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| Terrestrial Biodiversity |
| A DPSIR summary of the state of terrestrial biodiversity |
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Terrestrial biodiversity

# Introduction

Biodiversity is the variety and variability between living organisms on multiple scales including genes, species, and ecosystems (Cain, Bowman, & Hacker, 2014, p. 364) (Rosser & Walpole, 2012). Terrestrial biodiversity relates to biodiversity on the land rather than in marine or aquatic ecosystems. The DPSIR model, which stands for Drivers-Pressure-State-Impact-Response, is a tool used by, among others, the European Environment Agency to study and organize cause-and-effect relationships relating to natural resource management and the environment while considering economic, social and scientific information (Ness, Anderberg, & Olsson, 2008). In this framework, drivers or driving forces are social, economic or environmental developments such as, for biodiversity, population growth or economic growth (Svarstada, Petersen, Rothmanc, Siepeld, & Wätzolde, 2008). Pressures are consequences of these driving forces, which in turn effect the state (condition or changes) of the environment; the impacts of this state are damages to the environment or society, and finally responses are societal, decision-making measures implemented to mitigate or adapt to any of the first four phases (Ness, Anderberg, & Olsson, 2008). On the DPSIR model, biodiversity (including terrestrial biodiversity) can be considered a state[[1]](#footnote-1) (Houa, Zhoub, Burkharda, & Müllera, 2014). In this report, the current state of terrestrial biodiversity will be discussed in reference to the DPSIR model.

# 1. Driving forces[[2]](#footnote-2)

### 1.1. Increases in human population

#### 1.1.a. Food production (2.1,2,3,4,5)

Increasing global population has led to an increase in the demand for food (WWF, 2014); this results in conversion of land for agriculture, increase in greenhouse gas concentrations including the production of methane by livestock, crossover of invasive species from agriculture, and direct overexploitation of plants and animals for food. Food production leads to increase in nitrogen pollution by a variety of mechanisms including fertilizer, growing certain crops including soy, or flooding fields for rice (Cain, Bowman, & Hacker, 2014, pp. 576-577).

#### 1.1.b. Infrastructure (2.1,4)

Growing populations result in residential and commercial development and related consumption demands. These demands lead to habitat change (i.e. road building resulting in fragmentation or conversion of forests into urban areas), along with overexploitation of resources such as wood for construction (WWF, 2014).

#### 1.1.c. Energy (2.1,2,5)

The use and production of fossil fuels leads to production of CO2, a greenhouse gas, along with air and water pollutants (Covert, Greenstone, & Knittel, 2016). Habitat loss can also be attributed to energy production, for example in dam construction or mining (Rosser & Walpole, 2012).

### 1.2. Increases in global economic activity (2.3)

Global economic activity has increased by a factor of seven in the past 50 years and is expected to continue; a facet of this, globalization, increases interdependence and removes regional barriers. The associated increase in trade and travel results in the spread of invasive species (Millennium Ecosystem Assessment, 2005).

# 2. Pressures

According to the 5th Global Environmental Outlook report, there are 5 main threats (which can be considered DPSIR pressures) to biodiversity: in order of importance these are habitat loss, climate change, invasive species, overexploitation and pollution (Rosser & Walpole, 2012)­­­­. These 5 main factors are also stated in many other publications (e.g. (Cain, Bowman, & Hacker, 2014, pp. 528-534), (Millennium Ecosystem Assessment, 2005)). Occasionally, some additional factors are cited (e.g. (Alkemade, et al., 2009); these factors can generally be condensed into the 5 main categories.

Many of these pressures result in deaths and then extinctions or extirpations (i.e. local extinctions) of species or reduction in population sizes[[3]](#footnote-3). This constitutes a reduction in biodiversity because firstly, biodiversity relates to the number of species present on earth, secondly, communities with uneven distributions of organisms are less diverse (see 3.1.) and finally losses in individual species can lead to collapses of ecosystems due to interconnectivity such as interspecific facilitation and predator-prey relations (Cain, Bowman, & Hacker, 2014, pp. 367-375).

