Toulouse School of Economics

# Measuring biodiversity?

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October 18th, 2024

**FDIR workshop**

# Introduction

# What is this presentation about?

Perspectives from an agricultural economist and an environmental economist

Not a comprehensive review of current biodiversity measures (outside our scope); focus is on a select widely-used measures and some prevalent in academic research

The literature on biodiversity measurement is not mature: no consensus, often not peer-reviewed, not always transparent, near absence of tests of proposed measures

Set the context and highlight key challenges in biodiversity measurement

Provide a brief background of measurement strategies, and overview a few key scientific studies

# Biodiversity measures

Nearly 100 different indicators were suggested for the Aichi meeting of the Convention on Biological Diversity (CBD) (Dasgupta, 2021)

Mace et al. (2018) suggested three categories of measures to understand change in biodiversity (essentially to capture extinction risk, abundance and composition):

**(1) Conservation status:** Estimating near-future global losses of species (extinctions) such as the IUCN Red List Index (RLI)

**(2) Population trends:** Trends in the abundance of wild species such as the Living Planet Index (LPI)

**(3) Biotic integrity** (community composition): such as the Biodiversity Intactness Index (BII) or the Mean Species Abundance (MSA), which measure the terrestrial biodiversity that still remains compared to an undisturbed situation

And, for the lack of a better option, we may add biomass measures (vegetation cover etc.).

# Climate change vs. biodiversity loss

| Aspect | Climate Change (CC) | Biodiversity Loss |
|---|---|---|
| **Nature of the Problem** | Driven by increasing greenhouse gases (GHGs) in the atmosphere, causing global warming and extreme weather. | Caused by habitat loss, pollution, overexploitation, invasive species, and climate change itself. |
| **Measurement** | Primarily measured by global indicators such as atmospheric $CO_2$ concentrations, temperature rise, and sea-levels. | Measured at both **global** and **local** scales. Global indicators include species extinction rates, while local measures can involve species abundance or ecosystem integrity. |
| **Key Indicator** | $CO_2$ emissions, temperature changes, GHG concentrations. | Mean Species Abundance (MSA), Biodiversity Intactness Index (BII), Living Planet Index (LPI). |
| **Global vs. Local Impact** | A global issue that affects the entire planet, with some regional variations in vulnerability and impact. | Both a global and local issue. Biodiversity loss impacts ecosystems locally, but has global repercussions. |
| **Main International Body** | **IPCC** (Intergovernmental Panel on Climate Change). | **IPBES** (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). |
| **Key International Agreements** | **Paris Agreement (2015)** – aimed at limiting global warming to 1.5°C or 2°C above pre-industrial levels. | **Convention on Biological Diversity (CBD, 1992)** – aimed at protecting species and ecosystems globally. |
| **Economic Assessment** | **Stern Review (2006)** – focuse[illegible] the economic impacts of climate change | **Dasgupta Review (2021)** – emphasized the economic and financial risks of biodiversity loss. |

# What's the goal?

Economists' view: Maximize social welfare...

...but what is social welfare? How to account for inequality? For the risk of catastrophe? For future generations? For the intrinsic value of biodiversity? etc.

Differences between the economists' view and the ecologists' view?

Differences between the economists' view and the financial institutions' view?

# Objective vs. subjective welfare

Economists debate about whether we should maximize objective or subjective welfare (cf. experts' vs. lay people views about biodiversity)

People have a specific view about what we should preserve, cf. the prevalent preference about charismatic species (Metrick and Weitzman, 1998) Charisma? ▷

Meier et al. (2024) show that the public (as well as biodiversity experts and financial investors) derive the largest utility from species richness and reductions in the probability of extinction (and not from intactness)

**Table 2:** Example choice card.

| | Option A | Option B |
|---|---|---|
| Species richness | 50 | 200 |
| Expected extinction rate | 5% | 10% |
| Average population proportion | $\frac{200}{400}$ | $\frac{50}{56}$ |
| Proportion of natural habitat | $\frac{250\text{ ha}}{2500\text{ ha}}$ | $\frac{500\text{ ha}}{1000\text{ ha}}$ |

# Outline

1. Defining biodiversity
2. Dependence
3. Impacts
4. Measuring impact and tracking improvement

# Defining biodiversity

# What's the most diverse set?

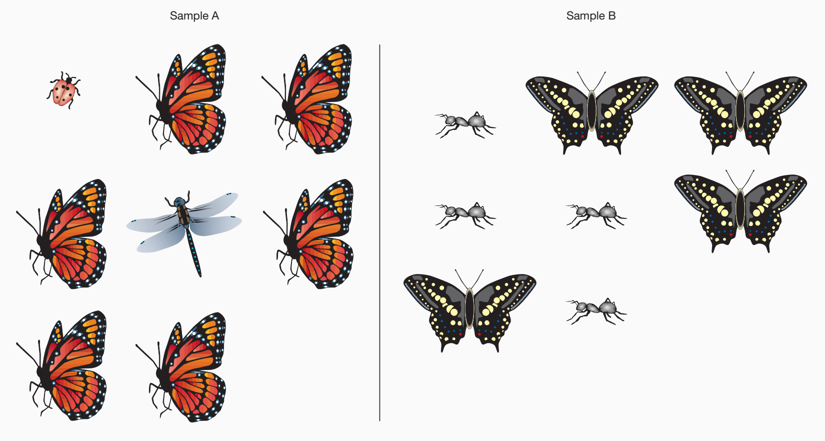
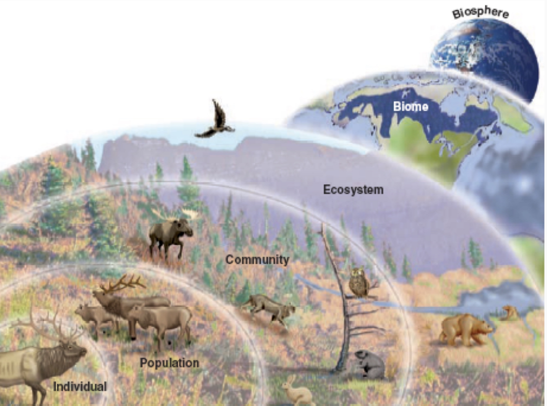



**Figure 1** Two samples of insects from different locations, illustrating two of the many different measures of diversity: species richness and species evenness. Sample A could be described as being the more diverse as it contains three species to sample B's two. But there is less chance in sample B than in sample A that two randomly chosen individuals will be of the same species.

