What are the most effective ways to protect, preserve, and rebuild ecosystems?

A guide for philanthropists

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Contents

Key takeaways

- **Ecosystem health provides a holistic view of ecosystems, taking into account their biodiversity, functioning, and resilience.** As such, we recommend focusing on ecosystem health as a measure of ecosystem integrity and collapse risk. The ecosystem health approach also incorporates intuitive notions of preserving vibrant ecosystems. Biodiversity, on the other hand, is unlikely to be a useful metric for prioritization as it can conflict with other aspects of ecosystem integrity.

- **The International Union for the Conservation of Nature (IUCN) has begun a process to assess the collapse risk of all ecosystems on earth based on an ecosystem health approach.** There is not enough data yet to attempt a global prioritization based on ecosystem vulnerability. However, we recommend that philanthropists use the IUCN risk data to compare candidate interventions that have been selected along other metrics such as human welfare or climate impacts.

- **We find that concentrating on wetlands, coastal systems and coral reefs as well as a geographical focus on Central Africa, Southeast Asia, and the Amazon Rainforest likely maximize the marginal impact of ecosystem protection**. This analysis of marginal impacts — ecosystem services — aims to capture all impacts of an ecosystem on human welfare. Examples include water purification and flood protection. Because ecosystem services are not traded on markets, there is large uncertainty in any individual estimates of ecosystem service values. However, combining multiple studies leads us to conclude that the above focus areas are most impactful.

- **An additional prioritization analysis based on climate impacts finds that carbon storage is largest for peatlands and seagrass beds, suggesting that protecting those ecosystem subtypes is particularly important.** In general, climate benefits are to a large degree included in ecosystem services. However, climate tipping points include the Amazon rainforest, which underscores its potential as a high-benefit ecosystem. Lastly, we do not have enough certainty to recommend a particular prioritization based on animal welfare considerations or risks of civilisational collapse.

- **Principles of cost-effective conservation interventions are a focus on low-cost and low-yield countries and areas with a high chance of counterfactual development.** Philanthropists should pay particular attention to potential displacement effects. Displacement occurs when conservation of a particular area merely shifts developers to expand on a different but equally societally valuable piece of land. If displacement is likely, conservation impact is low. To prevent displacement, we recommend funding large-scale projects that protect all or most of a specific ecosystem type within an area. However, these projects could negatively impact farmers as their most profitable land is no longer available. On a case-by-case basis, ecosystem benefits need to be weighed up against potentially lower farmer incomes.

- **Water quality protection programs should focus on areas with high eutrophication[1] potential in low-cost regions (e.g., West and East Africa, and Southeast Asia).** Lake Victoria, in particular, stands out as a potential focus area due to its high degradation risk and low intervention cost status. Additionally, we suggest philanthropists identify large organizations focussing on nutrient pollution of waterways and evaluate their cost-effectiveness based on whether their target areas are at risk of eutrophication, use proven nutrient pollution reduction interventions, and have low project costs.

[1] Eutrophication describes the process whereby an increase in nutrients in the water leads to excessive algae growth and a lack of oxygen to support other species.

Introduction

Ecosystems are ecological collectives defined by four elements (Keith et al. 2013):

1. A **biotic** component, such as the flora and fauna of an area
2. An **abiotic** complex, such as specific water resources
3. The interactions between and within the biotic and abiotic spheres
4. A physical space

As such, ecosystems are different from mere geographical landscapes or collections of animals or species. They describe environmental systems made up of different living and nonliving components and interactions between them. As a system, they can provide environmentally and socially important services such as water filtration or pollination. Adopting ecosystems as the unit of analysis therefore shifts the focus from conservation of certain areas or species to ecological collectives with various functions.

There is a wide variety of ecosystems on earth, from deep sea floors to savannahs and caves. The International Union for the Conservation of Nature (IUCN) has developed a global typology of the various ecosystems. Starting from 4 global realms (terrestrial, subterranean, freshwater, and marine), the typology further segments ecosystems into 25 biomes within these realms. These biomes are at the level of generality of savannahs, lakes, shoreline systems etc.[2]

Overall, ecosystems are threatened on a large scale today. While global numbers are hard to come by, select statistics indicate the degree of vulnerability. In North America, 33% of terrestrial ecosystems are threatened (Comer, Hak, and Seddon 2022). In Ecuador, 22% of forest ecosystems are threatened (Noh et al. 2020), and in China, 40% of wetlands are at risk (Convention on Biological Diversity).

This report provides a guide for philanthropists interested in protecting these threatened ecosystems. Section 1, Measuring Ecosystems, explores how the health and vulnerability of ecosystems can be quantified, investigating the concepts of ecosystem health, "preserving vibrant ecosystems", biodiversity, and measures of collapse risk. Section 2, Impacts of ecosystem decline, analyzes the benefits of ecosystem protection along the dimensions of human welfare, climate, civilisation progress, and animal welfare. It concludes with a list of heuristics based on which philanthropists can find ecosystems that are most beneficial for society. Section 3, Conservation Philanthropy, evaluates the expected cost-effectiveness of various philanthropic approaches, including traditional conservation projects, and finally provides recommendations for the most cost-effective interventions to protect ecosystems.

[2] See Appendix Table 1 in Keith et al. 2020 for a full list and Global Ecosystem Typology for an interactive website to explore the typology. The section on Impacts of ecosystem decline uses this typology to prioritize across different interventions as the functions and thus the value that ecosystems provide vary across types.

Measuring ecosystems

Key Points

- The health and collapse risk of ecosystems is most comprehensively measured in the framework of vigor–organization–resilience. That ecosystem health framework assesses the structure of an ecosystem (such as its biotic and abiotic components), its functioning (ecological processes such as nutrient cycling), and its resilience to external stressors.
- The IUCN currently gathers data on ecosystem health and collapse risk around the world. However, as of now, the data is geographically limited. As such, philanthropists can best use it as a final step to compare the vulnerability of specific ecosystem protection interventions that have been selected through prioritization based on another metric (such as an ecosystem's impact on human welfare and climate).

This section of the report aims to answer which metrics capture ecosystems' integrity and health and allow philanthropists to prioritize between different interventions based on this ecosystem vulnerability. Should the objective, for example, be to protect a large degree of biodiversity? Similarly, are there frameworks that can capture more intuitive notions of "preserving vibrant ecosystems"? A complete framework for prioritization must include the vulnerability of ecosystems as protecting those ecosystems that are not under threat is not impactful. This section aims to provide heuristics for vulnerability. The next section of the report will add other benefits to this framework, including the effects on human welfare and climate, which provide additional dimensions along which philanthropists can prioritize.

Ecosystem health

A common framework to assess ecosystem health is the vigor, organization, resilience (V–O–R) model (Kruse 2019, Rapport and Maffi 2011, Costanza 2012). In this framework, an ecosystem is healthy if it has its original structure (organization) and function (vigor) and can maintain them against potential external pressures (resilience). Palmer and Febria (2012) describe organization as measurements that describe an ecosystem at a specific point in time, such as the abundance of certain species or concentration of elements. Functional (vigor) measurements on the other hand describe ecological processes such as pollutant removal rates. Resilience is more difficult to measure as it quantifies the ability of an ecosystem to withstand potential pressures rather than current conditions.[3] One example, however, is functional redundancy: when multiple species perform the same ecological function within an ecosystem, it is often deemed more resilient as the loss of one species does not affect ecosystem functioning as much (Folke et al. 2004).[4] It is also important

[3] Dakos and Kefi (2022) provide an overview of different types of measures and outline the difficulties associated with measuring resilience.
[4] Kruse (2019) lists a wide range of ecosystem health indicators developed in the literature.

to note that individual indicators in different categories within the VOR framework are usually insufficient to measure overall ecosystem health in a useful way. For example, while a decline in organizational indicators is a sign of ecosystem decline, it usually doesn't provide insight into why the system is declining. Similarly, focussing only on ecosystem services (such as water provision for humans) contains no information as to whether these services can be sustainably provided over time (resilience/stability) (Palmer and Febria 2012). As such, combining indicators across the vigor–organization–resilience categories is crucial to assess overall ecosystem health.

Preserving vibrant ecosystems

There is also an intuitive notion of protecting “vibrant ecosystems”. This term doesn't have an academic definition. However, Grumbine (1994) reviews various sources that discuss the management of ecosystems — including lay environmental publications, policy documents, and academic articles across the fields of conservation biology, resource management, and public policy. He finds that across this variety of sources a few goals are frequently endorsed as part of protecting ecological integrity (quoted from Grumbine 1994):

1. Maintaining viable populations of all native species
2. Represent all native ecosystem types across their natural range of variation
3. Maintaining evolutionary and ecological processes (i.e., disturbance regimes such as regular floods and fires, hydrological processes, nutrient cycles)
4. Managing over periods of time long enough to maintain the evolutionary potential of species and ecosystems
5. Accommodating human use and occupancy within these constraints

It is striking that these goals, except for human use (5), mirror the vigor–organization–resilience framework developed in the ecosystem health literature closely. Maintaining viable populations and representing native ecosystem types refer to the structural indicators of abundance of species and elements (organization). Maintaining evolutionary and ecological processes describe the functional properties of ecosystems (vigor). Lastly, managing over long periods of time stresses the importance of sustainable ecosystems, described as resilience in the ecosystem health framework. In this report, we'll use **ecosystem health to capture intuitive notions about the value of preserving vibrant ecosystems.**

Biodiversity

Biodiversity in general describes the variety of life that exists on earth. There are different ways to conceptualize biodiversity (Purvis and Hector 2000), including the genetic variability (Stange et al. 2021) across organisms within a species, the diversity of ecosystems, and the abundance and richness of species. This section argues that, while biodiversity is a useful measure of an ecosystem's organizational and structural health, it should not be used as the sole objective to maximize for philanthropists who are interested in the protection of ecosystems more broadly. Intuitively one might argue that conservation should maximize the world's biodiversity as the abundance and diversity of species are worth protecting. However, using biodiversity as its own metric runs into various issues (see Brennan and Lo 2022 for a further overview).

Biodiversity vs Wilderness

The focus of protecting and restoring ecosystems is to preserve the natural state of an ecosystem before human interference. This focus on wilderness (or naturalness) often comes in conflict with pure biodiversity maximization. For example, in arid ecosystems, human use can bring about higher biodiversity: a farm built in a desert landscape will provide more habitat for species than the original ecosystem did. Similarly, Brennan (1988) describes temperate forests in which limited land clearing increases the diversity of tree species. A response to this critique might be that, at least among *conservation* projects, one should choose those that most guard against biodiversity loss. However, even in this limited case, biodiversity is just one consideration among many. Many areas that are regarded as important to conserve, such as many US national parks, are generally lower in biodiversity and instead prized because they are deemed aesthetic or sublime (Sarkar 2005). **As such, a primary focus on biodiversity would likely rule out many ecosystems widely deemed important to conserve and could even suggest actions that would go against the preservation of natural ecosystems.** Rather, biodiversity should be one consideration among many.

Biodiversity vs Ecosystem Vigor & Services

Many of the most productive ecosystems are not very species-rich. Similarly, the ecosystems that provide the most services for humans are on average lower in biodiversity (such as salt marshes for water filtration). As such, a focus on biodiversity alone might lead to prioritizing ecosystems that are high in different species but are not vibrant in the sense that they contain relatively few ecological processes or provide few services for humans (Brennan and Lo 2022).

Biodiversity is therefore best understood as an element of ecosystem health rather than its own metric based on which to prioritize.

Ecosystem risk and decline

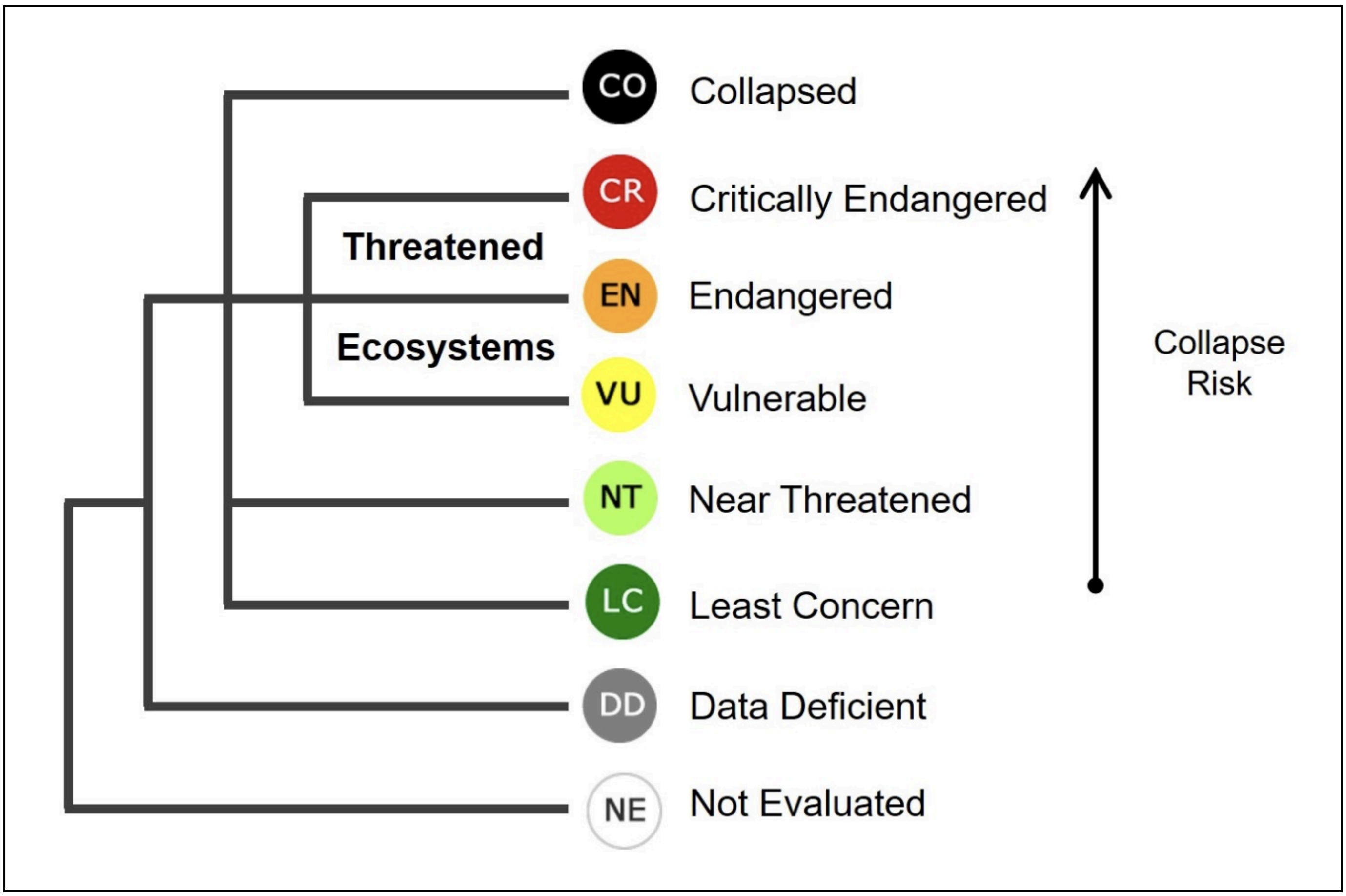
While the vigor–organization–resilience model provides a comprehensive conceptual framework to assess ecosystem health, it requires further operationalisation to assess the decline in ecosystem health across a range of ecosystem types: what are sufficient and (to the extent possible) transferable indicators to measure the structural and organizational health of ecosystems as well as their resilience? In order to measure an ecosystem's risk of collapse, Bland et al. (2018) outlines four steps:

