts on biodiversity*

| Ecosystem service affected | Examples |
|---|---|
| **Provisioning services** | |
| Biomass provisioning | Introduction to Europe of north American crayfishes infected with the fungus *Aphanomyces astaci* caused economic losses to fisheries (Vrålstad et al., 2011) |
| Genetic material | Invasive species may have high impacts on local populations and genetic stocks. |
| **Regulating services:** | |
| Global climate regulation | Invasive species may smother and destroy large tree species, reducing their mitigation of global climate regulation |
| Local climate regulation | *Bromus tectorum* in western North America has increased fire frequency by increasing fuel-bed flammability; outcompeted native vegetation is not as well adjusted. |
| Soil and sediment quality regulation services<br>Soil and sediment retention services | Slipper limpets (*Crepidula fornicata*) form dense mats changing the marine substratum making it unsuitable for deposit feeding bivalves.<br>Chinese mitten crabs can form dense burrowing colonies in riverbanks. This can cause erosion, the silting up of water ways affecting other wildlife |
| Water purification services<br>Water flow regulation services | The water hyacinth (*Eichhornia crassipes*) rapidly invades waterways and lakes where it can double in biomass in two weeks forming dense mats that affect water supply and quality. This is turn affects existing habitats and species |
| Flood mitigation services | Many invasive species are known to increase flood risk, e.g. Himalayan Balsam and Knotweed (Holdsworth, R., 2021; Townsend et al., 2022) die back in winter leaving large areas bare of vegetation unable to soak up or slow down rapid runoff during rainfall. |
| Coastal storm protection | Invasive species may influence coastal storm protection positively (Charbonneau et al., 2017) or negatively (James et al, 2020). |
| Pollination services<br>Biological control services | Introduced invasive species can outcompete native pollinators and biological control species. |
| Nursery population and habitat maintenance services | Introduced invasive species can reduce or damage the species and habitats that provide nursery and habitat maintenance functions. |
| **Cultural services:** | |
| Recreation-related services | Invasive species can impact recreational activities such as fishing and damage local economies (e.g. Lauber et al, 2020). They may also reduce access to an area and threaten human health and safety. |
| Visual amenity services | Invasive species often form a monocultural mass of weed of low biodiversity which is reduced in visual aesthetics. |

| Ecosystem service affected | Examples |
|---|---|
| Education, scientific and research services | Impacts to biodiversity has the potential to affect all dependent cultural ecosystem services. |
| Spiritual, artistic and symbolic services | |
| Ecosystem and species appreciation services | |

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# ANNEX: Cross Walk of different Impact Driver (Pressure) typologies

| Transparent | IPBES (ref#? by Align) | TNFD (2023b) | SBTN |
|---|---|---|---|
| *Impact Drivers* | *Direct Drivers of Change* | *Drivers of nature change* | *Pressures* |
| GHG Emissions | Climate Change | Climate Change | GHG Emissions |
| Non-GHG Air Emissions | Pollution: | Pollution & Pollution removal (incl non-GHG air, water and soil pollution) | Pollution: |
| | Non-GHG Air Emissions | | Non-GHG Air Pollutants |
| Water Pollution | Water Pollution | | Water Pollution |
| Solid Waste | Solid Waste | | Solid Waste |
| | Soil pollution | | Soil pollution |
| Land and Seabed use incl Soil pollution | Land/Sea-use change | Land / Freshwater /Ocean use change | Ecosystem use and use change |
| Water Consumption | Natural resource use and exploitation | Resource use / replenishment | Water Use |
| | | | Other resource use |
| | Invasive Alien Species | Invasive Alien Species +/- | Biological alterations/interferences |
| | Zoonoses | | Disturbances |