(Purvis and Hector, 2000)

# A definition

**Biodiversity:** "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." (United Nations, 1992)



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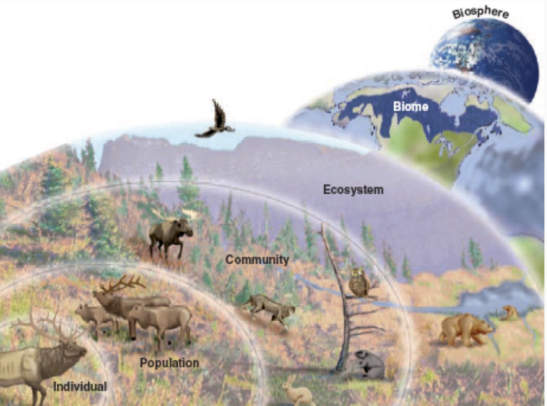


No matter how you measure it,
biodiversity is declining.
(Mill. Ecosyst. Asst., 2005; IPBES, 2019; IUCN, 2020)

# Biodiversity "erosion": >100,000 spp surveyed to date, >40,000 risk extinction

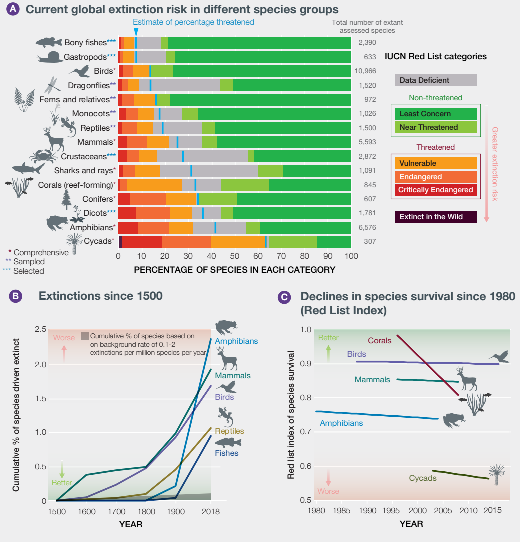


Figure SPM 3 A substantial proportion of assessed species are threatened with extinction and overall trends are deteriorating, with extinction rates increasing sharply in the past century.

(IPBES, 2019)

# Why conserve biodiversity?

# Biodiversity delivers "ecosystem services" (Nature's Contributions to People)

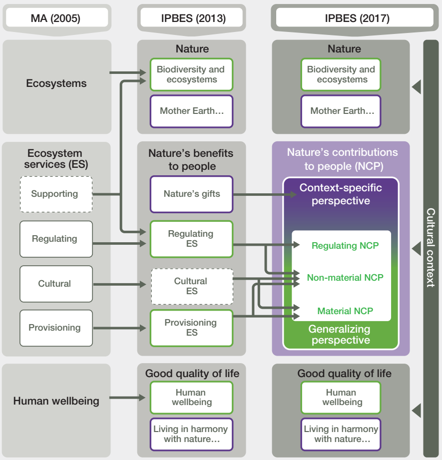


Figure 1 4 Evolution of nature's contributions to people (NCP) and other major categories in the IPBES CF (Díaz *et al.*, 2018) with respect to the concepts of ecosystem services and human wellbeing as defined in the Millennium Ecosystem Assessment (2003, 2005).

# Charismatic species

Why? Because historically, the threat was hunting/persecuting a species to its extinction.

E.g.: dodo, thylacine (Tasmanian tiger), passenger pigeon, several tiger species, gray wolf (locally), plains bison (almost).

It's also easier to conceive of. And study, and make rehabilitation plans.

A few examples.

# Why do we care?

Some individual species provide services that are measurable, albeit not always salient.

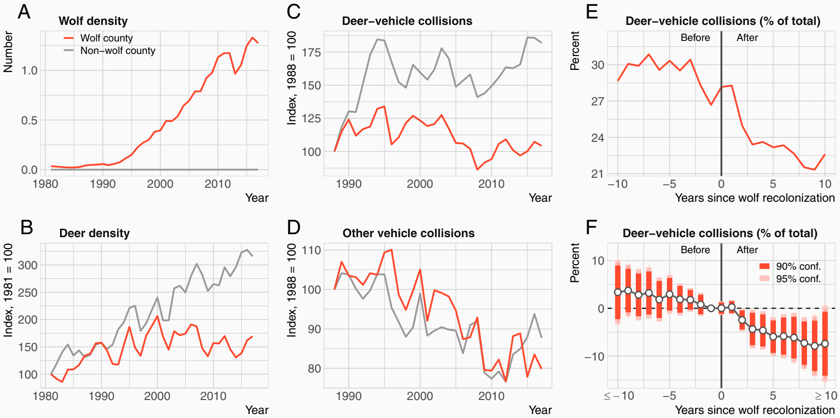


**Fig. 2.** Trends in wolf abundance, deer abundance, and roadway collisions. (*A*) Winter wolf population per 100 $km^2$ of deer range. Deer range is defined as

Source: Raynor et al. (2021, PNAS).

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Some spp provide services that are measurable but hardly salient. And sometimes the species isn't even glamorous at all.

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Source: USFWS. A little brown bat with white-nose syndrome.

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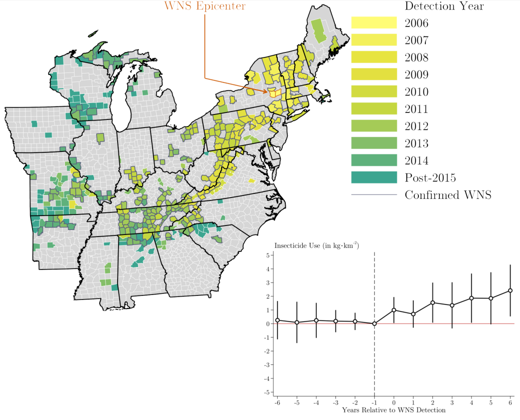


Source: Frank (2024, Science).

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Some spp provide services that are measurable but hardly salient. And sometimes the species isn't even glamorous at all.

Source: Wikimedia Commons. White-rumped vulture (*Gyps bengalensis*).
Photograph by Shantanu Kuveskar. Location: Shrivardhan, Raigad, Maharashtra, India.