- Define initial and collapsed state
- Describe collapse and recovery trajectories

- Identify collapse indicators
- Set quantitative thresholds for collapse indicators

The International Union for the Conservation of Nature (IUCN) has developed a mechanism to assess the risk and threat status of ecosystems as the basis for its effort to evaluate the risk of collapse of all of the world's ecosystems by 2025. It incorporates two types of evaluation in order to identify collapse indicators and measure an ecosystem's distance from collapse thresholds: risk assessment protocols and stochastic simulations. Risk assessment protocols require scoring ecosystems separately on a list of criteria that measure their health, such as the abundance of species. Simulation models, on the other hand, aim to evaluate an ecosystem's risk of decline and collapse holistically, based on the combination of various risk factors. The IUCN's final protocol includes 5 categories of indicators designed to measure an ecosystem's risk of collapse (Keith et al. 2013). Depending on the severity of degradation, an ecosystem receives a label on the following spectrum[5]:

Figure 1: Risk categories of the IUCN Red List of Ecosystems



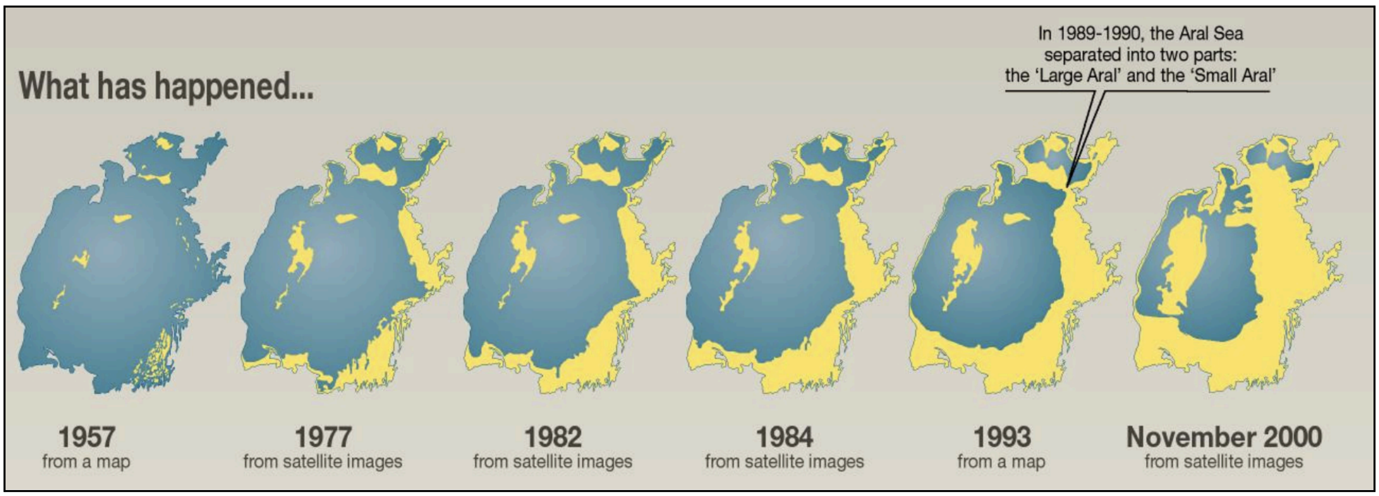
[5] Note that ecosystem collapse on its own is generally reversible. It is therefore different from species extinction. The report *Reducing Land Use and Returning Agricultural Land to Nature* argued that the irreversibility of species extinction requires a focus on species extinction. A similar argument does not apply to ecosystem collapse. Preventing the decline of an ecosystem from vulnerable to endangered is just as important as preventing its decline from critically endangered to collapsed.

Note: This figure is taken from the [IUCN Red List of Ecosystems](). It shows the various risk categories that an ecosystem can take on. Collapse risk increases from Least Concern to Collapsed. An ecosystem for which not enough data exists is listed as Data Deficient. An ecosystem for which an evaluation has not been attempted is listed as Not Evaluated.

The IUCN bases this overall risk categorisation of an ecosystem on the following five criteria which are themselves scored on the Least Concern — Collapsed scale outlined in Figure 1.

1. **Decline in distribution**: Has the area taken up by the ecosystem declined? This is usually measured through time series of maps, vegetation mapping, and remote sensing. Figure 2 provides an example of this criterion for the Aral Sea. The theory behind this criterion is that a decline in habitat implies that the ecosystem can sustain less biodiversity.[6]

Figure 2: Decline in distribution of the Aral Sea

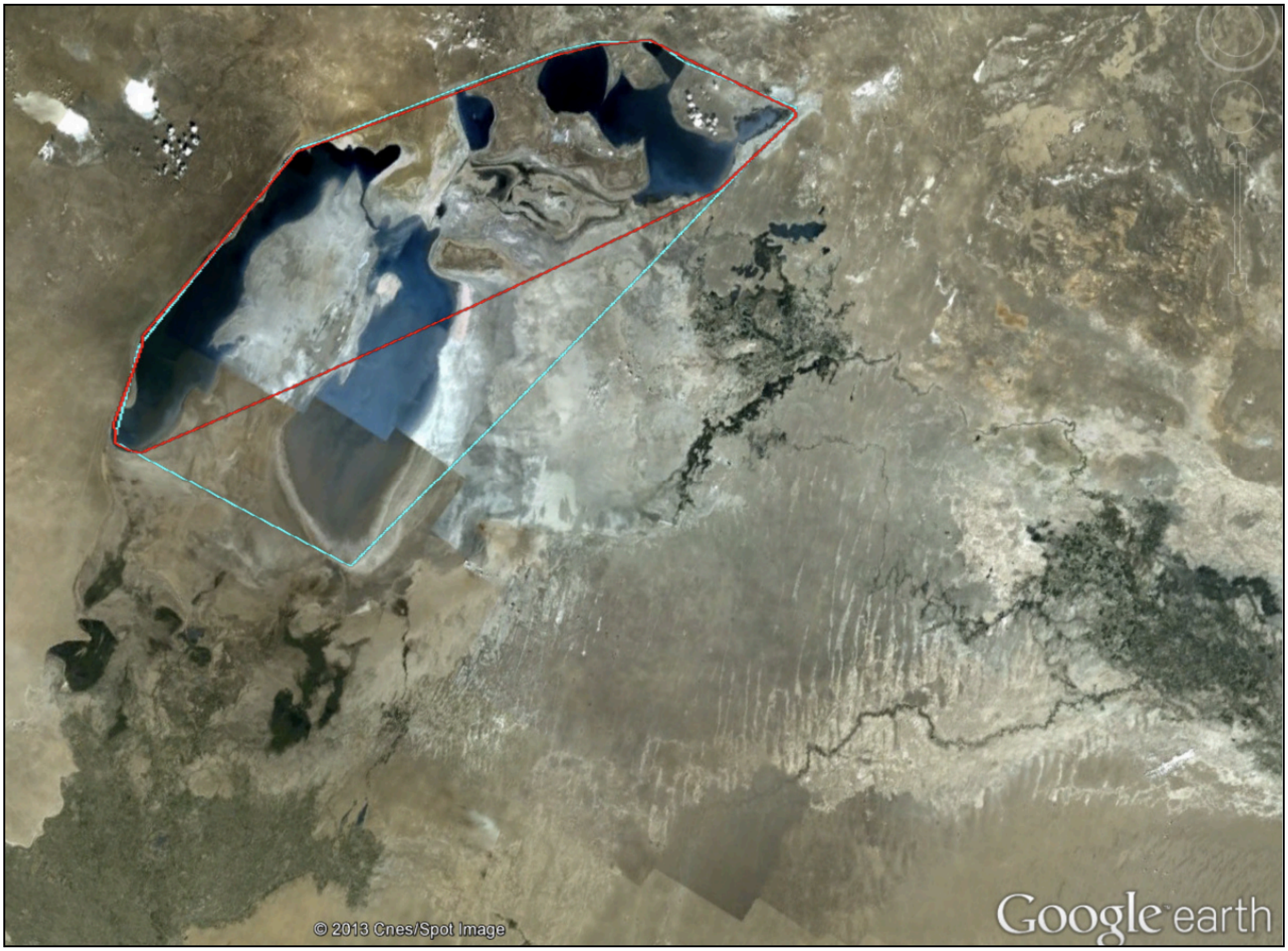


Note: This is part of Figure S5.6 in Keith et al. (2013). It shows the changes in surface area of the Aral Sea over 43 years from 1957 to 2000. Since there is substantial historical (incl. current) decline in the size of the Aral Sea without projected future improvements, it is rated *Collapsed* under criterion A (Decline in distribution).

2. **Restricted distribution:** Is the remaining area of an ecosystem geographically clustered? The reasoning behind this criterion is that threats to ecosystems such as alien species invasion or regional climate changes are often localized. When an ecosystem's area is geographically clustered, these threats are more likely to become a threat to the entire ecosystem. This variable is usually measured using spatial map criteria (such as the minimum convex polygon covering an ecosystem). Figure 3 shows this criterion for the Aral Sea.

[6] Note that our report *Reducing Land Use and Returning Agricultural Land to Nature* made use of this logic to argue that habitat loss is the primary driver of extinction risk.

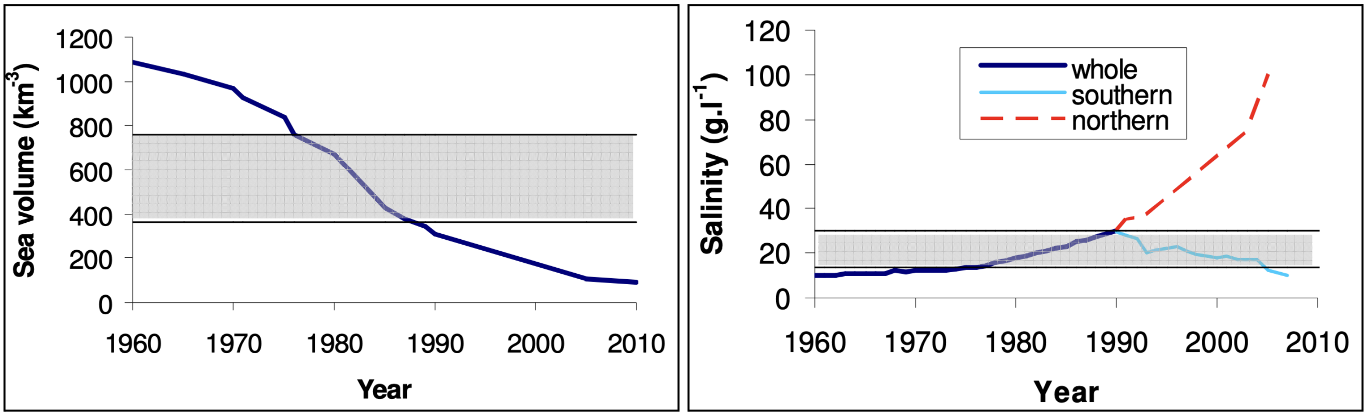
Figure 3: Restricted distribution of the Aral Sea



Note: This is Figure S5.7 in Keith et al. (2013). It shows the minimum convex polygons representing lower (red) and upper (blue) bounds of the current extent of occurrence of the Aral Sea surface waters. In recent years, the Eastern part of the Aral Sea has sometimes been filled with water (blue) and at other times has been dry (red). As the area of the polygons is between 25,000 and 40,000 sq km, the Aral Sea is rated *Vulnerable* under criterion B (Restricted distribution).

3. **Environmental degradation:** have the abiotic (physical/non-living rather than biological) components of the ecosystem degraded? When the environment of an ecosystem changes, it becomes less suitable for certain species and might not sustain the original ecological processes. This is usually measured by identifying abiotic characteristics whose decline causes a loss of biota (e.g., deforestation due to acid rain) and choosing variables to quantify this abiotic decline. Figure 4 shows two such variables for the case of the Aral Sea: salinity levels and overall water volume.

