Technical Report

UNU EHS

Accelerating extinctions

Authors: Liliana Narvaez, Zita Sebesvari, Jack O'Connor

Acknowledgements: We would like to thank Caitlyn Eberle, Sally Janzen, Yvonne Walz and Melisa Mena Benavides for their support in this research.

Interconnected Disaster Risks

Risk Tipping Points

2023

Table of Contents

Abbreviations

BGCI	Botanic Gardens Conservation International
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
FWC	Florida Fish and Wildlife Conservation Commission
HISC	Hawaii Invasive Species Council
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
IRP	International Resource Panel
MEA	Millennium Ecosystem Assessment
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSD	United Nations Statistics Division
UNU-EHS	United Nations University – Institute for Environment and Human Security
USNPS	United States National Park Service
WWF	World Wildlife Fund

Pollinators like the endangered monarch butterfly play a vital role in our natural ecosystems and food systems.
© Chris F / Unsplash

1. Introduction

Throughout Earth's history, many species have gone extinct as part of the evolutionary process that has shaped life on the planet. Extinction often proceeds slowly over thousands to millions of years (Ceballos and others, 2020), but through intense human activities such as land-use change, overexploitation, climate change, pollution and introduction of invasive species, we have put our foot on the extinction accelerator. There is well-documented evidence of a sharp increase in the number of extinctions of different animal and plant species since the beginning of the sixteenth century showing stark ecosystem degradation on rapid time scales (IPBES, 2019). For example, a study focusing on 32,000 species populations of amphibians, birds, fish, mammals and reptiles estimates the decline in wildlife as approximately 70 per cent since 1970 (WWF, 2022). The current rate of species extinction is at least tens to hundreds of times higher than natural background rates due to human influence (Pimm and others, 2014; De Vos and others, 2015; IPBES, 2019), with drastic consequences for all life on our planet.

Recent studies also suggest that extinctions could cascade through ecological dependencies between species in an ecosystem, setting off waves of secondary extinctions (Kehoe and others, 2021) and amplifying the effects of environmental degradation (Strona and Bradshaw, 2018). As ecosystems are built on intricate networks of connections between different species (see **Table 1**), the real impact of extinction may be much greater than we realize, especially as many species are highly interconnected and form strong, unique bonds with other species (Strona, 2022). The disappearance of such a strongly connected organism could trigger a secondary extinction or co-extinction (when one species' direct dependence on another leads to its extinction). Furthermore, a chain reaction of extinctions could occur after a strong connection is severed, leading to a loss of ecosystem function and services to the point where the ecosystem will never recover (Bland and others, 2017; BGCI, 2021). In short, extinction breeds extinction. We need to better understand the drivers of risk behind such accelerating extinctions and take measures to avoid this potentially catastrophic tipping point.

Type of interaction between species with relevance for co-extinctions	Examples of roles species take in an ecosystem
Mutualism: Both species benefit from each other (e.g. oxpecker bird feeds from the rhino's insects, helping them to get rid of it) **Commensalism:** One species benefit without harming the other (e.g. jackals follow tigers and feed from the remains of their pray) **Predation:** When one species benefits while the other perishes (e.g. owls or eagles hunting mice) **Parasitism:** When one species benefits at the expense of the other (e.g. spider hawk wasps use spiders' backs to lay their eggs on, after which the baby wasps feed on the still living spider)	Part of **food networks:** All species contribute one way or the other to food networks (e.g. in the food chain as the prey or predator of another species), but some have specific roles like **pollination** by fertilizing flowers supporting plant reproduction (e.g. honey bees), **seed dispersal** that spreads seeds contributing to plant distribution and growth (e.g. fruit birds), while others support the **nutrient cycle** through transfer and recycling (e.g. dung beetles). Provide **pest control:** Some species help to control and regulate certain populations that can harm others if their populations increase in numbers (e.g. flycatchers eat insects) Part of **waste disposal:** Some species play an important role in decomposition, helping in the disposal of dead matter (e.g. vultures) Provide **shelter/ecosystem architects:** Some species provide shelter and refuge for others, either in their structure (e.g. roots of mangrove trees) or through their activities like digging (e.g. gopher turtle)

__Table 1:__ Interactions between species and examples of roles in a given ecosystem.
Concepts based on Lang and Benbow (2013), Poisot and others (2021) and Markes (2022).