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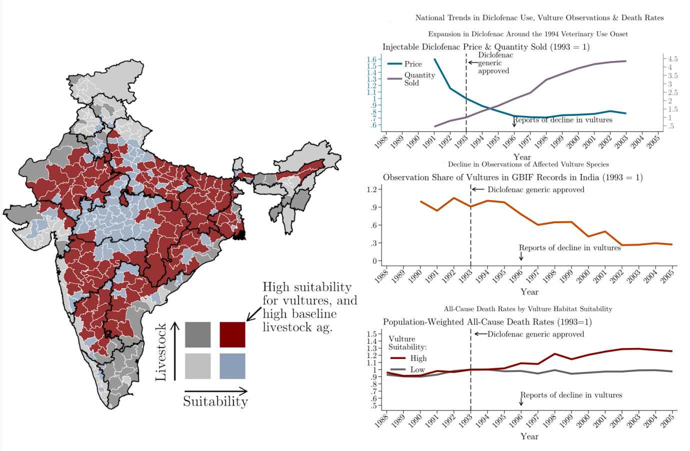


Source: Frank and Sudarshan (2024, AER).

# Canonical example: Buffalo trade, and near-extinction

Detroit, MI (1892) - source

# Why do we care?

Sometimes the benefits *are* salient yet OA conditions drive extinction. (Taylor, 2011)

E.g. despite tremendously valuable, the N. American bison was driven to near extinction (25-30 million hds early 1800s to $<$100 in 1886) because of

> *"(i) a price for buffalo products that was largely invariant to changes in supply; (ii) open access conditions with no regulation of the buffalo kill; and (iii), a newly invented tanning process that allowed buffalo hides to be turned into valuable commercial leather."*

## Why do we care? The one-species summary

Protean concepts of "ecosystem services" and, more recently, "nature's contribution to people." In some instances performed by a single species.

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- Cultural services (“charismatic megafauna”)
- Provision services (e.g., bison hides, baleen, timber)
- Regulating services (e.g., *Gyps bengalensis*, the white-rumped vulture)
- (Supporting services?)

(And yes that’s anthropocentric.)

ES - NCP ▷

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A single species can also serve as a guide for conservation, as indicator, or umbrella, or keystone species. More ▷

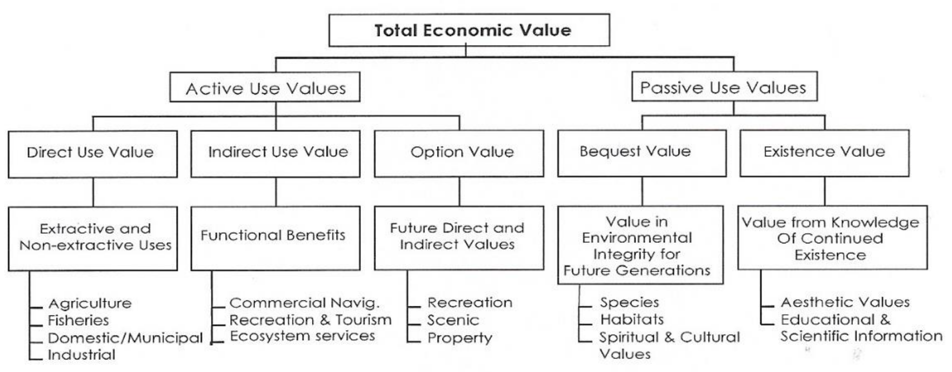
# Biodiversity... however you define it, matters

A few species contribute on their own to our well-being.

Many others contribute as communities.

Yet others are just there and might matter.

Even if they're very small ▷




Source: NZIER 2018. In decreasing order of tangibility to the user from left to right.

# Biodiversity... however you define it, isn't doing great

Many individual species are threatened (cf. IUCN).

Many more that we don't know, don't see, but are be affected by the same drivers.

A combination of local and global drivers that is making the problem "wicked" (DeFries and Nagendra, 2017).

## What to preserve?

*The* question.

Aside from the *justification*, one can pragmatically consider the threats:

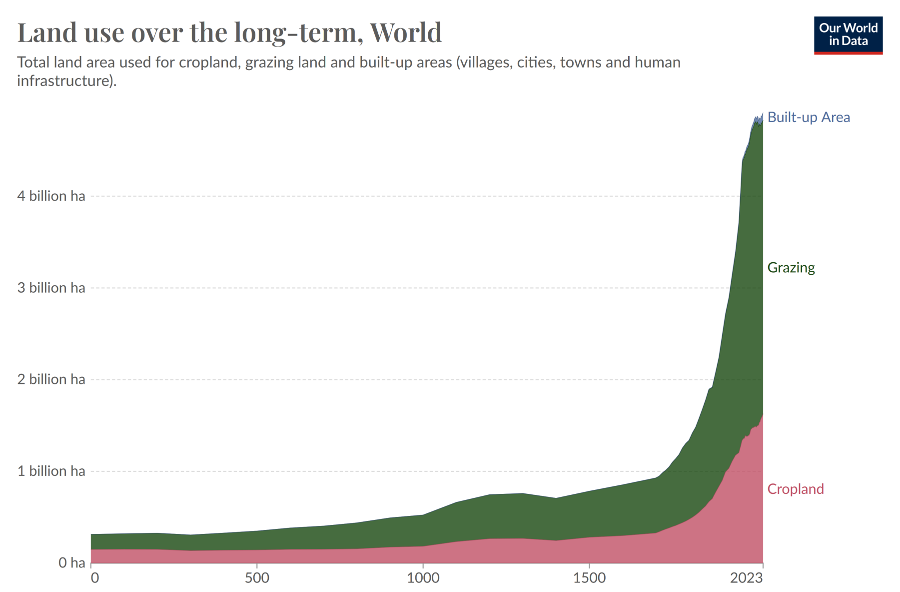
- Habitat loss (to LUC)
- Climate change
- Hunting, poaching, overexploitation
- Alien invasive species
- Pollution

$\rightarrow$ **Proximal threats.** Each points to policy tools (command-and-control, incentive-based, behavioral) and approaches.