### 2.1. Habitat Change

#### 2.1.a. Habitat degradation

Habitat degradation is human-caused change (e.g. logging) that reduces habitat quality for certain species. As it affects some species more than others, it results in changes in evenness and thus a loss of biodiversity (see 3.1). Habitat degradation also leads to increased venerability to invasive species (Cain, Bowman, & Hacker, 2014, p. 530).

#### 2.1.b. Habitat fragmentation

The effects of habitat fragmentation, the division of originally continuous habitat into smaller, separated areas due to human impacts such as road building, as per the island biogeography theory, depend on island size and separation distance. Larger ‘islands’ or fragments, that are closer together, will have higher species richness than smaller, more isolated fragments (Cain, Bowman, & Hacker, 2014, p. 420). This is because smaller habitats cannot support species that require a larger range[[4]](#footnote-4), or as many individuals as larger fragments. A locally declining population is more likely to be resuscitated by a closer nearby population. Furthermore, habitat fragmentation results in isolation, meaning that species cannot disperse across a landscape in order to find resources. Finally, more fragmented areas have higher proportions of edge areas that have differences in climate and where access is easier for invasive species and pollutants (Rei, et al., 2010).

#### 2.1.c. Habitat loss

Habitat loss is the complete conversion of habitat into other use areas by humans, leading to loss of entire ecosystems and death of organisms previously inhabiting the area. It has been uneven between ecosystem types, for example effecting 50% of wetlands in the 20th century (Rosser & Walpole, 2012). Cultivated systems such as livestock production areas cover at least quarter of the earth’s terrestrial surface and 10-20% more grassland and forestland is expected to be converted by 2050 (Millennium Ecosystem Assessment, 2005).

### 2.2. Climate change

Climate change, a DPSIR pressure on biodiversity, leads to extinctions because species (especially specialists) are unable to adapt to rapid changes in temperature, shifts in climactic zones or extreme weather events such as droughts and floods (Omann, Stocker, & Jäger, 2009). These changes in climate can lead to deaths due to trauma from extreme conditions or decreases in water availability and quality (Millennium Ecosystem Assessment, 2005).

### 2.3. Invasive species

Invasive alien species (introduced, non-native species with growing populations that have large effects on communities) can result in large declines or extinctions of native species by either out-competing them, preying on them, or changing the properties of the ecosystem around them (Cain, Bowman, & Hacker, 2014, p. 530). Relatedly[[5]](#footnote-5), diseases can cross over from domesticated animals, leading to deaths in wildlife.

### 2.4. Overexploitation

Overexploitation, harvesting at a rate not sustainable for the population, leads to species extinctions and thus a loss of biodiversity as above. Harvesting food and other resources for fueling a growing population, from a diminishing natural area is one example of this, but it can also include harvesting live or dead animals for trade, or overhunting. Rare species can become more sought after, raising their value and leading to an overexploitation vortex towards extinction (Tournant, Joseph, Goka, & Courchamp, 2012). Overexploitation can also lead to habitat degradation (Cain, Bowman, & Hacker, 2014, p. 531).

### 2.5. Pollution

Pollutants cause physiological stresses on organisms along with habitat degradation and biodiversity loss. For example, persistent organic pollutants such as DDT or flame retardants get bioaccumulated and biomagnified[[6]](#footnote-6), causing immune, reproductive, and developmental problems in mammals (Cain, Bowman, & Hacker, 2014, p. 533). Human-caused increases in pollutants are considered one of the most important pressures on terrestrial ecosystems; their importance is expected to increase in the future. (Millennium Ecosystem Assessment, 2005). More biologically available nitrogen is now produced by humans than nature; the deposition of nitrogen into terrestrial ecosystems leads directly to lower plant diversity. Phosphorus has similar effects to those of nitrogen; its use has tripled between 1960 and 1990 (Millennium Ecosystem Assessment, 2005).