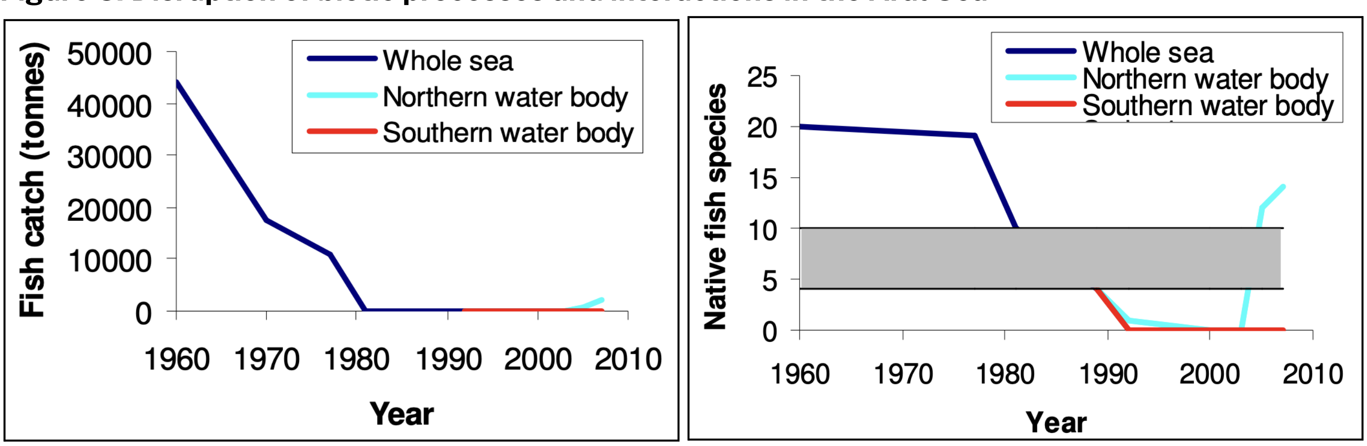
Figure 4: Environmental degradation of the Aral Sea



Note: The two panels are Figures S5.8 and S5.9 in Keith et al. (2013). The left panel shows trends in total volume of the Aral Sea. The right panel shows the average salinity of the Aral Sea. Both panels display a time series from 1960 to 2010, relative to a bounded threshold of ecosystem collapse. As both indicators are now substantially outside the ecosystem bounds, the Aral Sea is rated *Collapsed* under criterion C (Environmental degradation).

4. **Disruption of biotic processes and interactions:** have ecological functions of the ecosystem declined? This criterion speaks directly to the functioning/vigor aspect of an ecosystem. Ecosystem assessments measure it by identifying biotic variables that serve as a proxy for the functioning of an ecosystem such as functional redundancy (the presence of multiple species fulfilling similar ecological roles). Figure 5 shows sample biotic variables for the Aral Sea.

Figure 5: Disruption of biotic processes and interactions in the Aral Sea

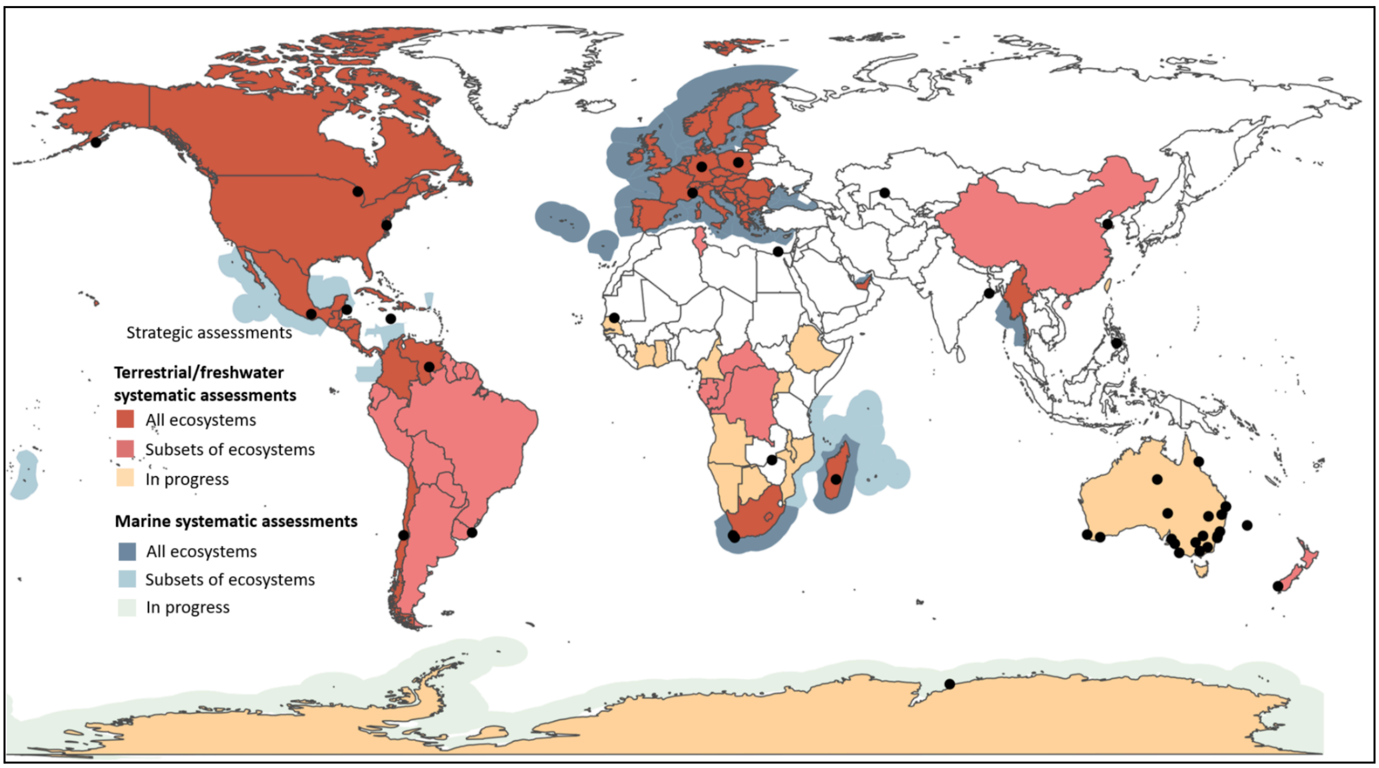


Note: The two panels are Figures S5.10 and S5.11 in Keith et al. (2013). The left panel shows the commercial fish catch in the Aral Sea from 1960 to 2010. The right panel shows the number of native fish species during the same time frame. There is virtually no commercial fish catch today. The number of native species has declined from 20 to about 0 in the early 2000s. Since then, the Northern water body has recovered 70% of its original species while the Southern water body has not. As both indicators indicate large collapse, the Aral Sea is rated *Collapsed* under criterion D (Disruption of biotic processes and interactions).

5. **Quantitative estimates of risk of ecosystem collapse:** what probability of collapse do stochastic models predict? These models can incorporate information across various dimensions of ecosystem health and thus capture interactions that are not represented by looking at each dimension individually.[7]

Prioritization based on ecosystem health and risk has been done at various regional scales (e.g., Noss, LaRae, and Scott 1995 for the US or Etter et al. 2020 for Colombia). However, to our knowledge, such prioritization does not exist on a global scale. Rowland et al. (2020) have combined IUCN RLE data into ecosystem health indices for prioritization. However, IUCN currently has limited data. Figure 6 shows the state of global assessments. Note that high-biodiversity areas such as East Africa and Southeast Asia are missing. The usable database on their website contains only about 13% of all those assessments. As such, data is not usable for direct global prioritization. However, it is a good resource to prioritize among a smaller set of possible ecosystem protection interventions that has been identified through prioritization based on other criteria (e.g., climate, human welfare, animal welfare, etc.)

Figure 6: Coverage map of the IUCN Red List of Ecosystems assessment



Note: This figure is from the International Union for the Conservation of Nature's Red List of Ecosystems Database. For each country globally, it shows the progress of the systematic assessment of ecosystems. For terrestrial ecosystems, dark red indicates that all ecosystems have been assessed. Light red indicates that some, but not all, ecosystems have been evaluated. Orange indicates that the assessment is in progress. Since many countries, especially high-biodiversity

[7] No such analysis has been carried out for the Aral Sea. However, Table 6 in Keith et al. (2013) provides examples of such analyses for other ecosystems.

areas, are missing and the online database contains only 13% of all assessments, this data is not suitable as a starting point for a global prioritization.

Heuristics for prioritization

There are various metrics in the conservation field that one might use as heuristics for prioritizing. Biodiversity, the abundance and diversity of species, for example, has intuitive appeal. However, as described above, it often runs counter to other considerations such as wilderness/naturalness and the functioning of ecosystems. Another metric, ecosystem health, provides a more holistic framework to measure the ecological integrity of ecosystems. Prominent models focus on the organization and functional structures of ecosystems and their resilience. As such, they capture a more complete range of ecosystem integrity, and align more closely with the popular notion of "protecting vibrant ecosystems". **Philanthropists should focus on interventions that look at ecosystems holistically, aiming to preserve their structure, functioning, and resilience** as opposed to focussing on singular metrics such as biodiversity maximization.

Concretely, there is limited data on the vulnerability of ecosystems around the world. The International Union for the Conservation of Nature aims to assess the risk of all ecosystems by 2025 using the holistic ecosystem health (V–O–R) model. However, currently only certain countries have finished their evaluations, and only a small part of the completed assessments are already available (see Figure 6 above). It is therefore difficult to prioritize globally based on ecosystem risk data. However, **we recommend that philanthropists use the IUCN data, where available, to prioritize among a set of funding opportunities that have been first identified through the other metrics described in the next section (e.g., the impacts of an ecosystem's collapse on climate or human/animal welfare).**

Impacts of ecosystem decline

Key Points

- Human welfare impacts of ecosystems are measured as *ecosystem services*. For human welfare, successfully protecting coastal systems, wetlands, and coral reefs is likely most beneficial. Geographically, protecting ecosystems in the Amazon rainforest, Central Africa, and Southeast Asia is on average most impactful.
- Many climate benefits are captured by ecosystem services. Additionally, climate *tipping points* can be mitigated by focussing protection on the Amazon rainforest. More specific ecosystem subtypes that have a high potential for carbon storage are peatlands (subcategory of wetlands) and seagrass beds (subcategory of coastal systems).

- We do not have enough certainty in the risks of civilisation collapse from multiple ecosystem collapse to recommend a particular prioritization. Further, there is little research on which ecosystems ought to be protected to avert these civilisation collapse scenarios.
- We do not recommend a particular prioritization for philanthropists interested in animal welfare due to a) our lack of data on wild animal suffering, and b) large unanswered ethical questions whose resolution might imply that a particular prioritization is harmful.

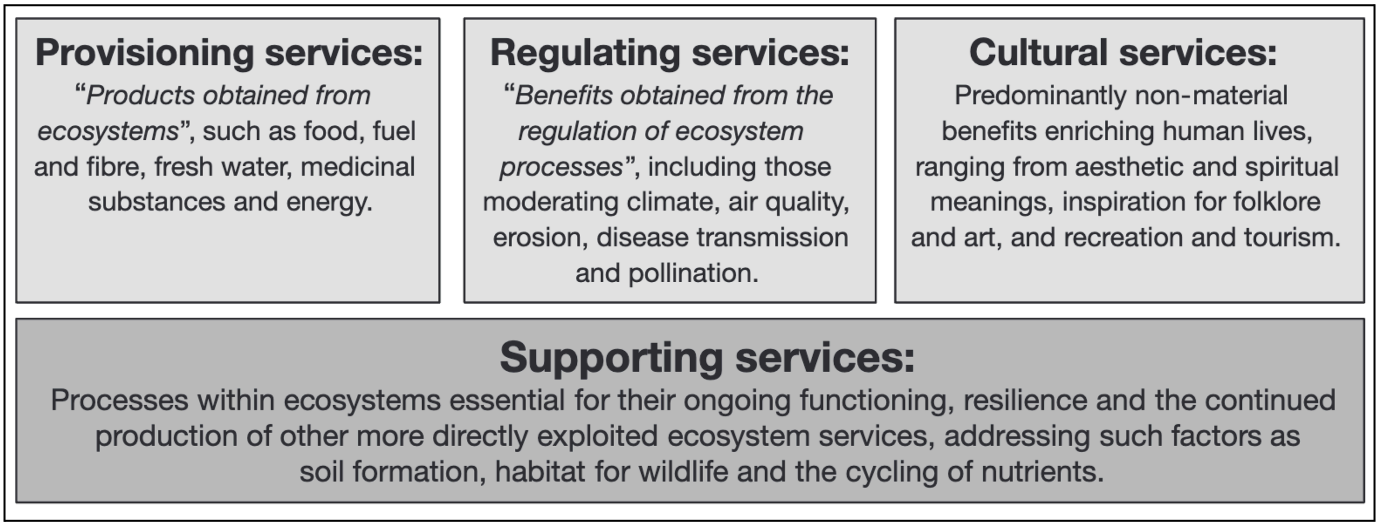
Human welfare

The concept of ecosystem services aims to capture ecosystems' value to humans. To be specific, ecosystem services as defined by the UN Millennium Ecosystem Assessment are "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment (Program) 2005). These services are wide-ranging and often segmented into 4 categories (following Everard 2022):

1. **Provisioning services**. Ecosystems might provide products for human consumption, such as food, fresh water, and timber.
2. **Regulating services**. Various ecosystems moderate the environment with benefits to humans, such as soil erosion prevention, flood protection, and pollination.
3. **Cultural services**. Humans find ecosystems to be of cultural value, for example as inspiration for art or for recreational and touristic purposes.
4. **Supporting services**. Services that are intermediate to the production of other services, for example providing habitat for animals, which might then be hunted for food. By definition, these services provide no value to humans beyond the value provided by the provisioning, regulating, and cultural services they enable.