White rhinos with bullock pecking birds on their backs walking through the African bush of Zimbabwe. Oxpecker birds help care for the rhino in a symbiotic relationship. © Elizabeth DeBruin / iStock

1.1 What do we talk about when we talk about extinctions?

The extinction of a species implies the complete disappearance of a species from Earth and is generally considered a natural process as a part of life's history and evolution, going back to before humans roamed the planet. Extinction happens when the last member of a species dies without a successor, as a result of the cumulative disappearance of individuals and populations. The extinction of a species, in turn, can lead to the loss of genetic diversity, which affects ecosystems (Miller, 2013), as every species plays an ecological role for the functioning of said ecosystems. Furthermore, extinctions can be classified in various ways. For example, mass extinction is used for those extinctions that have occurred at the global level affecting almost all living creatures in a short period of time in the geological scale. Local extinction, on the contrary, applies when a species is considered to be gone from a specific area but populations still remain in other areas.

Beyond classifications and particularities, extinction means losing a species, which might also lead to the decline of other species (see **Table 2** for examples). Indeed, it is not just about the loss of the single species, but also the likelihood of extinction of ecological interactions either in the aftermath or in parallel to the disappearance of the species (Valiente-Banuet and others, 2015). Because species oftentimes provide functions, habitat or resources to other species, the extinction of a species inevitably affects the ecological interaction or ecological networks, putting all the interactions in which it participates in at risk of disappearing (Valiente-Banuet and others, 2015; Morton and others, 2022). However, the impact of an extinction on other species is not easy to predict and can vary from just minor disturbances to secondary or multiple extinction processes and depends on many factors such as the type of interaction, the level of dependency as well as the availability of alternatives.

Species	Status/Where	Impacts on other species/ecosystem (functions, services)
Dodo bird *(Raphus cucullatus)*	**Extinct** (1688-1717)/Mauritius (Indian Ocean)	The dodo was a large, frugivorous bird which did not have any known predators until the arrival of humans to the island. Their disappearance is linked to the destruction of their natural habitat and the introduction of animals (e.g. pigs, cats, dogs) by the colonizers. Studies indicate that at least one-third of native fruits in Mauritius cannot be naturally dispersed without the dodo, as there is no other animal on the island big enough to swallow their seeds (Kitchener, 1993; Albert and others, 2021). This is an example of the root cause "Colonialism" (see Chapter 3.2.5)
California condor louse *(Colpocephalum californici)*	**Extinct** (1980s) After the California condor went into captivity	The California condor almost went extinct due to pollution from agricultural chemicals and lead poisoning, with only 23 birds left in the 1980s, until conservation efforts by the U.S. government saved the species. However, a louse that used only this condor as host went extinct after the conservation programme indicated that all condors should be rid of parasites, though the louse was harmless to its host. While there is not much known about the role of this parasite, it could have provided information about the evolution of the condor (Colwell and others, 2012). The louse extinction is an example of the root cause "Insufficient risk management" (see Chapter 3.2.2)
California condor *(Gymnogyps californianus)*	**Critically endangered/** North America	
Sea otter *(Enhydra lutris)*	**Endangered** (locally extinct during 1714–1911)/ North Pacific Ocean (Alaska)	Sea otters act as keystone species, as they prey on sea urchin populations to keep balance in the kelp forest. Without sea otters, the urchins overgraze the kelp forest, which provides habitat for almost 1,000 other species. Due to overhunting, otters went locally extinct in a few areas, and populations are still in the process of recovering (Estes and others, 2016; Gullixson, 2019; USNPS, 2023). This is an example of the root cause "Undervaluing environmental costs" (see Chapter 3.2.1)
Gopher tortoise *(Gopherus polyphemus)*	**Vulnerable/** south-eastern United States	The gopher tortoise, an ecosystem architect, is a vulnerable species that digs burrows that are used by more than 350 other species for breeding, feeding, protection from predators and avoiding extreme temperatures. The critically endangered dusky gopher frog, which helps control insect populations and prevent pest outbreaks in longleaf pine forest ponds, relies extensively on these burrows for survival. If the gopher tortoise goes extinct, the dusky gopher frog will likely follow, affecting the entire forest ecosystem (FWC, 2023). The pressures on the gopher tortoise are mostly related to urban expansion, as such this is an example of the driver "Risk-intensifying land use" (see Chapter 3.1.1)