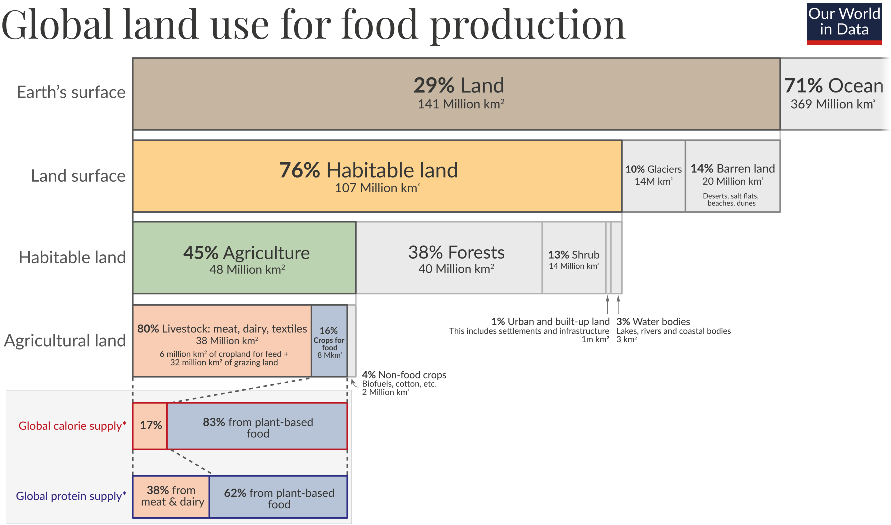
LUC being the most damaging and pervasive, we shall dwell on it today.

# Current threats... and solutions

# Land use change



# Land use change




*Includes fish and seafood from aquaculture production, which uses land for feed. If wild fish catch is also included, animal products would provide 18% of calories and 40% of protein.
Data sources: UN Food and Agriculture Organization (FAO) and Poore and Nemecek (2018).
OurWorldinData.org – Research and data to make progress against the world's largest problems.

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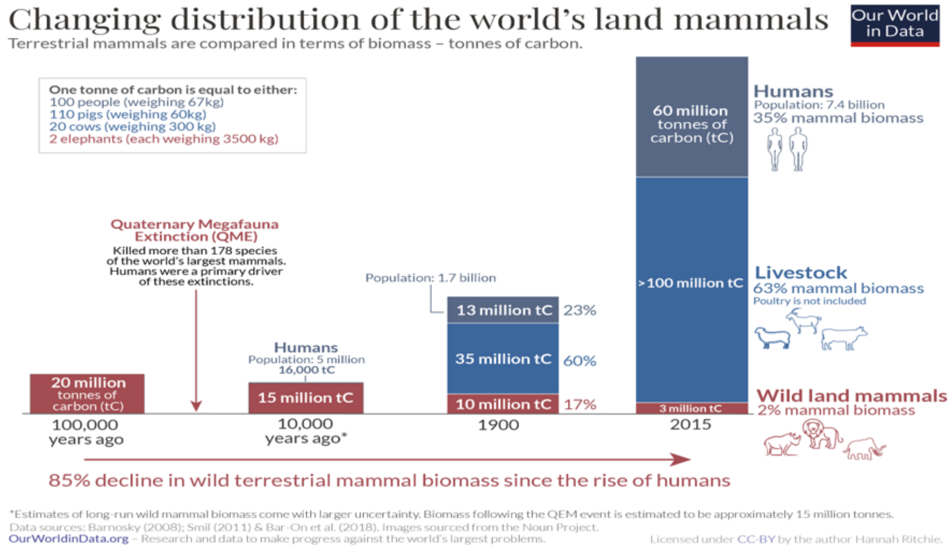

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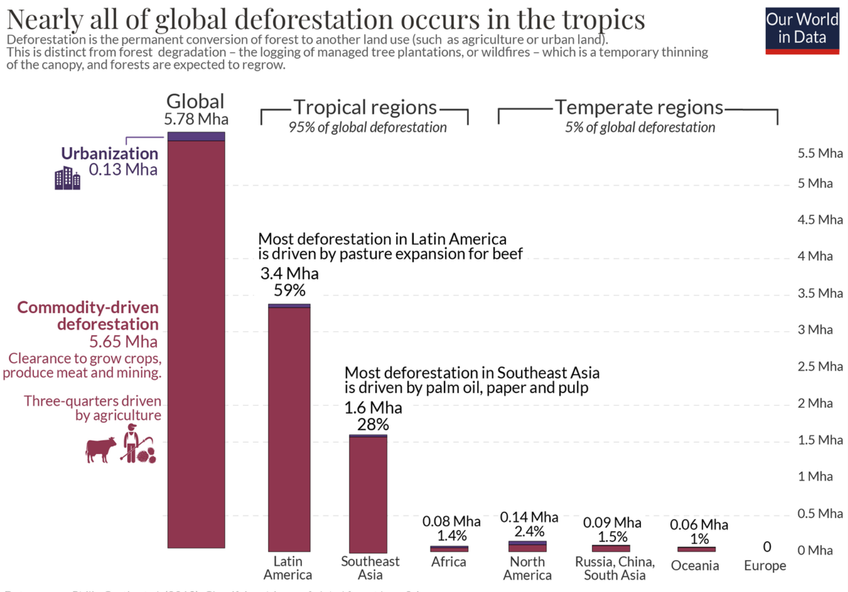


# Land use change

> Environ Sci Technol. 2017 Mar 21;51(6):3298-3306. doi: 10.1021/acs.est.6b05296. Epub 2017 Jan 29.

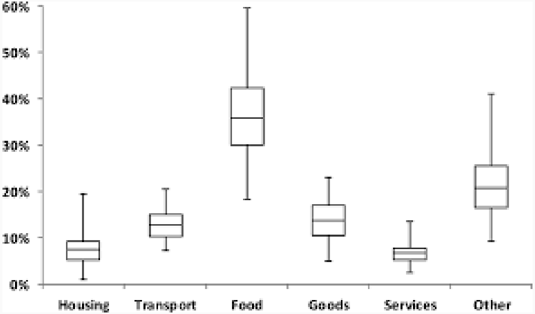
**Quantifying Biodiversity Losses Due to Human Consumption: A Global-Scale Footprint Analysis**

Harry C Wilting [1], Aafke M Schipper [1], Michel Bakkenes [1], Johan R Meijer [1], Mark A J Huijbregts [1] [2]

Affiliations + expand

PMID: 28072521 DOI: 10.1021/acs.est.6b05296

Free article




First study to systematically quantify biodiversity losses in relation to land use and GHG emissions

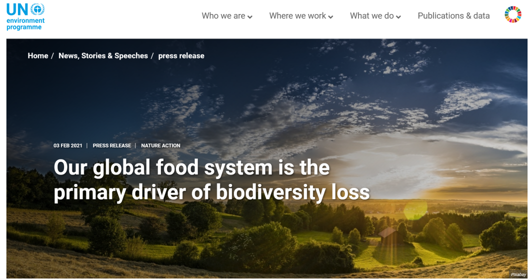
Use MSA as a biodiversity measure

Considering 45 countries, the biodiversity loss per citizen shows large variations across countries