Figure 7 provides further examples of the different types of ecosystem services. Today, there are various classifications schemes for ecosystem services that differ in the specific typology but have in common the segmentation into provisioning, regulating, and cultural services. These classification schemes include The Economics of Ecosystems & Biodiversity (TEEB), Common International Classification of Ecosystem Services (CICES), and UK National Ecosystem Assessment (NEA) frameworks.

Figure 7: Typology of ecosystem services



Note: This figure is Figure 2.3 in Everard (2022). It shows a breakdown of the four types of ecosystem services: provisioning, regulating, cultural, and supporting. Supporting services do not directly provide value to humans. Their contribution is captured entirely by their support of the other three categories of ecosystem services.

It is important to note here that ecosystem services might depend on various characteristics of the ecosystem. Some services depend strongly on the existing biodiversity in an ecosystem, such as food, fiber, or biologically based fuels. Others, however, depend on its geological (abiotic) characteristics. Examples are flood protection, soil-forming, and the provision of habitat for wildlife (Everard 2022).

In order to understand the relative importance of different ecosystems to human welfare it is important to assign quantitative values to different ecosystem services as provided by different ecosystems in different contexts. Researchers take various approaches to estimate ecosystem service values as, unlike other goods, ecosystem services are not traded on markets.[8] Three main categories of approaches are (following Markandya 2019):

1. Physical Linkage. These valuations are based on the links between an ecosystem service and a traded good. If, for example, an ecosystem provides an input for a marketed good, the effect that a change in the ecosystem has on the final good's market price equals the value of that ecosystem's provisioning service.
2. Revealed Preference. These approaches aim to extract information about a consumer's willingness to pay for an ecosystem service based on their observable actions. One example is to take the travel cost to a recreational site as a lower bound for the recreational value of that

[8] When a service is traded on a market, it is straightforward to generate a ballpark estimate or lower bound of the value of that service. A stylised chain of logic proceeds as follows. Consider one seller who provides a certain service and one buyer. If the service is traded at a given price, it follows that the buyer's marginal value from that service is higher than the price (as otherwise the buyer would rather not buy the service). As such, the price of that service is a lower bound for its marginal value, which can in many cases serve as a rough, conservative approximation.

ecosystem for that consumer. The reasoning is that the consumer would only pay a given travel cost if their recreational value from that trip was at least as high.

3. Stated Preference. Generally the weakest method: it asks people how much they value ecosystems, which can be biassed by hypothetical and strategic reporting of preferences.

Overall, ecosystem service valuation is difficult because no market prices exist and different types of ecosystem services only lend themselves to certain types of valuation methods. However, these valuations provide a first basis to prioritize between different ecosystems.

The most comprehensive database of valuations of the services that various ecosystems provide is the Ecosystem Services Valuation Database (ESVD). It includes about 9,500 valuation data points that include standardized monetary values together with characteristics of the ecosystems such as their biome, the type of ecosystem service, their region, and more. As noted above, the estimates of total economic value are generally quite weak as it's difficult to estimate the economic value of ecosystem services in the absence of market prices. That being said, there are two sources connected to the database that provide analysis of ecosystem service valuations: DeGroot et al. (2010) and DeGroot et al. (2013). Based on these articles, we estimate the following orders of magnitude for the values of ecosystem services for 10 different ecosystem types in column 2[9]:

DeGroot et al. (2013) conducts a similar analysis using arithmetic means of the total economic value of different ecosystem types and finds

Ecosystem type	**Total economic value in USD/hectare/year (order of magnitude, based on DeGroot et al. 2010)**	**Total economic value in USD/hectare/year (average values, from DeGroot et al. 2013 Table 1)**
Coastal systems	4,450 (4)	28,917 (3)
Coastal wetlands	20,727 (1)	193,845 (2)
Coral reefs	4,091 (5)	352,915 (1)
Grasslands	958	2,871
Inland wetlands	6,614 (2)	25,682 (4)
Open oceans	33	491
Rivers & lakes	4,898 (3)	4,267
Temperate forests	382	3,013
Tropical forests	1,414	5,264 (5)
Woodlands	177	1,588

9 The underlying data for these means are the minimum and maximum total economic values across various studies included in the database. We form the geometric mean of the maximum and minimum value to get an estimate of the correct order or magnitude. We caveat that these estimates are designed to be on the right order of magnitude and should not be used as estimates of the expected value of ecosystem services.

qualitatively similar results (see column 3, adapted from their Table 1). However, the ordering among the highest-value biomes differs somewhat. The table visualizes this by including in parentheses ranks from sorting ecosystems by their valuations in descending order. **Based on both analyses, we estimate the following ecosystem types generally provide the most benefits to humans:**

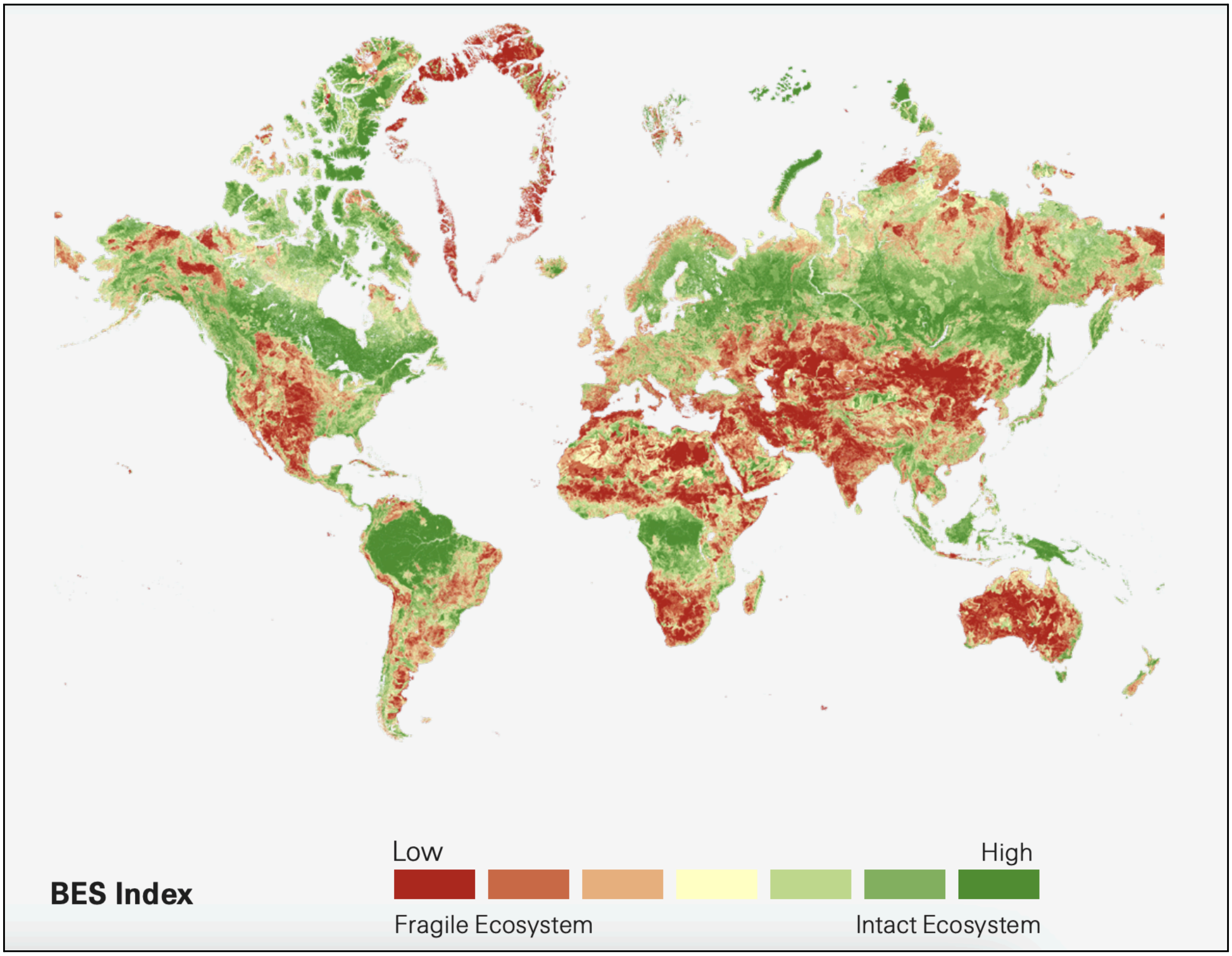
- **Coastal systems**
- **Coral reefs**
- **Wetlands (both inland and coastal)**

The economic value of coastal systems consists primarily of recreation, tourism, and storm protection (see, for example, Mehvar et al. 2018). Among all ecosystem services, recreation and tourism value contribute the most to the high value of coral reefs (see Cesar, Burke, and Pet-Soede 2003; also DeGroot et al. 2010). Coastal wetlands derive much of their economic value from their potential to treat wastewater (see, for example, Breaux, Farber, and Day 1995). Lastly, inland wetlands' most valuable service is the moderation of extreme events such as flood protection and water regulation (see ESVD).

Retsa et al. (2020) provides an additional source of data on ecosystem service valuations on a global scale. They built an ecosystem services index, using data on 10 different services, mapping them globally using one proxy variable for each (such as forest cover for timber provision). Figure 8 shows their findings globally. Areas in green are those that are both intact and provide a large degree of ecosystem services. As such, areas in green are good targets for conservation when they also have high chances of counterfactual development. While the ecosystem services in this index do not have monetary values assigned, it is likely a good first pass at finding those ecosystems that provide a lot of value for human welfare (as, in general, an ecosystem with more services is more valuable than one with fewer services). We furthermore think it is a useful addition to the evidence base as the other article discussed above relies on selected case studies only and does not provide a standardized global view. **The broad geographic regions that stand out are Central Africa, Southeast Asia, and the Amazon Rainforest.**[10] There are also high ecosystem service index values in large parts of Canada. However, because of higher land purchase and implementation costs in more developed countries such as Canada, we think these are less likely to be impactful giving opportunities.

Figure 8: Global map of the biodiversity and ecosystems (BES) index

[10] Willcock et al. (2023) consider various ecosystem services separately and find similar geographical patterns.



Note: This figure is Figure 7 in Retsa et al. (2020). It shows the Biodiversity and Economic Services (BES) index for ecosystems on a global map. Areas in green have the most ecosystem services and are most intact. In contrast, areas in red are fragile ecosystems with fewer ecosystem services. If areas in green have a high counterfactual chance of development (e.g., for agriculture), they are high-priority targets for conservation as many services can be counterfactually protected.

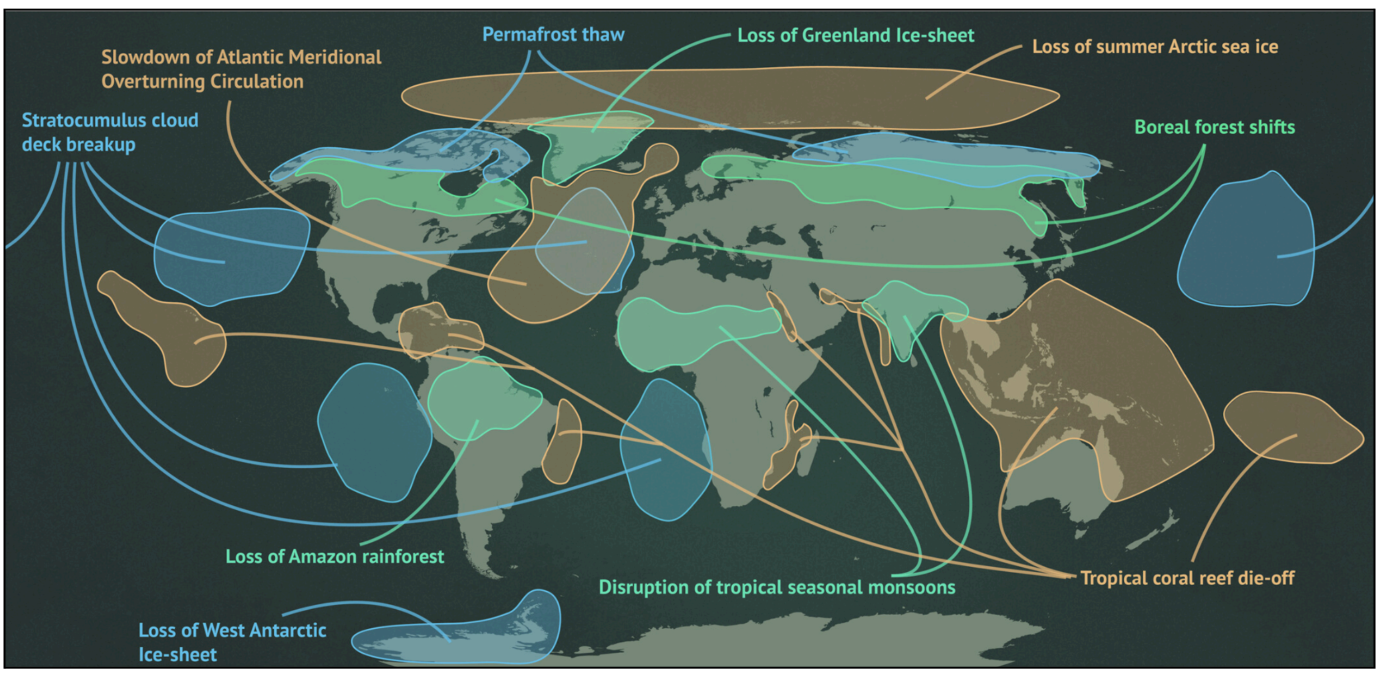
All else equal, this analysis indicates that **philanthropists can maximise impact by protecting coastal systems, coral reefs, and wetlands, as those are the ecosystems that provide the most value to humans**. **In general, protecting ecosystems in the Amazon rainforest, Central Africa, and Southeast Asia is likely to provide comparatively high ecosystem service value.** Of course, this does not take into account the potential varying costs of conservation across these ecosystem types. We provide a fuller picture in the last section of the report, in which we combine the benefits of ecosystems estimated here with the costs of conservation.