# 3. State[[7]](#footnote-7)

### 3.1. Measurement

In order to comment on the state of biodiversity, the methods of measurement of biodiversity must be outlined.

It is difficult to quantify biodiversity, or even the rate of biodiversity loss for several reasons. To start with, as per the definition, biodiversity ranges from genetic differences between species up to global scales. For example, it can be said that there are four defined levels of biodiversity in ecology[[8]](#footnote-8).

Measures of local or alpha biodiversity can be calculated via several different indices. This could include species richness, the total number of organisms present, or other indices such as the Simpson Index, Shannon-Weiner index, or the Evenness index, which include not only the number of species present but also factors such as how similar the abundance of each species, in order to account for communities with very large numbers of organisms of few species not being very diverse.

Although species richness can be estimated on a global scale, it fails to give the whole picture as it ignores beta diversity and so doesn’t accurately represent effects such as biotic homogenization (see 3.2).

A further complication is that the very large, unknown number of species on the planet is difficult to estimate, and it is challenging to determine with certainty that a species is globally extinct. Nonetheless, for certain groups of species with more complete data, estimations can be made. For example, species extinctions in mammals and birds now happen at a rate of about 1 per year, which is quite extreme compared to a natural ‘background rate’ of the expected natural extinctions (derived from fossil record data) of 1 extinction per 200 years (Cain, Bowman, & Hacker, 2014, pp. 524-525). Nonetheless, including only extinctions as indicators of biodiversity loss is flawed because it omits smaller-scale biodiversity losses (i.e. if a species is only extirpated).

Several scientific studies have tried to estimate global biodiversity. For example, the PREDICTS database is a meta-analysis of studies with data pertaining to local-scale biodiversity across the planet and how it is effected by anthropogenic pressures (Hudson & Newbold, 2014). Another example of an attempt to estimate global terrestrial biodiversity uses extrapolation of data from local richness and measures of complementarity[[9]](#footnote-9) (Colwell & Coddington, 1994).

### 3.2. Worldwide trends

Biodiversity loss has already exceeded its planetary boundary[[10]](#footnote-10) (Rockstrom, et al., 2009)

#### 3.2.a. By pressure

Human activities, especially conversion and degradation of habitats, are causing global terrestrial biodiversity declines (Newbold, et al., 2015). The effects of the pressures on biodiversity (see 2.1-2.5) and their effects in the past century along with their current trend are outlined in the following table:

Table 1: Historical and current trends in impacts on biodiversity by pressure in selected terrestrial biomes, after (Millennium Ecosystem Assessment, 2005)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Threat  Biome | Habitat Loss | Climate Change | Invasive Species | Over-exploitation | Pollution |
| Boreal Forest | ↗ | ↑ | ↗ | → | ↑ |
| Temperate Forest | ↘ | ↑ | ↑ | → | ↑ |
| Tropical Forest | ↑ | ↑ | ↑ | ↗ | ↑ |
| Temperate Grassland | ↗ | ↑ | → | → | ↑ |
| Tropical Grassland | ↗ | ↑ | ↑ | → | ↑ |
| Desert | → | ↑ | → | → | ↑ |
| Mountain | → | ↑ | → | → | ↑ |
| Polar | ↗ | ↑ | → | ↗ | ↑ |

|  |  |  |
| --- | --- | --- |
| Effect in past century | Current trend | |
| Low | ↘ | Decreasing Effect |
| Moderate | → | Continuing Effect |
| High | ↗ | Increasing Effect |
| Very High | ↑ | Rapidly Increasing Effect |

From Table 1., it is clear that in the past, habitat loss has had the most high or very high effects biodiversity in terrestrial biomes. Those effects are generally expected to stay relatively constant. Contrastingly, climate change has primarily had low effects in the past but those effects are expected to rapidly increase in all terrestrial biomes.

#### 3.2.b. Species loss

The earth is losing species at an accelerating rate (Cain, Bowman, & Hacker, 2014, p. 524). According to the WWF’s Living planet report in 2014, there has been a sharp decline in biodiversity, marked by a 39% decrease in terrestrial species between 1970 and 2010 (WWF, 2014).