Food consumption is the most important driver of biodiversity (40%)

More than 50% of biodiversity loss in developed economies occurs outside their territorial boundaries

# Land use change

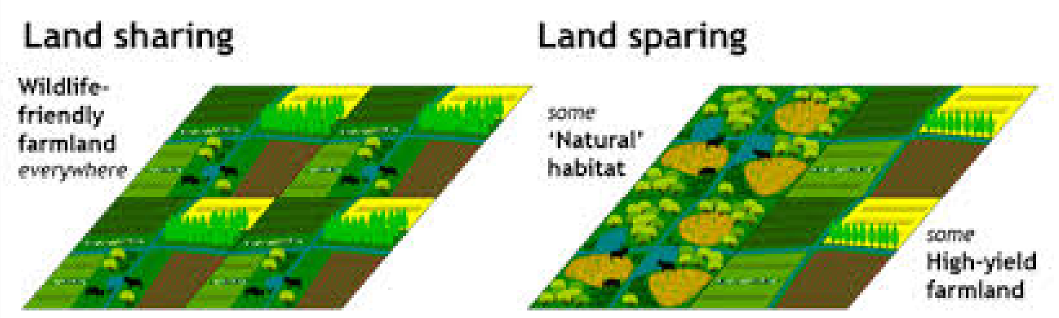



Chatham House report (2021): "agriculture is the identified threat to 24,000 of the 28,000 (86%) species at risk of extinction"

## Three proposed levers:

- Firstly, **global dietary patterns need to move towards more plant-heavy diets**, mainly due to the disproportionate impact of animal agriculture on biodiversity, land use and the environment. Such a shift, coupled with the reduction of global food waste, would reduce demand and the pressure on the environment and land, benefit the health of populations around the world, and help reduce the risk of pandemics.
- Secondly, **more land needs to be protected and set aside for nature.** The greatest gains for biodiversity will occur when we preserve or restore whole ecosystems. Therefore, we need to avoid converting land for agriculture. Human dietary shifts are essential in order to preserve existing native ecosystems and restore those that have been removed or degraded.
- Thirdly, **we need to farm in a more nature-friendly, biodiversity-supporting way, limiting the use of inputs** and replacing monoculture with polyculture farming practices.

# The land sharing land sparing debate




Land sharing: low-yielding, wildlife-friendly agriculture on a larger land footprint

Land sparing: high-yielding agriculture on a small land footprint

# The land sharing land sparing debate

**Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared**
Ben Phalan, *et al.*
*Science* **333**, 1289 (2011);
DOI: 10.1126/science.1208742

**Key Finding**: Land sparing tends to perform better for biodiversity in a range of studies (but the debate is ongoing)

**Counterintuitive Insights**:

- Intensive farming might be better for biodiversity than expected, as it requires less land overall
- Organic farming has lower yields— 5% to 35% less productive (Seufert et al., 2012)—requiring more land, which can negatively impact biodiversity

**Open questions**: How to select the right perimeter? How to make things comparable (e.g., constant production)? How to deal with the risk of misunderstanding (e.g., favoring land sparing)? How to measure the LUC impact on biodiversity?

# Back to measurement

# Measuring, what for?

The "**threats**" angle easily points to policies/actions to counter biodiversity erosion.

On the other hand, the **rationale** for biodiversity conservation dictates what "type" of biodiversity we seek to preserve.

This in turn determines which metrics is adequate.

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- **Spatial scale** Global? Admin unit? Plant, field?
- **Activity specificity** Should one be able to trace back the impacts/improvements to one activity/entity?
- **Precision** Are proxies okay? Umbrella species? Habitat $\equiv$ biodiversity?
- **Temporal scale/scope** How far back in time? How frequent?
- ...

# How does one measure diversity? The ecologists' way

- Count species: **Species richness**
- Other indices accounting for distribution: **Shannon, Simpson indices**, evenness, etc.
- Phylogenetic diversity ($\sim$ how related)
- **Functional diversity** (requires knowing who is around)
- **Indicators:** sensitive spp., or "keystone species," or extremely well documented groups.

Function ▷

While the limitations of species richness are recognized, it often ends up being the only measure used (feasible).

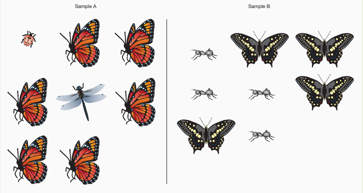



**Figure 1** Two samples of insects from different locations, illustrating two of the many different measures of diversity: species richness and species evenness. Sample A could be described as being the more diverse as it contains three species to sample B's two. But there is less chance in sample B than in sample A that two randomly chosen individuals will be of the same species.

Source: Purvis and Hector (2000).

# How does one measure diversity? Popular indices

Popular but not developed today:

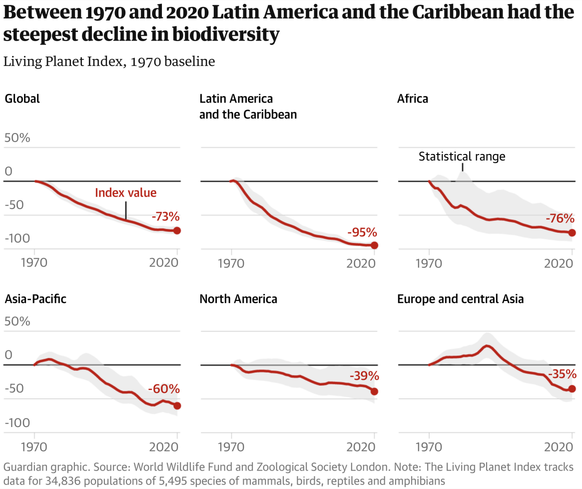
- Biodiversity Intactness Index (Scholes and Biggs, 2005) ∼ modelled, site-specific
- RedList Index (UICN) ∼ extinction risk, from data
- Species Threat Abatement and Recovery (STAR) (Mair et al., 2021) ∼ modelled, site-specific, pushed by IUCN for mainstreaming

Today:

- Living Planet Index ∼ population declines (extinction risk), from data, global
- Mean Species Abundance ∼ distance from "intact" state, modelled, site-specific

# Living Planet Index (LPI, WWF)

Measures the **average change** in **observed population sizes** of 5,495 **vertebrate** spp.




Source: theguardian.com.