Climate

In general, ecosystem services cover benefits to climate stabilization, often in categories such as "climate regulation" (see, e.g., DeGroot et al. 2010). As such, a prioritization based on the human welfare/ecosystem services discussed above captures many of the climate benefits. This section adds two considerations: the climate tipping points hypothesis (such as Amazon rainforest dieback) and more specific ecosystem subtypes relevant for climate (such as peatlands). These provide additional prioritization heuristics for philanthropists focussed specifically on climate.

There are various conceptualisations of climate tipping points in the academic literature. McKay et al. (2022) provide a simple definition: tipping points are thresholds beyond which a small perturbation of a system induces a qualitatively different response in that system. Specifically, tipping points are reached when the climate system changes in a way that is self-perpetuating as a result of the qualitative change. While tipping points always indicate substantial changes to the climate, they fall into two categories depending on the geographical scale of those changes: some tipping points have only regional environmental effects, while others have a global climate impact. In that way, tipping points provide a lens that is different from ecosystem services which estimate benefits starting from local effects as opposed to the overall climate system. McKay et al. (2022) and Wang et al. (2023) both provide lists of global and regional climate tipping points (see Figure 9).

Figure 9: Candidate tipping points covered in Wang et al. (2023)



Note: This figure is Figure 1 in Wang et al. (2023). It shows potential climate tipping points and their approximate location on a global map. Wang et al. (2023) define tipping points as "components of the Earth system which may respond nonlinearly ... by transitioning toward substantially different long-term states upon passing key thresholds"

The majority of tipping points are largely caused by global temperature increases themselves, as is the case for example for the melting of ice sheets. However, two potential tipping points[11] have causes that can be further prevented through ecosystem protection and conservation. These are:

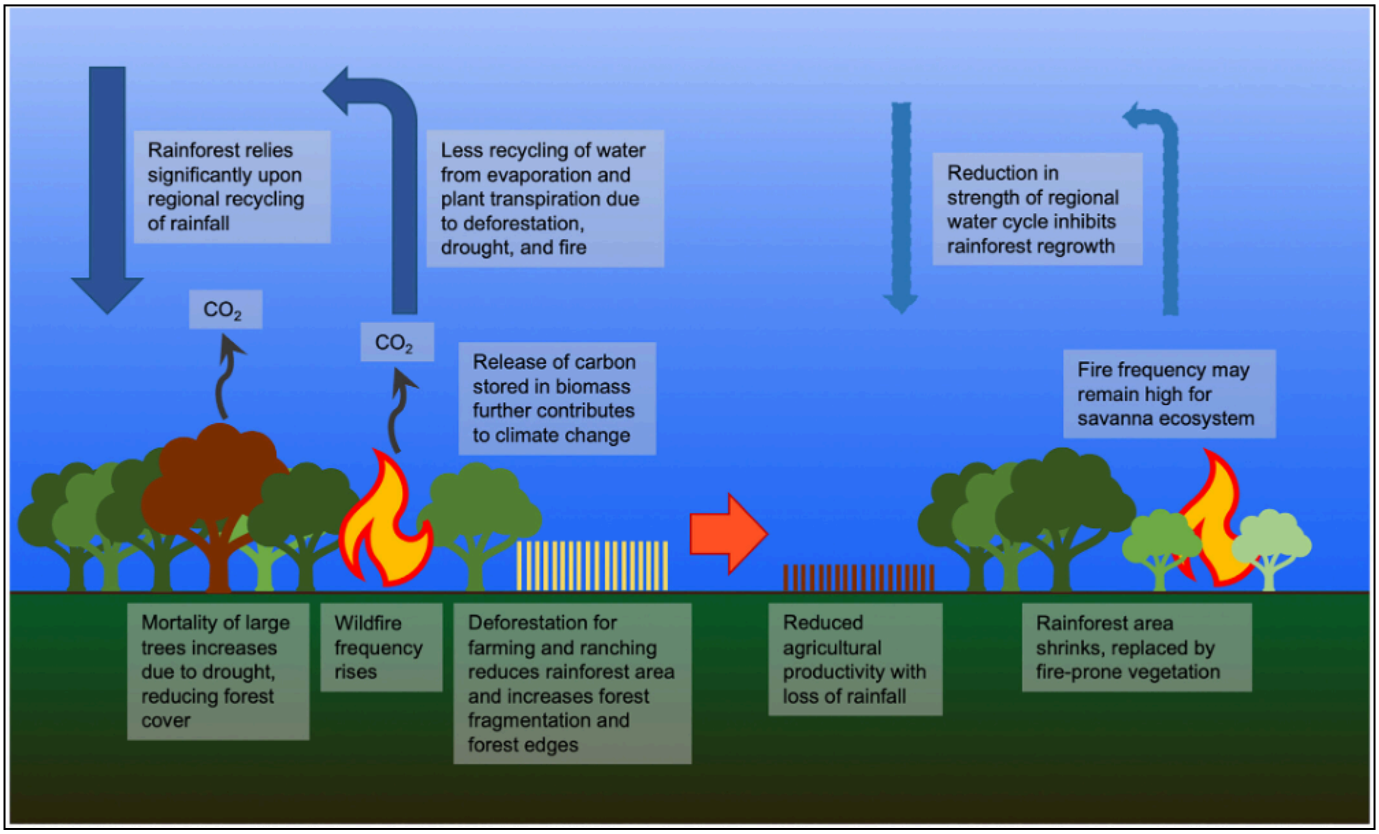
1. **Tropical coral reef die-off.** Coral reefs face various threats including overfishing, land-based pollution, and increases in temperature (Hughes et al. 2017b). Coral reefs are considered a tipping point because they have a widespread impact on human welfare by supporting recreational activities, tourism, and fishing, on which many people's incomes rely.
2. **Loss of Amazon rainforest.** The Amazon rainforest has historically been a major carbon sink for human emissions. Mainly because of deforestation and droughts, the Amazon has shrunk by about 20%. Studies that argue for an Amazon rainforest tipping forecast that the Amazon might further undergo a self-perpetuating cycle in which crossing a threshold of deforestation somewhere between 25–40% might cause more drying which turns parts of the rainforest into a savannah-like state. However, the IPCC has low confidence that this tipping point would be crossed before 2100 (see below).

Figure 10 shows the feedback loops posited by Amazon rainfall-dieback theory. The Amazon, especially during the dry season, relies heavily on rainfall that is recycled by vegetation in the Amazon itself. As deforestation increases, there is less vegetation to capture water, thereby increasing droughts and the duration of dry season. This reduction in precipitation then leads to the death of large trees due to reduced soil moisture (Ivanov et al. 2012; Nepstad et al. 2008) and an increased risk of wildfires due to dead vegetation and drier conditions (see, e.g., Brando et al. 2014). Both of these factors in turn lead to further deforestation. This interplay forms a self-perpetuating cycle, which is projected to turn parts of the Amazon into a savannah-like ecosystem.

We note that there is substantial debate about whether a tipping point exists for the Amazon rainforest, and, if so, what the quantitative threshold is. Nobre et al. (2016), one of the main studies arguing for the Amazon rainfall-dieback theory, notes that "the existence of … tipping points still requires further research". Similarly, Wang et al. (2023) in their article on global tipping points caveats that there is an ongoing debate about the Amazon dieback theory and whether deforestation would be a biome-wide tipping element.[12] This article provides a short popular overview of the various views on dieback-theory. Even if a tipping point exists, the exact threshold is unclear. While Sampaio et al. (2007) find a 40% threshold — a number that has been cited many times since — other studies find a lower threshold of 20–25% (Lovejoy and Nobre 2018). Notably, the Intergovernmental Panel on Climate Change (IPCC) concludes in their 2021 report that they have low confidence any threshold would be crossed before 2100 (see, e.g., the technical summary in Intergovernmental Panel On Climate Change 2023). Overall, we are not certain what the threshold is, but adopt the IPCC's view that the chance of Amazon dieback in the 21st century is likely low. However, if philanthropists come across funding opportunities in the Amazon that have a high marginal impact by reducing the chance of dieback, they should investigate those opportunities and the credibility of more imminent dieback feedback loops in more detail.

[11] There is some evidence (Paul et al. 2016) that the disruption of tropical monsoons, another tipping point, is partly caused by deforestation. However, more research is needed.
[12] Some further articles in support of the dieback theory are Boulton, Lenton, and Boers (2022), and Wunderling et al. (2022).

Figure 10: Diagram of causes, feedbacks, and impacts associated with Amazon dieback



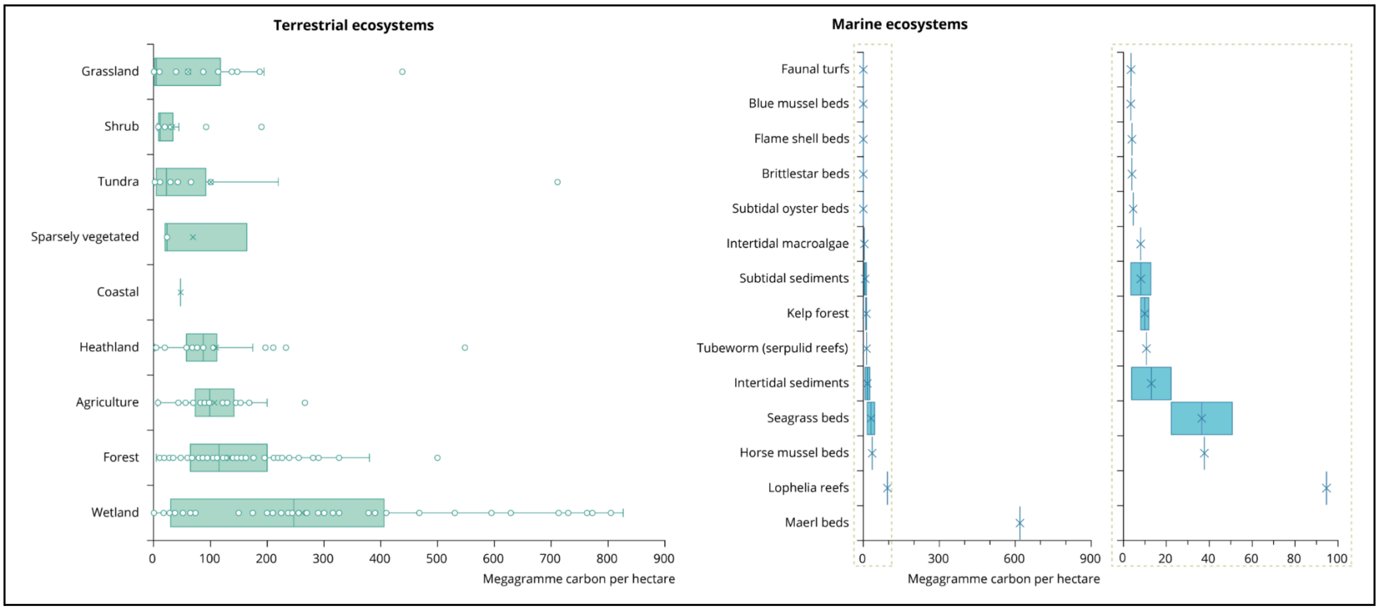
Note: This is Figure 12 in Wang et al. (2013). It shows the self-reinforcing cycle of Amazon rainforest dieback. In this model, deforestation beyond a certain threshold leads to a reduction in rainfall in the Amazon, which increases the mortality of large trees and frequency of wildfires, which in turn lead to further deforestation.

The impacts on coral reefs, mostly on recreation and tourism, are already well-captured in ecosystem services. The potential self-perpetuating cycle of Amazon rainforest loss as it reaches around 20–40% deforestation, however, is not fully captured through the ecosystem services approach (since at that threshold the marginal cost of further deforestation is far larger due to self-perpetuation). Philanthropists focussing on climate should include the benefits of protecting the Amazon rainforest in their prioritization.