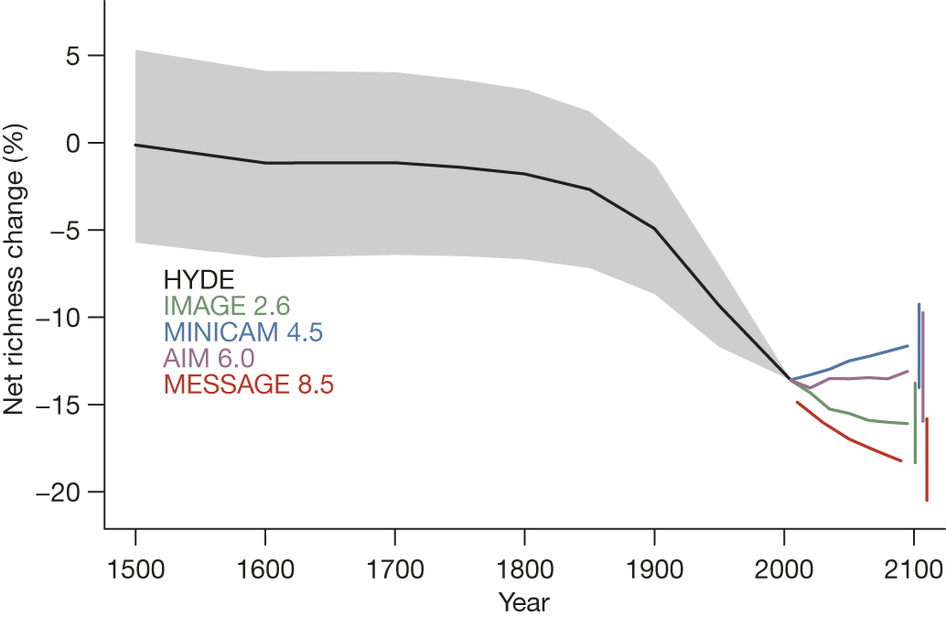


Figure 1: Projected net change in local richness, from (Newbold, et al., 2015)

Figure 1. shows a steep loss in biodiversity (by the species richness index) starting in the mid-1800s. The four predictions take into account different changes in land use, climate and human population sizes. Predictions show either a continued loss or a lessened net richness change; however, no predictions show biodiversity returning near pre-1800s levels.

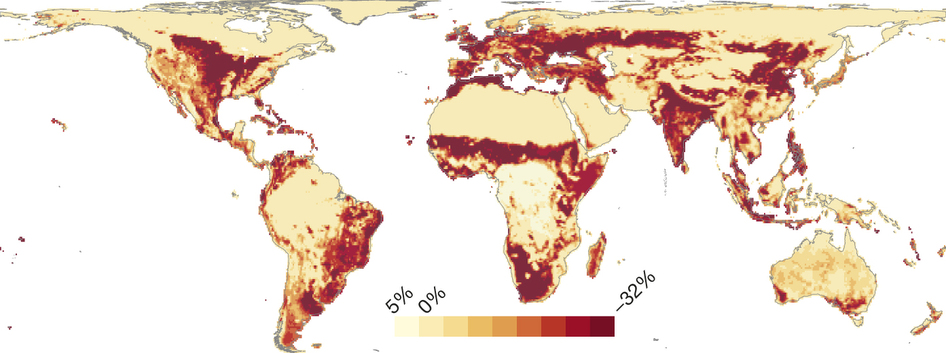


Figure 2: Net change in local richness by 2000 from (Newbold, et al., 2015)

Figure 2. demonstrates that, similarly to how biodiversity is not constant around the world[[11]](#footnote-11) local biodiversity loss varies by location, dependent upon driving factors and pressures.

#### 3.2.c. Biotic homogenization

Biotic homogenization is when groups of species become dominated by a small number of pervasive species and is an example of a loss in biodiversity ignored[[12]](#footnote-12) when considering only species richness. It is the result of humans having diverse impacts on species: some positive leading to the expansion of certain species, some negative leading to the decline of certain species. (Millennium Ecosystem Assessment, 2005).