# Mean Species Abundance (MSA)

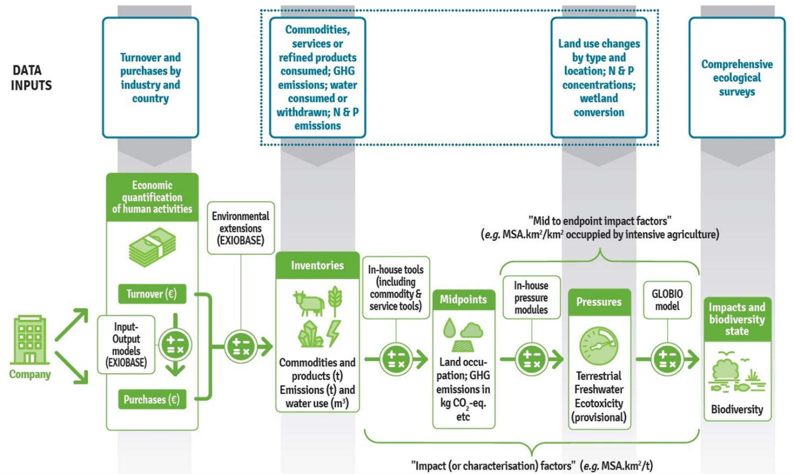
A model-based composite measure. Maps activities to pressures (EXIOBASE):

- Land use
- Fragmentation of natural ecosystems
- Human encroachment
- Atmospheric nitrogen deposition
- Climate change
- Hydrological disturbance due to direct water use, and due to climate change
- Wetland conversion
- Freshwater eutrophication
- Land use in catchment of rivers, and wetlands
- Ecotoxicity (experimental for now!)

... and pressures to (modelled) changes in species abundance in a given place (via GLOBIO). (CDC Biodiversité, 2021)

# The French CDC and other institutions use MSA

The Global Biodiversity Score (CDC) is based on the MSA. → Aims at raising awareness and communicating on status and trends... for now.



# Comparing these two popular measures

## Summary of Differences:

| Feature | MSA (Mean Species Abundance) | LPI (Living Planet Index) |
|---|---|---|
| **Main Focus** | Species abundance relative to pristine conditions | Population trends of vertebrate species |
| **Methodology** | Model-based, estimates abundance based on environmental pressures | Data-driven, tracks real population changes |
| **Species Coverage** | All species (plants, animals, invertebrates) in an ecosystem | Vertebrate species (mammals, birds, reptiles, amphibians, fish) |
| **Baseline** | Pristine or undisturbed condition | Population status in 1970 |
| **Geographic Scope** | Global models, applied at various spatial scales | Based on monitoring data, coverage can be uneven |
| **Use in Policy** | Used in scenario modeling, policy evaluation (e.g., GLOBIO) | Public communication, tracking global biodiversity trends |

# Conclusion

What metric, for what biodiversity, for which user(s)?

At the end of the day, it all depends on the actions that are taken in response to the disclosure of biodiversity measures

# Regulation vs. CSR (and sustainable finance)

Traditional economists' view (Friedman, 1970): Market failures (such as environmental externalities) require government regulation ⇒ CSR not needed

Modern view (Besley and Ghatak, 2007; Bénabou and Tirole, 2010): Regulatory failure ⇒ CSR may help

But CSR is challenging: Free-rider problem, limited consumers/investors' information, evidence of greenwashing, unanticipated perverse effects (e.g., additionality)

# Implications?

Suppose a pharmaceutical company actively engage in preserving species and biodiversity, driven by the hope of discovering medicinal properties. What is the market failure here? Is there a need for the government's intervention and public biodiversity metrics?

Suppose that a company is regulated because of its impact on biodiversity (e.g., its production is taxed). What is the regulatory failure? Is there a need for CSR or sustainable finance?

More generally, how to account for preexisting market and regulatory failures? Should biodiversity measures and their use consider these failures?

# Appendix

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# Charisma is...

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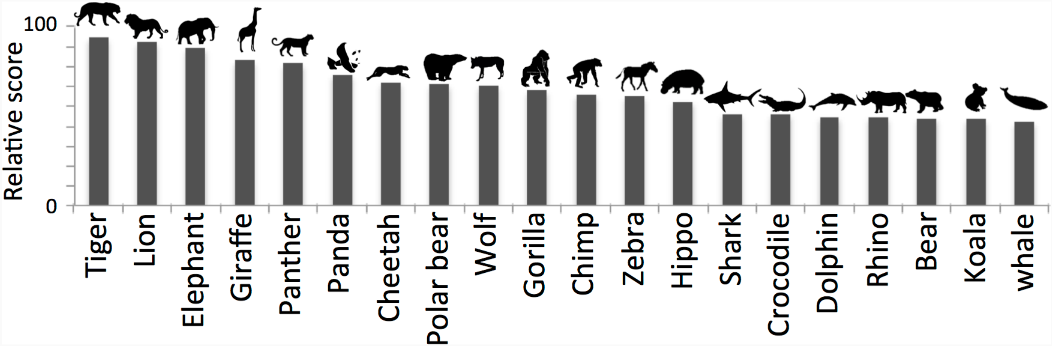


Source: Albert et al. (2018).

# Option value?

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SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

# Corporate control and global governance of marine genetic resources

**Robert Blasiak[1,2]*, Jean-Baptiste Jouffray[1,3†], Colette C. C. Wabnitz[4†], Emma Sundström[1], Henrik Österblom[1]**



**Who owns ocean biodiversity? This is an increasingly relevant question, given the legal uncertainties associated with the use of genetic resources from areas beyond national jurisdiction, which cover half of the Earth's surface. We accessed 38 million records of genetic sequences associated with patents and created a database of 12,998 sequences extracted from 862 marine species. We identified >1600 sequences from 91 species associated with deep-sea and hydrothermal vent systems, reflecting commercial interest in organisms from remote ocean areas, as well as a capacity to collect and use the genes of such species. A single corporation registered 47% of all marine sequences included in gene patents, exceeding the combined share of 220 other companies (37%). Universities and their commercialization partners registered 12%. Actors located or headquartered in 10 countries registered 98% of all patent sequences, and 165 countries were unrepresented. Our findings highlight the importance of inclusive participation by all states in international negotiations and the urgency of clarifying the legal regime around access and benefit sharing of marine genetic resources. We identify a need for greater transparency regarding species provenance, transfer of patent ownership, and activities of corporations with a disproportionate influence over the patenting of marine biodiversity. We suggest that identifying these key actors is a critical step toward encouraging innovation, fostering greater equity, and promoting better ocean stewardship.**

## INTRODUCTION

The prospect of the ocean generating a new era of "blue growth" is increasingly finding its way into national and international policy documents around the world and has spurred a rush to claim ocean space and resources (*1*, *2*). If economic activities in coastal and offshore areas are to expand in an equitable and sustainable manner, in line with the Sustainable Development Goals (SDGs), progress is needed toward addressing multiple and potentially conflicting uses of ocean space within national jurisdictions, in addition to developing a consistent rapidly evolving frontier where the worlds of science, policy, and industry meet (*12*). The adoption of the Nagoya Protocol in 2010 represented an important step within the international policy arena to define obligations associated with monetary and nonmonetary benefit sharing of genetic resources and their products sourced from within national jurisdictions (*13*). No such mechanism currently exists for ABNJ.