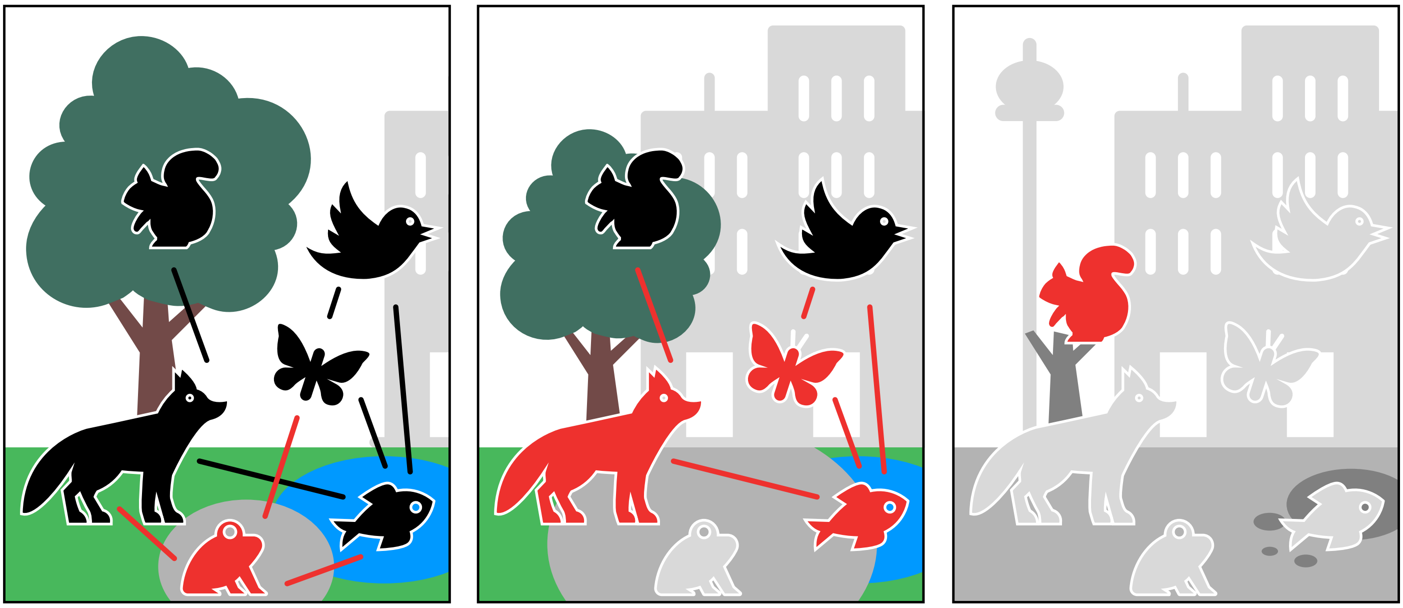
Table 2: *Examples of extinct (red) and threatened species - vulnerable (yellow), endangered (orange) and critically endangered (brown), according to the IUCN red list criteria (IUCN, 2023) and their impacts on another species/ecosystem.*

Steller's sea cow *(Hydrodamalis gigas)*	**Extinct** (approx. 1768)/ North Pacific Ocean (Alaska-Russia)	The Steller's sea cow was an herbivore that ate algae in the kelp forest. It was hunted to extinction for its fur and oil and may have been collateral damage from hunters that were after sea otters (see above). There are records of a sea bird that fed on the parasites from the back of the sea cow, and though there is no record of the impact, the sea bird was probably also affected after the disappearance of the sea cow (Bullen and others, 2021; Bullen, 2020). This is an example of the root cause "Undervaluing environmental costs" (see **Chapter 3.2.1**)
Javan tiger *(Panthera tigris sondaica)*	**Extinct** (1976)/ Java Island (Western Pacific Ocean)	The Javan tiger went extinct after more human settlements started to colonize the island. It preyed on the Javan rusa, a type of deer listed as "vulnerable" to extinction due to habitat loss and overhunting. The decline of one of its prey combined with habitat fragmentation contributed to declines in the population of Javan tigers and eventually to their extinction. A conservation plan in the 1930s and 1940s attempted to save the species, but is reported as failed (Seidensticker, 1986; Seidensticker, 1987). This is an example of the driver "Insufficient future planning" (see **Chapter 3.1.6**)
Javan rusa *(Rusa timorensis russa)*	**Vulnerable/** Java Island (Western Pacific Ocean)	
Spix's macaw *(Cyanopsitta spixii)*	**Extinct** (in the Wild)/ eastern Brazil	The Spix's macaw, a seed disperser, relied on a species of trumpet tree (*Tabebuia caraiba*) in Brazil for nesting and other purposes. However, land-use change in favour of agricultural expansion caused the local decline of the trumpet tree. As the Tabebuia caraiba trees started to decrease, the macaw did as well (Juniper and Yamashita, 1991). Now the macaw is considered to be extinct in the wild — although some individuals are kept in captivity, and the conservation efforts show some progress. This is an example of the driver "Risk-intensifying land use" (see **Chapter 3.1.1**)
Wild tulips *(Tulipa spp.)*	50 species threatened e.g. **endangered** *Tulipa bifloriformis* and *Tulipa korolkowii*/ Central Asia	The wild tulips are originally from Central Asia, but due to the effects of climate change, at least 50 species are considered to be threatened with extinction. They are bioindicators of a healthy, well-functioning ecosystem since they have a close relation with pollinators, particularly bees. Wild tulips are very sensitive to temperature changes and thrive in cool mountain temperatures. However, the population of wild tulips is decreasing as temperatures rapidly increase, and they are not able to adapt to such new conditions (Wilson and others, 2021). The loss of wild tulips endangers wild bees, contributing to the decline of pollinators and, consequently, to food insecurity. This is an example of the driver "Atmospheric warming" (see **Chapter 3.1.2**)