While the ecosystem service approach allows prioritization across major biome groups, further research has investigated which ecosystem types within those biomes provide the highest potential for carbon sequestration and storage per unit of land. European Environment Agency (2022) found based on EU data that **among terrestrial ecosystems, wetlands, and peatlands in particular, are the largest carbon stores per area, followed by forests. Among marine ecosystems, seagrass beds, maerl beds[13], and lophelia[14] reefs hold the highest carbon storage potential** (see figures 11 and 12)**.**

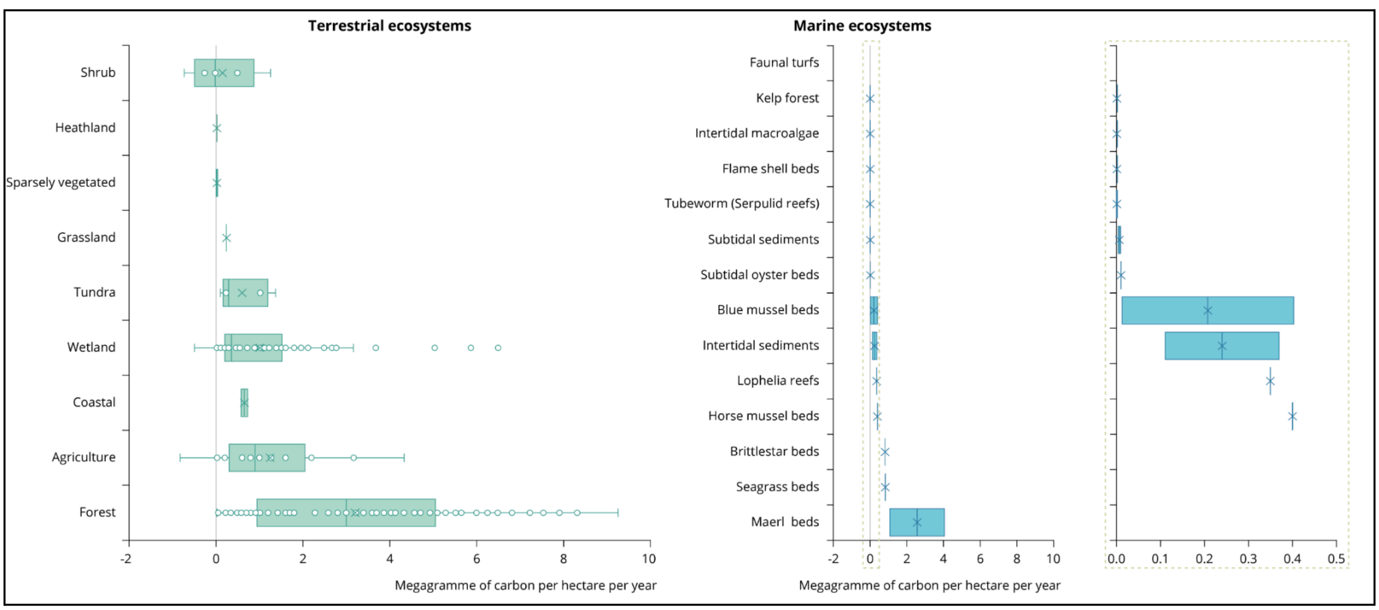
[13] Maerl is a type of coralline red algae.
[14] Lophelia is a cold-water coral.

Figure 11: Average levels of carbon storage in terrestrial and marine habitats in the EU



Note: This is Figure 1 in European Environment Agency (2022). Both panels show carbon storage by ecosystem type in megagramme carbon per hectare. Each dot represents an underlying data point from previous studies, and the values indicated by an x are averages by ecosystem. Wetlands in particular have high carbon storage potential within terrestrial ecosystems. Within marine ecosystems, Maerl beds and Lophelia reefs have particularly high carbon storage values.

Figure 12: Average carbon sequestration rates in terrestrial and marine habitats in the EU



Note: This is Figure 2 in European Environment Agency (2022). Both panels show carbon sequestration by ecosystem type in megagramme carbon per hectare per year. Each dot represents an underlying data point from previous studies, and the values indicated by an x are averages by ecosystem. Forests in particular sequester a large amount of carbon compared to other terrestrial ecosystems. Within marine ecosystems, Maerl and seagrass beds have particularly high carbon sequestration rates.

Lastly, Strassburg et al. (2020) looks at the global distribution of climate benefits from the protection of ecosystems and finds that **the protection of ecosystems in Southeast Asia and Central Africa is on average most impactful because of their high climate benefits (as measured by increases in potential carbon stock) and low land purchase costs for restoration and conservation.** It is striking that those broad geographical regions, which come from an entirely different methodology, are similar to those identified in the ecosystem service section.

In conclusion, the concept of ecosystem services covers most climate benefits. **Wetlands and forests likely have the highest impact on climate.** The discussion on tipping points revealed that protecting the Amazon rainforest in particular could be impactful, too. Lastly, **more specific ecosystems with high carbon storage potential are peatlands and seagrass beds**. In general, the most cost-effective conservation and restoration opportunities for climate likely lie in Southeast Asia and Central Africa due to their high climate benefits and low land purchase costs.

Civilisational progress

Insofar as civilisational progress is captured by human welfare, the marginal impact on civilisational progress of various ecosystems is contained in ecosystem services. This section aims to answer whether there are additional non-marginal effects on civilisational progress. To be concrete: could it be that the collapse of not only one but select combinations of ecosystems has an effect on civilization that is larger than the effect of each ecosystem collapse separately?

In general, arguments to this effect refer to historical case studies. One prominent example is the collapse of society on Easter Island that is often claimed to be a result of environmental change including large-scale deforestation. Another example is the downfall of Classic Maya civilization which might have partly been due to overpopulation and environmental degradation (Diamond 2006). We are uncertain to what extent the collapse of these societies are useful analogies for today's world. Easter Island for example was an isolated small-scale civilisation, and the Maya civilisation's technological abilities and knowledge for adaptation to environmental change were far less developed than today's civilisation. The Centre for Existential Risk notes to that end that "environmental changes are associated with many historical cases of societal 'collapses'. However the likelihood of occurrence of such events and extent of their socioeconomic consequences remains uncertain".

However, even assuming that large-scale ecosystem collapse presents an outsized risk to global civilization today, there are — to our knowledge — no studies that analyze which ecosystems in particular would have such an outsized impact if they were to collapse simultaneously. While there are some novel attempts to identify such aggregated risks in relation to climate change — such as multiple breadbasket failure, see Janetos et al. (2017) — they have not been studied enough to provide a basis for prioritization. There are also some general factors that have led to the decline of societies in the past (see Diamond 2006), such as overfishing and deforestation. However, those are not specific enough to be a basis for prioritization. In conclusion, while there might be non-marginal aggregate risks to civilization from the collapse of multiple ecosystems simultaneously, we are unsure how large this risk is and do not currently have a basis for prioritization as more research is needed. At the same time, the fact that there is initial research in this area, with experts deeming the risk uncertain (as opposed to low/negligible) makes us believe that funding additional research might be an impactful way to make progress in the ecosystem protection space. We recommend that philanthropists look for projects that seem particularly likely to answer questions that would cause experts to change their beliefs. If, for example, civilisational risks are negligible, this area likely does not need to be studied further. If, however, it turns out that there are underexplored and underestimated risks, initial work in this area has the potential to spur future research and thus be especially impactful.

Animal welfare

This section analyzes how ecosystem collapse impacts animal suffering, and whether there are ways to prioritize the protection of ecosystems based on the reduction of animal suffering. The study of wild animal welfare is a very nascent field (for an introduction see, e.g., Animal Ethics 2020). As a result, identifying the largest issue facing wild animals caused by ecosystem collapse is impossible without further original research. However, there are a few unanswered questions that make us uncertain about any particular prioritization at this point:

As a rough first approximation, we might use the decline in population sizes that a habitat can sustain as a proxy for the decline in animal welfare. The reasoning is that if land cannot sustain a large population, their basic requirements for life cannot be met. That is to say that an ecosystem might not provide enough food or water for these animals. As suffering and potentially dying from hunger or thirst causes suffering in animals[15], we think the decline in biodiversity (and particularly animal abundance) is a good first indicator of an ecosystem's impact on animal suffering[16]. We might therefore conclude that ecosystems that are facing a large decline in animal abundance (possibly measured by biodiversity more broadly) are those whose conservation likely has comparatively large potential to reduce the suffering of animals within them.

[15] There are various pieces of evidence that support the belief that animals experience pain. Many animals exhibit both behavioural and physiological responses to pain that are similar to humans: they vocalise in response to pain, avoid situations associated with pain, and exhibit increased heart rates and stress hormones. Similarly to humans, these responses decrease in animals when they are given pain-reducing medication. One might object that, even if animals experience pain, this suffering is not morally relevant (see, e.g., Miller 2021), for example because they do not feel as though the pain belongs to them (similar to pain asymbolia, which causes humans to report that the pain does not matter to them). However, given that pain receptors as well as areas of the brain that process information about pain have developed similarly in humans and many animals (Sneddon 2018), it is likely that the features of pain that make it morally relevant for humans, are also present in animals.

[16] The converse is also true. An increase in animal suffering would be a similarly good predictor of the decline in biodiversity as the correlation between both variables does not depend on which variable is the predictor vs the target of the prediction.

However, the above argument only concerns the suffering of currently living animals. It is different from an argument that the counterfactual existence of more animals themselves is something good. Such an argument would require answering other questions including whether wild animal lives are worth living and various questions in population ethics (including whether it is good to bring into existence a life worth living and, if it is good, whether the risk that a life might not be worth living implies that we ought not bring it into existence even though it might be far more likely that it would be worth living). Our uncertainty about these questions prevents us from even recommending a focus on conserving ecosystems that face a large decline in animal abundance. Concretely, if wild animal lives on average are not worth living, protecting the habitat of such animals causes the existence of more animals in the future whose lives are on net lives of suffering. While we are not sure whether and which animal lives are not worth living, or how to value the suffering of not yet born animals, there is large potential to cause more harm than good. As such, we currently do not recommend any particular prioritization for the purposes of promoting animal welfare.

Conservation philanthropy

Key Points

- The largest drivers of ecosystem decline among the ecosystem types that provide the most benefits to society are agricultural expansion (wetlands) and coastal development as well as nutrient runoff (coastal systems).
- Conservation can play a targeted role in the protection of peatlands and seagrass beds when projects ensure that the development they prevent doesn't merely shift to nearby areas of similar societal value — for example through conserving all peatland in a local area. In such cases, the benefits need to be weighed up against potential harms to farmers.
- Water quality protection programs are most effective when they focus on reducing the nutrient pollution of high-risk bodies of water in low-cost environments, such as West and East Africa, and Southeast Asia. Lake Victoria, in particular, deserves further consideration.

The previous two sections investigated prioritization based on the *benefits* of various ecosystems. This section explores the likely *cost-effectiveness* of different conservation and restoration measures. At the end of this section, we combine the two sets of findings and list heuristics that support philanthropists in identifying the interventions that are most effective as measured by the ratio of benefits to costs.

Overall, there are two direct approaches to ecosystem protection: conservation and restoration. Conservation describes the protection of ecosystems that are intact, i.e., that have not been degraded. Restoration, on the other hand, describes measures that aim to return ecosystems to their initial state after they have been degraded. We have previously (see our report *Reducing Land Use and Returning Agricultural Land to Nature*) concluded that **conservation is on average more**

cost-effective than restoration because conservation doesn't require any active restoration measures and restoration doesn't fully restore ecosystem health.

From the discussion in the previous section, we identified the following heuristics for ecosystems whose protection would provide outsized benefits.

- Regions: Central Africa, Southeast Asia, Amazon Rainforest
- Ecosystems: Coastal systems (with seagrass beds being a likely very effective subcategory), wetlands (peatlands being a particularly beneficial type of wetland), and coral reefs.[17]

Before proceeding, we note that coral reef protection is unlikely to be an impactful funding opportunity. Many coral reefs likely cannot be saved because of the global rise in temperatures. It is likely that corals will bleach under the current climate change trajectory. As a result, reducing other causes of coral reef decline are probably ineffective as coral reefs are unfortunately likely to be destroyed even in the presence of those interventions (Hughes et al. 2017a).

The biggest drivers of decline and collapse in the above ecosystems are:

- **Agricultural development causing wetland loss** (Ballut-Dajud et al. 2022) and peatland degradation in particular (UNEP 2022).
- **Coastal development and declining water quality (such as nutrient and sediment runoff) for coastal systems** and seagrass beds in particular (Waycott et al. 2009, Orth et al. 2006)

These drivers suggest that there are two main avenues for protecting the most beneficial ecosystems:

- Reducing land use and development in the most valuable ecosystems
- Reducing runoff and pollution into coastal ecosystems

Reducing agricultural land use and development

Our report *Reducing Land Use and Returning Agricultural Land to Nature* provided guidance on how to approach reducing land use and development through alternative protein funding. It also outlined general principles for high-impact conservation funding: a focus on low-cost countries and low-yield areas with high counterfactual chance of development. Funding should ideally be directed towards large projects that run over a long period of time to leverage economies of scale.

Unlike in our report *Reducing Land Use and Returning Agricultural Land to Nature*, however, there might be targeted conservation initiatives that are effective for ecosystem protection in addition to the more structural long-term land use reduction through alternative protein development. The reason for this is that there are some ecosystems that are particularly high-impact, such as peatlands, which make up only about 3% of global total land. Because of that small area, **reducing**

[17] Rivers, lakes, and tropical forests have slightly lower ecosystem service values but their protection could still be cost-effective.

land use in general will mostly target land that provides comparatively few services. Therefore, targeted conservation initiatives, while they do not have the large-scale impact of reducing global land use substantially, could protect particularly valuable ecosystems such as peatlands in the Congo Basin (Miles et al. 2017) or Indonesia (Terzano et al. 2023).

One important consideration for conservation is whether these projects will merely displace development. To give an example, consider a large forest area whose land is equally valuable for both developers and for society everywhere. Suppose an agricultural developer intends to develop a certain piece of land. Placing that piece under conservation management likely has zero impact as the developer will instead expand on an equally valuable nearby plot of land. To avoid this pitfall, **conservation programs should target areas whose conservation will not lead to mere displacement of development to a similar ecosystem.** For a second example, consider an agricultural firm that is planning to drain a wetland near nearby forest in order to make room for farming. Placing the wetland under conservation in this case has the marginal benefit of the difference in cost to society from wetland vs forest degradation. As such, **philanthropists should consider the following heuristic: a focus on the large-scale protection of an entire ecosystem so that development will take place on less valuable nearby land instead of other nearby land within the same ecosystem.** A hypothetical example would be to protect entire ecosystems of peatlands in a particular region in Indonesia. It would on the other hand be less impactful to protect small shares of larger ecosystems such as a rainforest. In such cases, long-term land use reduction approaches such as developing alternative proteins are likely the best way forward.