# 4. Impacts

Ecosystem functions are biological processes involving the flow of nutrients and energy in, out and through food webs; ecosystem services are a subset of ecosystem functions: flows of value to humans based on the state or quantity of natural capital (Sukhdev, Wittmer, Schröter-Schlaack, & Nesshöver, 2010). Biodiversity loss decreases ecosystem functioning of terrestrial ecosystems (Cardina, et al., 2006). The impacts of the currently declining state of biodiversity can be categorized into ecosystem services (Sukhdev, Wittmer, Schröter-Schlaack, & Nesshöver, 2010). Although the ecosystem services relate explicitly to humans, they often have related effects on the environment which are also outlined below.

### 4.1. Ecosystem services[[13]](#footnote-13)

#### 4.1.a. Provisioning

##### 4.1.a.i Food

Increases in biodiversity result in increases in plant production (Winfree, 2013). This is because plant diversity increases plant production since multiple species can be more productive than a single species as they can occupy a greater range of niches. This leads to increases up the food web due to bottom-up effects and has positive impacts on humans because, for example, meat from wild animals is a critical food source for many countries.

##### 4.1.a.ii. Water quality

Ecosystems with greater species richness are more effective at removing nutrients from water. Excessive nutrient content is considered a leading cause of global water pollution (Cardinale, 2011).

##### 4.1.a.iii Human health

Biodiversity loss lowers the quantities of raw materials available for the discovery of potential drugs and biotechnology and effects the spread of human diseases (Alves & Rosa, 2007).

#### 4.1.b. Regulating

##### 4.1.b.i. Carbon fixation

Plants take in CO2 as they undergo photosynthesis and change it into organic carbon (Cain, Bowman, & Hacker, 2014, p. 113). Increased plant production from increased biodiversity (see 4.1.a.i.) results in more photosynthesis and thus more carbon fixation. The reduction of atmospheric CO2 , a greenhouse gas, reduces global warming and therefore biodiversity has a positive effect on both humans and the environment.

##### 4.1.b.ii. Biological control

Plant biodiversity promotes resistance to invasive species by lowering their ability to establish or thrive due to increases in crowding (Lugnot & Martin, 2013).

##### 4.1.b.iii. Pollination

Declines in pollinator biodiversity result in extinctions of other plant species (Abrol, 2012). Insect pollination, mostly by bees, is necessary for 75% of all crops that are used directly for human food worldwide (Abrol, 2012). In this way, declines in pollinator diversities contribute to other biodiversity declines along with lower food crop supplies for humans.

##### 4.1.b.iv. Stability & resilience

Biodiversity contributes to ecosystem resilience, including the ability to continue to provide ecosystem services in changing environmental conditions (Sukhdev, Wittmer, Schröter-Schlaack, & Nesshöver, 2010). Biodiversity stabilizes ecosystem function over space or time by response diversity: different species have different responses to environmental change (Winfree, 2013).

#### 4.1.c. Supporting

##### 4.1.c.i Soil fertility, & structure

Biodiversity has several positive effects on soil including increases organic matter content, better nutrient cycling and the promotion of water retention (Lugnot & Martin, 2013). This allows farmers to need less fertilizer and to be able produce food more efficiently (which in turn have positive environmental effects such as reducing the driver or food production (see 1.1.a.).

#### 4.1.d. Cultural

##### 4.1.d.i Aesthetic value

Humans, especially in developed countries, tend to value complexity and diversity in their surrounding landscapes such as wildflowers, or while bird watching (Tscharntkea, et al., 2012).

# 5. Responses[[14]](#footnote-14)

### 5.1. Convention on Biological Diversity

The Convention of Biological Diversity is the most comprehensive international biodiversity protection regime (Markussen, Buse, & Garrelts, 2005). It was signed at the Earth Summit in Rio in 1992, and implemented at the end of 1993. The convention has many focal areas, outlined in Figure 3., each with goals, sub-targets and indicators, that demonstrate the mitigations of pressures on biodiversity and the reduction of negative impacts such as losses of ecosystem services.