Transnational corporations have a unique ability to capitalize on and monopolize markets characterized by global scope and com-

# Option value?

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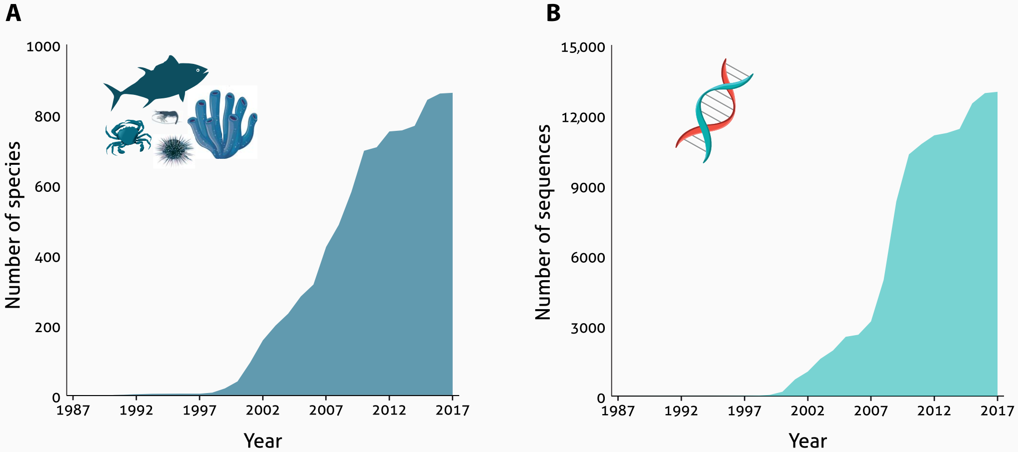


**Fig. 1. Growing commercial interest in MGRs.** Cumulative number over time (1988–2017) of (A) marine species with patent sequences and (B) patent sequences from marine species.

**MGR:** marine genetic resources, i.e., genetic material of actual or potential value. Source: Blasiak et al. (2018).

# Option value?

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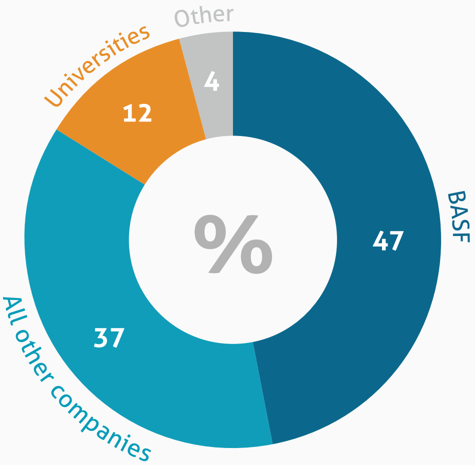


**Fig. 2. Percentage of patents with international protection associated with MGRs that were registered over the period 1988–2017 by BASF, all other companies (*n* = 220), universities (*n* = 78), and other actors (*n* = 26; including governmental bodies, individuals, hospitals, and nonprofit research institutes).**

Source: Blasiak et al. (2018).

# The numbers game

Aside from inventories, a germane question is about figuring out the number of spp on Earth (vs. those we've already id'd).

May (1986) kicked us off with his "How many species are there?"

> *ONE of the first things that an extraterrestrial might ask about the planet Earth is how many species are on it. If this extraterrestrial had only our own current knowledge to rely on, the answer would be astonishingly vague: somewhere between 1.5 and 30 million species of plants and animals.* *(May, 1986)*

At the time, $\simeq$1 mo spp id'd (*named and catalogued*), he guesstimates 3-5 mo in total. (Noting, as, an aside, that "*Indeed, to a good approximation, all species are insects!*)"

Many papers since then exploiting empirical regularities in species distribution (size, etc.) have come up with estimates. Mora et al. (2011), for instance, puts it at 8.7 million ($\pm$1.3 million SE).

# Benefits of, and limits to the one-species approach

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**Benefits:** Some species *are* appreciated for their direct/indirect economic, ecosystem, cultural contributions to people.

Others are thought to be good indicators of ecosystem health.

Saving/restoring them can have measurable benefits (e.g. apex predator reintroduction).

Saving/restoring them can mean saving/restoring other things, too.

**Limits:**

# Benefits of, and limits to the one-species approach

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Saving/restoring them can mean saving/restoring other things, too.

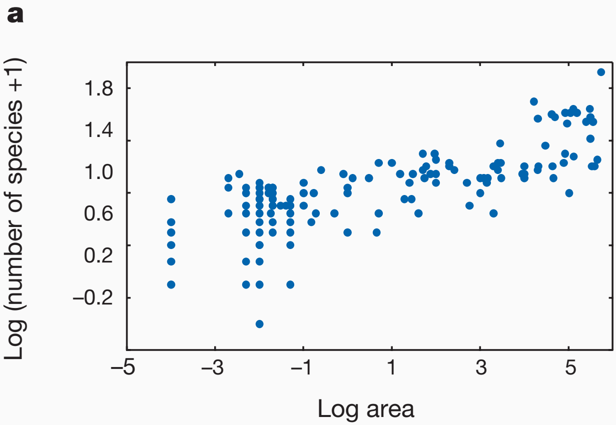
**Limits:** Cosmetic? Focus on charismatic megafauna? Is it a problem that an obscure endemic species with a small range will vanish? That ecosystems get simplified and impoverished despite the persistence of some spp we care about/can see and measure? The whole is more than the sum of its parts.

# Habitat loss

# “Half the Earth”?

Famous entomologist late E.O. Wilson deems it necessary to set aside a “Half-Earth.”

Grounded in his theory of island biogeography (MacArthur and Wilson, 1967).