As the size of conservation projects increases, the potential negative impacts on agriculture become larger, too. For example, if peatlands are by far the most profitable source of income and all peatlands in one's neighborhood are placed under conservation status, there might be large negative income effects on farmers. These effects need to be weighed up on a case-by-case basis when evaluating funding opportunities.

Water quality protection

Coastal systems and seagrass beds in particular are damaged by nutrient and sediment runoff as well as the leaking of industrial and municipal sewage. These changes to a marine ecosystem reduce the oxygen available to the flora and fauna, causing their decline and thereby degrading the ecosystem.

There are two main ways through which these issues reduce oxygen levels. Nutrient runoff — the washing of nutrients from farm plots into waterways — as well as the leaking of waste into bodies of water cause hypoxia through nutrient pollution and the resulting eutrophication[18]. For the case of the US, Haworth et al. (2000) outline the large scale on which nutrient pollution (usually the excessive addition of ammonia, ammonium, nitrate, and phosphates) leads to a range of environmental problems along the coastline, noting that more than 60% of coastal rivers and bays in the continental

[18] Eutrophication describes the process whereby excess nutrients lead to higher algae growth, displacing other species and leading to a loss of biodiversity and change to the species composition of an ecosystem.

US are moderately or severely degraded as indicated by: “harmful algal blooms, dead zones, fish kills, some shellfish poisonings, loss of seagrass and kelp beds, some coral reef destruction, and even some marine mammal and seabird deaths.”

The second way through which water pollution reduces oxygen levels is through sediment runoff and water clouding. Penn State describes the issue of sediment runoff: the pollution of water by different types of sediment, which can range from gravel to tiny soil particles (<2mm in diameter). This runoff can come from soil, construction sites, poorly maintained roads, and farm fields. One pathway through which sediment runoff degrades ecosystems is by turning water cloudy, thus obstructing sunlight and limiting photosynthesis of aquatic plants, reducing oxygen, and increasing water temperature.

Interventions to reduce nutrient pollution

While it would exceed the scope of this report to investigate in detail interventions to improve water quality, this section lists a few options that are plausibly promising based on initial research.

The USDA lists three interventions to reduce nutrient and sediment runoff from farm plots:

- Filter strips to remove sediment, organic matter, and pollutants from runoff and wastewater
- Cover crops to reduce soil erosion, and hold onto nutrients when crops aren’t growing
- No-till farming to reduce soil erosion, keeping sediment and organic matter out of waterways

We note that these interventions are the same three interventions that we separately identified in our report *The Good, the Bad, and the Ugly of Regenerative Farming* as having a strong evidence base supporting positive effects on agricultural runoff. This overlap increases our confidence that these interventions are some of the more effective ways to reduce agricultural nutrient pollution. Iowa State provides an excellent and more extensive overview of farming practices and their expected effects on nitrogen and phosphorus runoff as well as yields (see their tables on pages 3 and 4).

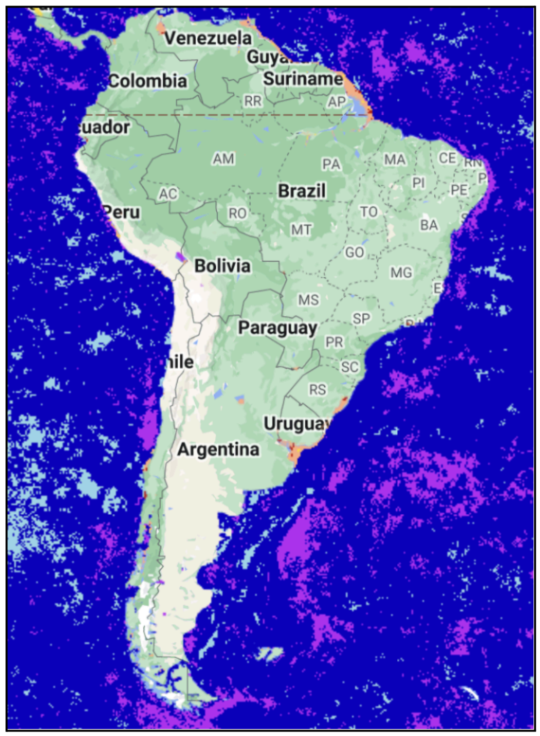
It would be further useful to investigate interventions aimed at reducing nutrient pollution due to animal waste and industrial leakage as well as sediment runoff. However, our cursory research indicates that there are few NGOs working on those pathways. As such, we recommend first identifying NGOs that target high-impact ecosystem areas and then evaluating their cost-effectiveness directly.

Global geography of hypoxic water areas

In general, there is limited quantitative data on the extent of coastal system degradation and runoff at both local and global scales (Hoel, Fredston, and Halpern 2022). However, in recent years, there have been initial attempts to begin to categorize coastal areas into lower and higher risk areas. Halpern et al. (2009) analyzed the total risk to coastal ecosystems, regardless of the specific threat, and Hoel et al. (2022) analyzed the risk to a subset of coastal ecosystems (mangroves, seagrasses, and stony corals) including the number of species prevalent in each ecosystem.

In a particularly extensive way, Maúre et al. (2021) provide a global assessment of the eutrophication potential of the world's coastal zones and inland bodies of water using satellite data. They have developed an interactive website, global-eutrophication-watch, that allows those interested to zoom into areas around the world and analyze their eutrophication risk. As they do not provide a breakdown of hotspots[19], we conducted our own initial analysis using this tool. We briefly evaluate each continent separately below, listing a handful of examples of areas with high eutrophication risk.

Figure 13A: Eutrophication Potential in South America



Note: This figure is a screenshot from global-eutrophication-watch. Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

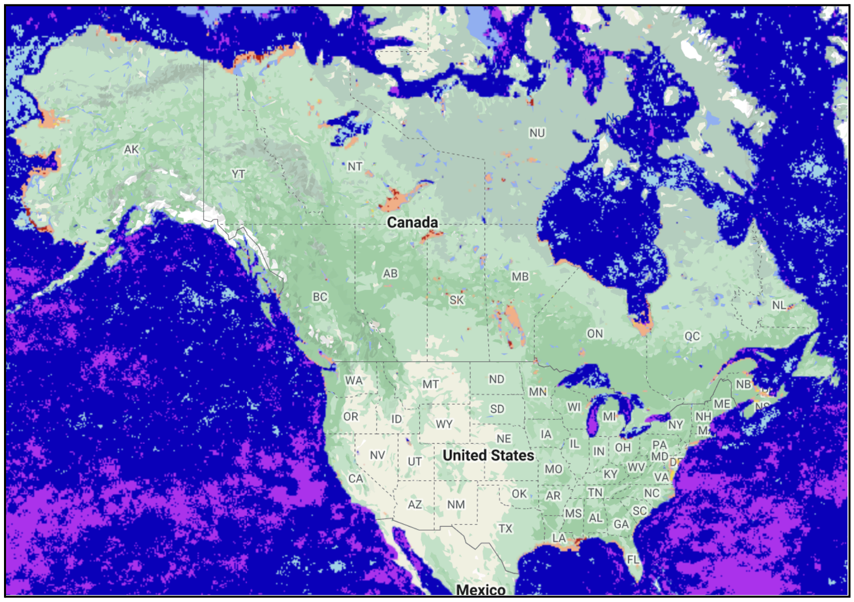
We find that in South America (Figure 13A), eutrophication potential is highest in the following areas:

- Río de la Plata basin, between Argentina and Uruguay
- Lagoa dos Patos in the Brazilian state of Rio Grande do Sul. Research as early as 1994 (Niencheski and Windom 1994) has noted the impact of fertilizer use on increased nutrient levels in the lagoon

[19] While they list data on marine zones in Table 1, this data also includes indicators that are high for natural reasons (e.g., the Benguela nutrient-rich current in Southern Africa) and not due to runoff, and thus distorts the overall prioritization.

- [Lago de Maracaibo](#) in Venezuela, which suffers from eutrophication due to agricultural sewage

Figure 13B: Eutrophication Potential in North America

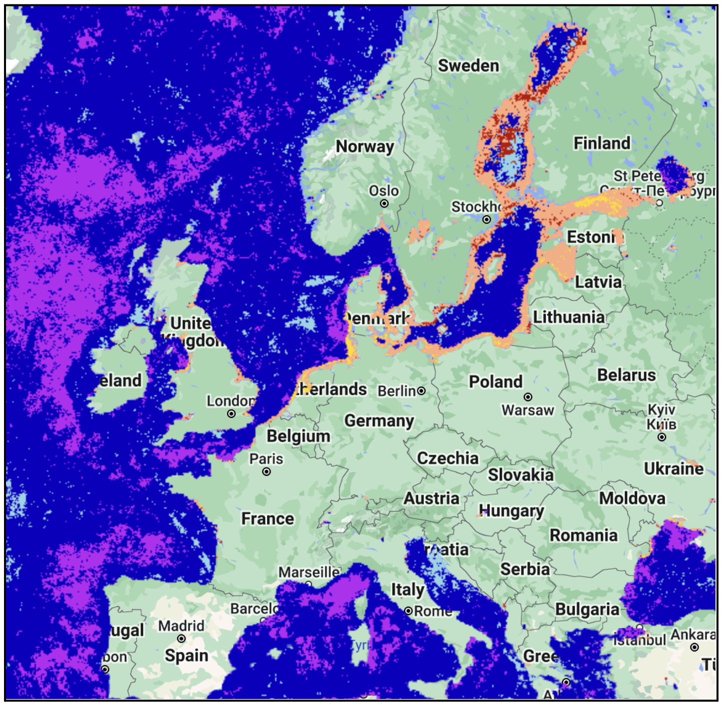


Note: This figure is a screenshot from global-eutrophication-watch. Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

There is little eutrophication potential in Central America (figure omitted). Within North America (Figure 13B), it is highest in the following places:

- The coastline of Louisiana, USA
- Certain parts of the US East Coast, especially Chesapeake Bay, Delaware Bay, and Long Island Sound
- James Bay, Canada, between Ontario and Québec
- Large parts of the coastline of Alaska, USA, and the Northwest Territories, Canada

Figure 13C: Eutrophication Potential in Europe

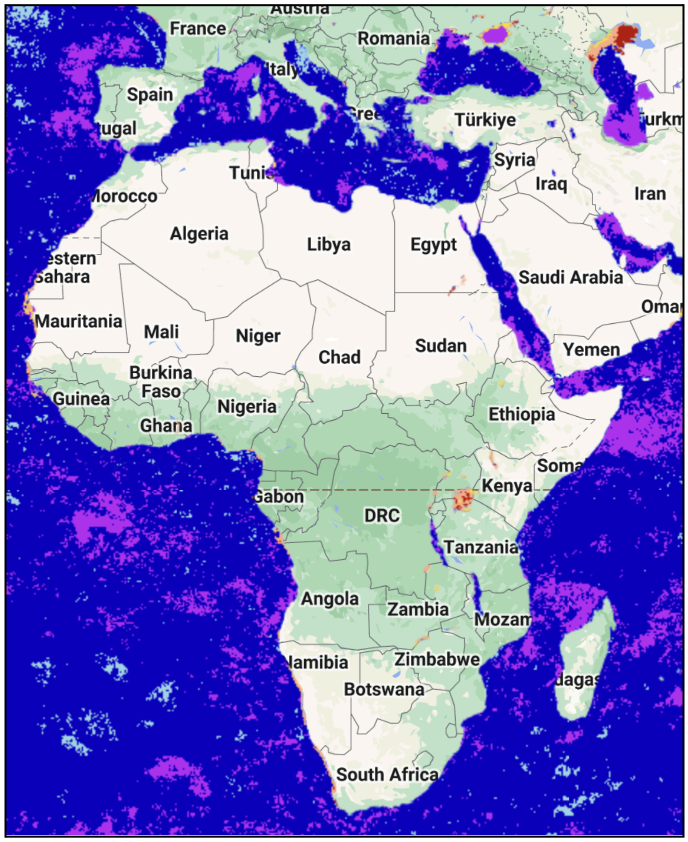


Note: This figure is a screenshot from [global-eutrophication-watch](). Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

In Europe, the [Baltic Sea](), including the Gulf of Riga, Gulf of Bothnia, and Finnish Gulf stand out as having particularly extensive coastal eutrophication potential. Some other areas with high eutrophication are:

- The German Bight and the coastline of much of the Netherlands and Belgium, including Markermeer and IJsselmeer
- The Southeastern part of Lake Ladoga, Russia
- Vänern, Sweden
- Oslofjord, Norway

Figure 13D: Eutrophication Potential in Africa



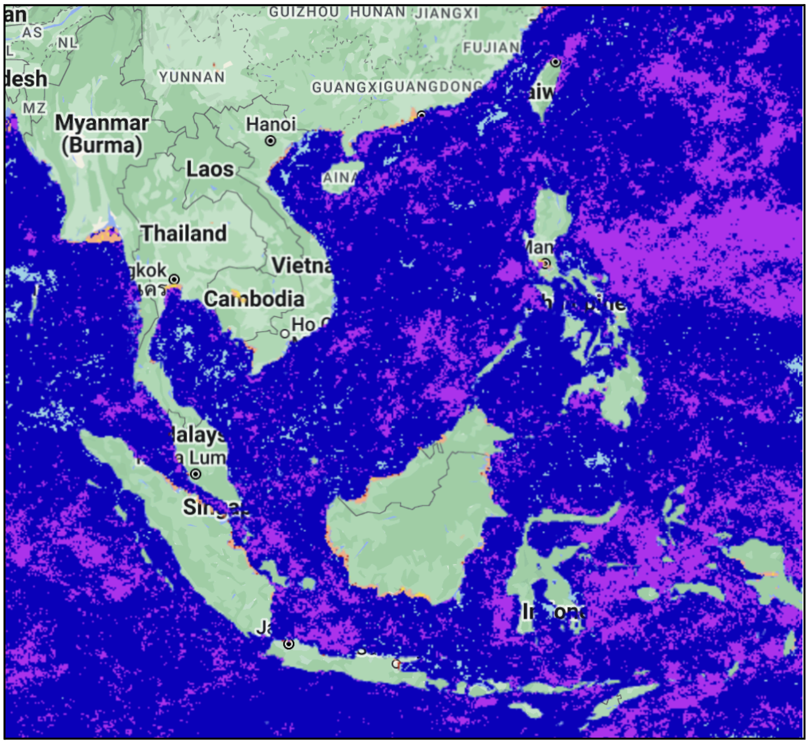
Note: This figure is a screenshot from [global-eutrophication-watch](). Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

In Africa, the following places stand out as regions with high CEP:

- Lake Victoria and various lakes in the vicinity, including Lake Turkana, Lake Kyoga, Lake Albert. However, other large lakes in East Africa do not have high CEP (such as Lake Tanganyika and Lake Malawi)
- Large parts of the coastline of Namibia and the Western part of South Africa
- The coastline from the Republic of the Congo to Northern Angola, especially around Cabinda, Angola, near the mouth of the Congo River
- The coastline of Mauritania and The Gambia

Oceania generally shows very low eutrophication damage (figure omitted).