Figure 3: Focal areas of the CBD text (UNEP, 2015)

Reducing the rate of loss of the components of biodiversity, including: (i) biomes, habitats and ecosystems; (ii) species and populations; and (iii) genetic diversity;

Promoting sustainable use of biodiversity;

Addressing the major threats to biodiversity, including those arising from invasive alien species, climate change, pollution, and habitat change;

Maintaining ecosystem integrity, and the provision of goods and services provided by biodiversity in ecosystems, in support of human well-being;

Protecting traditional knowledge, innovations and practices;

Ensuring the fair and equitable sharing of benefits arising out of the use of genetic resources; and

Mobilizing financial and technical resources, especially for developing countries, in particular least developed countries and small island developing States among them, and countries with economies in transition, for implementing the Convention and the Strategic Plan.

In the convention text, there were many targets set for 2010. Although none of the 21 targets were achieved worldwide, there was local and regional progress for goals such as reducing the impact of pollution or conservation at certain scales (Alkemade, et al., 2009).

### 5.2. Endangered species legislation

#### 5.2.a. CITES, 1975

The Convention on International Trade in Endangered Species of Wild Fauna and Flora is an international agreement, aiming to ensure that international trade of species does not threaten their survival. CITES targets the pressure of overexploitation, currently protecting over 35,000 species of animals and plants (CITES Secretariat, 2013).

#### 5.2.b. National legislation examples

Around 170 countries have national biodiversity strategies and action plans (Alkemade, et al., 2009).

##### 5.2.b.i. ESA, 1973

In the United States’ Endangered Species Act, listed species cannot be killed, harmed or traded, their critical habitat must not be damaged or destroyed, and there is an obligation to prepare recovery strategies. (Waples, Nammack, Chocrane, & Hutchings, 2013). It therefore reduces pressures such as habitat loss and overexploitation of specific species

##### 5.2.bii. SARA, 2002

Canada’s species-at-risk legislation, the Species At Risk Act, was enacted to prevent wild species from becoming extirpated or extinct. Assessment is done by COSWEIC[[15]](#footnote-15), and the government chooses to list, refer back, or not list suggestions based on socioeconomic factors. The effects of listing are similar to those of ESA but recovery strategies must be prepared within a set amount of time (Waples, Nammack, Chocrane, & Hutchings, 2013).

#### 5.2.c. Endangered Species Assessment Lists

##### 5.2.c.i IUCN Red List

The International Union for the Conservation of Nature Red List, assesses the status of species (as in Figure 4.) to inform decisions and priorities for conservation action.

(-) Extinction Risk (+)

Figure 4: Structure of the categories of the IUCN Red List after ( IUCN Species Survival Commission, 2012)

### 5.3. Protected areas

Across the world, different levels of government along with NGOs and other groups have responded to biodiversity loss by creating protected areas as an attempt to mitigate the pressure of habitat change. Connected, large reserves buffered from areas of intense human use are effective at sustaining biodiversity (Cain, Bowman, & Hacker, 2014, p. 559). Challenges in implementing protected areas such include human rights of native groups and pressures from industry. Many studies are being done on whether sustainable use conservation areas[[16]](#footnote-16) can be effective in preserving biodiversity (Almudi & Kalikoski, 2010).

Furthermore, work is being done towards ecological restoration or ‘rewilding’ of lands, including an expected 200,000 square kilometers of land in Europe by 2050 (Alkemade, et al., 2009).

### 5.4. Market tools

One example of a market tool is payments for ecosystem services, which are voluntary mechanisms creating positive incentives for limiting activities that cause environmental degradation.

#### 5.4.c.i. REDD+

Reducing Emissions from Deforestation and forest Degradation is a UN program which incentivizes developing countries to keep forest stands by offering payments for actions done to reduce or remove forest carbon emissions. This targets the pressures of both climate change and habitat loss.