Earthworm diversity in Europe. Source: Gaston (2000).

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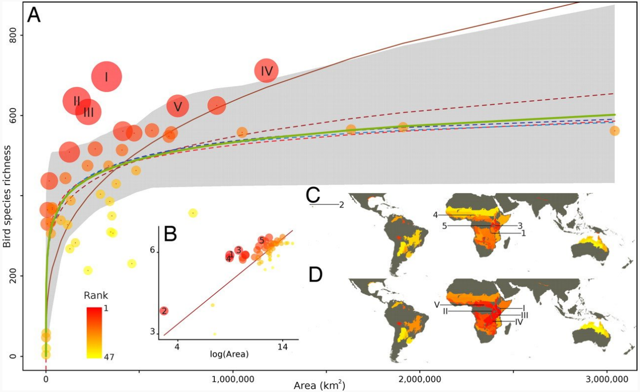


Source: Guilhaumon et al. (2008).

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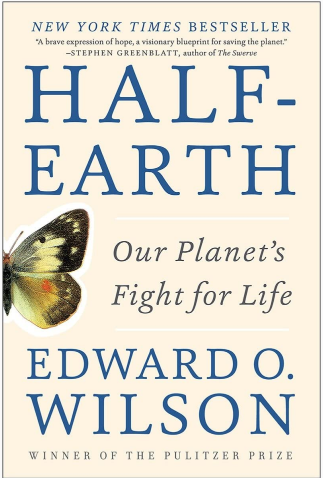

# Debates

Can you imagine a few?

- Optimal size?
- Adaptation to climate change?
- Definitely not efficient (not designed to be).
- Economic incentives ignored. The literature of unintended consequences is rife with examples! (Lueck and Michael, 2003; Runge et al., 2019; Fienup and Plantinga, 2021)
- Land-sharing vs. land-sparing (Phalan et al., 2011).
- Global common good vs. local people(s). (Ferris and Frank, 2021)
- Effective? (Ferraro et al., 2007; Gerber and Hatch, 2002)

# More on IPBES

# The IPCC of biodiversity

The first assessment of biodiversity conducted by an intergovernmental body.

Same idea as the IPCC:

- Take and assess all the *available* scientific evidence (scientists)
- Establish the consensus, probabilize the rest
- Increasing political involvement towards the end to produce the SPM.

IPCC started in 1988 to synthesize the evidence on climate change, its extent, causes, and consequences.

Currently at AR6 (Sept 2022). While no original knowledge produced, fosters harmonization of practices, and consensus-building *is* a form of knowledge production.

IPCC comparison ▷

# Nature's Contributions to People & Ecosystem Services

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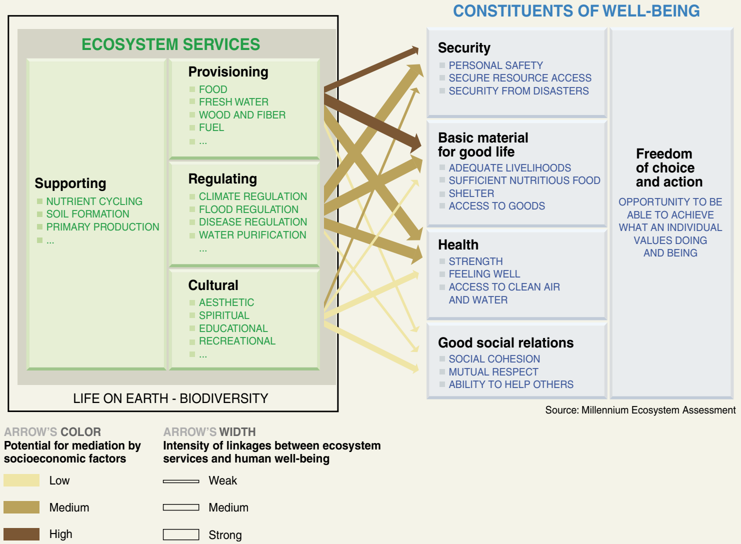


Source: Millennium Ecosystem Assessment, 2005.

# Nature’s Contributions to People & Ecosystem Services

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| FOCI OF VALUE | TYPES OF VALUE | | EXAMPLES |
|---|---|---|---|
| NATURE | Non-anthropocentric (Intrinsic) | | Animal welfare/rights |
| | | | Gaia, Mother Earth |
| | | | Evolutionary and ecological processes |
| | | | Genetic diversity, species diversity |
| NATURE’S CONTRIBUTIONS TO PEOPLE (NCP) | Anthropocentric | Instrumental | Habitat creation and maintenance, pollination and propagule dispersal, regulation of climate |
| | | | Food and feed, energy, materials |
| | | Relational | Physical and experiential interactions with nature, symbolic meaning, inspiration |
| GOOD QUALITY OF LIFE | | | Physical, mental,emotional health |
| | | | Way of life |
| | | | Cultural identity, sense of place |
| | | | Social cohesion |

Current Opinion in Environmental Sustainability

Source: Pascual et al., 2017.

# The Species Number Game

# Rare species contribute to functional diversity yet we know little about them

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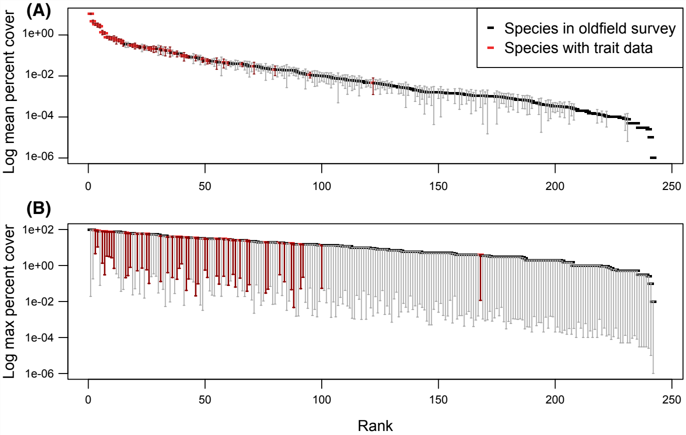


**Figure 2.** Rank-abundance plots of the 248 plant species present in the Cedar Creek oldfield survey, using two of the four definitions of rarity: (A) mean abundance for each species; error bars are ±1 SE and (B) maximum abundance for each species; bars show the range down to the mean abundance value. Species for which we have trait data, and are thus included in our analyses, are highlighted in red. Species are ranked from the most common to the most rare.

Source: Jain et al. (2014).