Figure 13E: Eutrophication Potential in Southeast Asia

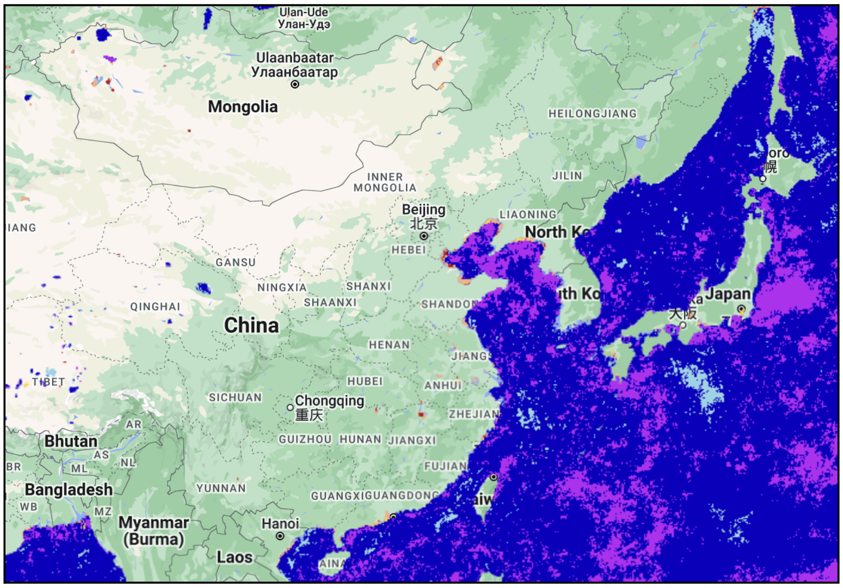


Note: This figure is a screenshot from [global-eutrophication-watch](). Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

In Southeast Asia, regions with high eutrophication risk are:

- Coastline of North, South, and West Kalimantan, Indonesia
- Some parts of the Eastern coastline of Sumatra, Indonesia
- Gulf of Martaban, Myanmar
- Bay of Bangkok, Thailand

Figure 13F: Eutrophication Potential in East Asia



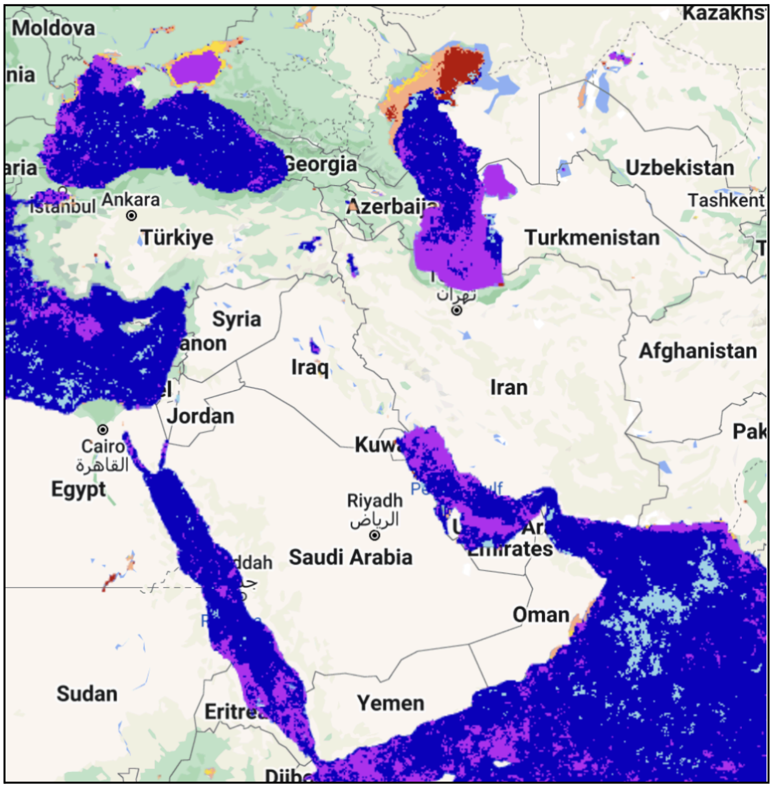
Note: This figure is a screenshot from [global-eutrophication-watch](). Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

In East Asia, there are relatively few high CEP areas:

- Some parts of the Chinese coastline, including some parts of Guangdong, near Hong Kong
- The three bays in the Bohai Sea: Bohai Bay, Laizhou Bay, and Liaodong Bay
- The central parts of Korea Bay, near Dandong, China

In South Asia, there are relatively few high-CEP areas, mainly the coastline near Surat, India (figure omitted).

Figure 13G: Eutrophication Potential in Western Asia



Note: This figure is a screenshot from global-eutrophication-watch. Areas with higher eutrophication potential are shown in yellow, orange, and red. Areas with low eutrophication potential are marked light blue, dark blue, and purple.

In Western Asia, the Northernmost part of the Caspian Sea stands out as being at particularly high risk from eutrophication — in particular the part bordered by Kazakhstan. Additional high CEP areas are:

- Southern coastline of Oman
- Sea of Azov

Having put together a list of areas globally most at risk from eutrophication, we combine them with a list of the countries that contain these areas by their level of GDP/capita. In those areas, as we noted in the report *Reducing Land use and Returning Agricultural Land to Nature*, implementation costs of interventions are particularly low. **The following regions have high eutrophication risk (and thus high benefits from water quality protection) as well as low wage levels and implementation costs:**

- Countries in West Africa: **The Gambia, Mauritania, Angola, Republic of the Congo**
- Countries in East Africa: **Uganda, Tanzania, Kenya**
- Countries in South and Southeast Asia: **India, Myanmar, Indonesia**

The GDP per capita in the least-developed countries is around 10x lower than the GDP per capita in the median country on this list (China), **suggesting that there could be large differences in cost that philanthropists could make use of to achieve high cost-effectiveness in mitigating the expected amount of eutrophication.**

Overall, there are only a handful of studies on eutrophication in West Africa (see, e.g., the summary map in Diaz 2016), indicating that the issue hasn't yet been mapped extensively. While there is some initial research that suggests that eutrophication is indeed a widespread issue (Kenfack, Beguere, and Boukerrou 2016), our research has found no sizable NGOs working on nutrient pollution in West Africa.

In contrast, there is substantial prior work, both academically and through governmental agencies, on the eutrophication of Lake Victoria in East Africa (see Verschuren et al. 2002). The Lake Victoria Environmental Management Programme (LVEMP) included multiple sections on eutrophication in their 2005 report (chapter 6, chapter 8). While the IUCN does not contain a systematic assessment of the ecosystem risk of Lake Victoria, it has indicated previously that about a fifth of the 651 species in the basin are at risk of extinction, with three quarters of the 205 endemic species at high risk (Sayer, Máiz-Tomé, and Darwall 2018).

The East African Community and the World Bank are currently the main actors focussing on environmental protection of Lake Victoria. Based on initial research, we believe it is likely that there are NGOs that might work on nutrient pollution in Lake Victoria, too. Given the likely very low implementation costs, philanthropists should search for and evaluate potential funding opportunities in this space[20].

An additional search did not uncover many NGOs working on nutrient pollution of high-CEP ecosystems in India, Myanmar, and Indonesia.

Overall, we recommend that philanthropists take a three-pronged approach for their initial search of funding opportunities in the space of water quality protection, which should then be evaluated further:

- NGOs addressing nutrient pollution in Lake Victoria
- Organizations that address nutrient pollution in coastal systems and wetlands globally
- Organizations that focus on the interventions mentioned above: cover crops, no-till farming, and agroforestry buffer strips

Recommendations for high-impact giving

[20] While freshwater lakes provide on average fewer ecosystem services than coastal systems, it is plausible that the cost-effectiveness of interventions focussing on Lake Victoria is nevertheless substantially higher than those addressing the nutrient pollution of coastal systems in a country that is at a higher level of development (e.g., China). Wage levels differ by a factor of 10 whereas the ecosystem services differ by around a factor of 4 (see the section on Human Welfare)

To put all our findings together, we recommend the following heuristics for high-impact giving.

Firstly:

- **Funding land use recommendations,** i.e., supporting policy advocacy for governmental support of cultivated meat R&D and plant-based meat commercialisation, is still likely to be impactful to reduce the degradation of important ecosystems.

Within conservation, philanthropists should:

- **Focus on wetlands (peatlands in particular) and coastal systems (seagrass beds in particular).** These biomes provide on average the most ecosystem services. As such, their protection is likely to provide especially many benefits.
- **Focus on Central Africa, Southeast Asia, and the Amazon Rainforest**. Central Africa and Southeast Asia are areas in which ecosystems provide a comparatively large amount of value to humans (in both instrumental, e.g., flood protection, and aesthetic/recreational ways). The Amazon Rainforest has the potential to have large benefits because of its plausible role as a climate tipping point.

To identify cost-effective conservation projects, philanthropists should:

- **Focus on large-scale projects in low-cost countries and low-yield areas with a high counterfactual chance of development**. These are the same principles as outlined in the report *Reducing Land Use and Returning Agricultural Land to Nature*. In that report, we concluded that large projects have lower costs due to economies of scale, and that projects in low-cost and low-yield areas have lower implementation and potential land purchase costs.

For conservation projects to be impactful, it is crucial that they do not simply displace agricultural development to a similarly valuable ecosystem. As such, we recommend

- **Funding projects that would cover all of a certain ecosystem type in an area (such as all wetlands in a given area)**. However, the benefits of these projects need to be weighed up against the potential negative impacts on farmers who might need to choose less profitable land for agricultural expansion.

In later stages of the funding opportunity selection process, philanthropists can:

- **Make use of the IUCN data on ecosystem vulnerability to narrow down a long list of potential conservation projects**. Protecting those ecosystems that are most at risk along a variety of dimensions will help to steer funding towards those ecosystems that are most in need. Here, it is crucial to ensure that ecosystem conservation programs not only target certain measures of ecosystem integrity (such as biodiversity or the continued provision of services) but all major components of ecosystem health.

Water quality protection has the potential to address one of the major sources of degradation of coastal systems and freshwater lakes and streams. Our analysis of areas at high risk of eutrophication — which would thus benefit most from interventions — found that there are specific areas on almost all continents that are at high risk of eutrophication and ecosystem degradation. As such, we recommend the following process to identify cost-effective interventions:

- **Selecting areas at high eutrophication risk** (see Global geography of hypoxic water areas) and
- **Evaluating programs targeting such areas in low-cost environments** (e.g., a low-income country)
- Additionally, investigating large organizations that target
    - **the environmental protection of coastal systems** (incl. coastal wetlands); or
    - **the implementation of nutrient pollution reducing practices** (e.g., agroforestry, cover crops, and no-till farming)

Lake Victoria is one potential promising area that deserves further investigation. It stands out as it is at high risk of eutrophication, has existing environmental projects and is located in a low-income country with lower implementation costs.

Conclusion

This report provided a framework for prioritization of ecosystem protection. We first argued that ecosystem health is the best metric to gauge an ecosystem's overall integrity and collapse risk. While there is so far limited data on ecosystem risk, it can be used to distinguish between a pre-selected funding opportunities so that funds are steered towards the ecosystems most under threat.

The benefits of ecosystems for human welfare are calculated through ecosystem services. These services that range from flood protection to recreation are difficult to quantify but various studies point to a selection of biomes (wetlands, coastal systems) and geographies (Southeast Asia, Central Africa, Amazon Rainforest) that provide the most benefits on average and should be priorities for ecosystem conservation. An additional look at climate identified peatlands and seagrass beds in particular as high-value ecosystems.

Principles of cost-effective conservation are a focus on low-cost and low-yield countries and areas with a high chance of counterfactual development. It is particularly important that conservation projects take into account displacement effects. In order to mitigate them, we recommend funding large-scale projects that protect all or most of a specific ecosystem type within an area. This approach has the additional benefit of leveraging economies of scale. However, as these projects are more restrictive for agricultural development, they might cause larger negative effects on farmers. These potential side effects need to be considered when ultimately deciding whether to fund a given conservation programme.

Water quality protection projects have the potential to protect marine ecosystems in particular. We have outlined areas worldwide that are at high risk of eutrophication while having low implementation costs. Philanthropists should investigate funding opportunities within those areas. As the number of NGOs in this space (high-risk areas in low-income countries) is limited, it will be most effective to first identify potentially promising organizations and then evaluate each organizations' likely cost-effectiveness according to the criteria outlined in the section on water quality protection.

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