# Conclusion

Drivers such as growth of the world population and economy result in pressures on biodiversity including habitat change, climate change, invasive species, overexploitation and pollution. These pressures have had variable low to extremely high impacts on biodiversity in the past century and are expected to have generally continuing to rapidly increasing effects in the future. Currently, the earth is losing biodiversity at an increasing rate. The loss of terrestrial biodiversity has many negative effects on society and the environment, which can be summarized in losses of ecosystem services. Responses such as legislation, protected areas and market tools primarily mitigate pressures to varying degrees of success.

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1. The loss of terrestrial biodiversity can be considered an impact of states such as water quality (Tsai, Tzeng, Fu, & Wu, 2009); however, as it is the focus of this report, the most meaningful analysis will be from considering it a state. [↑](#footnote-ref-1)
2. The driving forces lead directly to pressures. Section numbers of the most important related pressures are indicated next to the driving forces. Precise details are explained section 2. [↑](#footnote-ref-2)
3. Loss of individuals in populations can be amplified due the extinction vortex effect: having fewer individuals in a population can have a positive feedback resulting in extinction. This could be due to Allee effects, when the difficulty in finding mates at low population densities causes population growth to decrease, or because smaller population sizes have a greater likelihood of being driven to extinction by chance events (Cain, Bowman, & Hacker, 2014, pp. 260-262) [↑](#footnote-ref-3)
4. This (in addition to loss of individuals) leads to changes in food webs as top predator abundances decrease, resulting in greater abundances of primary consumers and so an overall decrease in plant productivity, resulting in decreases in other species such as birds (Feeley & Terborgh, 2006). [↑](#footnote-ref-4)
5. Disease is often grouped with invasive species e.g. (Crowl, Crist, Parmenter, Belovsky, & Lugo, 2008) [↑](#footnote-ref-5)
6. Bioaccumulation is the progressive increase in concentration of a substance in an organism’s body over its lifetime. Biomagnification is the increase in concentration of a substance in animals at higher trophic levels (Cain, Bowman, & Hacker, 2014, p. 491) [↑](#footnote-ref-6)
7. This section aims to provide a summary of global historical & current trends relating to the state of biodiversity. Many specific numerical examples of the state of biodiversity relating to pressures can be found within section 2. [↑](#footnote-ref-7)
8. This includes alpha diversity, or diversity at a community scale; beta diversity, the difference in species between communities; gamma diversity, species diversity at a regional scale; and finally, global biodiversity (Cain, Bowman, & Hacker, 2014, p. 406) [↑](#footnote-ref-8)
9. Related to beta diversity [↑](#footnote-ref-9)
10. Planetary boundaries are thresholds which, if surpassed, result in unacceptable environmental change impacts on humans (Rockstrom, et al., 2009) [↑](#footnote-ref-10)
11. There tend to be more species around the equator due to factors such as climate (Cain, Bowman, & Hacker, 2014, p. 414) [↑](#footnote-ref-11)
12. One example would be that conserving all threatened species in ecological preserves while converting the remainder of the land into monoculture cropland, although maintaining species richness, does not maintain biodiversity as it fails to account for genetic, ecosystem, and landscape diversity (Millennium Ecosystem Assessment, 2005) [↑](#footnote-ref-12)
13. Brief examples of ecosystem services improved by biodiversity are outlined in this section, categorized by type of ecosystem service. This is not a comprehensive list. [↑](#footnote-ref-13)
14. There have been many different responses to terrestrial biodiversity loss on a variety of scales. This is again not a comprehensive list but outlines important responses or examples of responses on smaller scales. [↑](#footnote-ref-14)
15. Committee On the Status of Endangered Wildlife in Canada , an independent panel of scientific experts who compile data and assess risk within IUCN Red List categories [↑](#footnote-ref-15)
16. In these areas, groups of traditional people can continue to use the land and often help reduce species extinctions (Almudi & Kalikoski, 2010) [↑](#footnote-ref-16)