Table 2: *Examples of extinct (red) and threatened species - vulnerable (yellow), endangered (orange) and critically endangered (brown), according to the IUCN red list criteria (IUCN, 2023) and their impacts on another species/ecosystem.*

2. Risk tipping point

The natural process of extinction is being accelerated by human activity (Pimm and others, 2014; Ceballos and others, 2015; De Vos and others, 2015; Urban, 2015; IPBES, 2019; Ceballos and others, 2020). Every ecosystem is built on a network of species interactions where each is dependent on another, forming chains and webs of interdependencies that can help to build resilience against shocks but also present potential vulnerabilities (Montoya and others, 2006). The current crisis of biodiversity loss, driven by risk-intensifying land use, atmospheric warming, pollution, introduction of invasive species and lack of information, to name a few, is not only a tragedy of the loss of countless lives of organisms worldwide, but also puts the intricate web of species relationships in nature at risk of catastrophic failures. As we lose biodiversity, in terms of the number or, importantly, different types of species that perform critical functions in ecosystems, the number of links and interactions a species can rely on for survival decreases. All of this increases the risk that the loss of a single species will sever a critical connection and lead to cascading extinction effects (Kehoe and others, 2021). These critical connections create strongly connected species. Depending on how an ecosystem's network of interactions is structured, the loss of these connections due to a single extinction can create potential risk tipping points as extinctions will cascade and multiply (Baumgartner and others, 2020). Such chain reactions can have extreme consequences beyond the natural system because as we lose species, our ecosystems also lose genetic diversity which compromise ecosystem functions and services (Miller, 2013). Therefore, our society's reliance on species for critical services like food production is also compromised. Considering that ecosystems underpin human well-being in different ways (Fisher and others, 2023), once the accelerating extinctions risk tipping point is reached, the irreversible loss of species and ecosystems represents an imminent threat for a sustainable future.



Graphical representation of the accelerating extinctions tipping point. The left square shows the increasing environmental degradation and habitat loss pressures on species (red species endangered) and the potential connections that are also threatened. The middle square shows the extinction of a strongly connected species (grey) and the consequences on other species (now in red). The right square shows the resulting cascading extinctions (grey) leading to ecosystem collapse. Notice the advance of land-use change pressures in the back and consequent loss of natural habitat for species (loss of green replaced progressively by grey).

3. How did we get here?

3.1 Drivers

3.1.1 Risk-intensifying land use

In the early 1800s, with the advent of the Industrial Revolution, an energy transition to coal took place, accompanied by an increase in human population and an expansion of agriculture. Humans profoundly changed the environment leading to a decline in plant and animal species (Johnson and others, 2017). All these changes transformed the Earth in ways never seen before, and almost 250 years later, we are still continuously changing our remaining natural landscape, driving us little by little to a riskier future. Many of the implemented land-use changes, such as those related to the transformation of natural ecosystems to agricultural land and settlements, led and continue to lead to habitat loss and fragmentation (IPBES, 2019; Morrison and others, 2020; Fumy and Fartmann, 2021). For example, some projections indicate that under a business-as-usual scenario, almost 90 per cent of a total 19,859 species of terrestrial vertebrates (birds, mammals and amphibians) will lose their habitat due to agricultural expansion by 2050 (Williams and others, 2021).

Usually, several different drivers contribute to the extinction of a species; however, there are drivers that have more weight than others in the extinction of a particular species. Unsustainable agricultural expansion was a main driver for the extinction of the Spix's macaw extinction in the wild. The official declaration of "extinction in the wild" in 2019 by IUCN (Kupferschmidt, 2022), evidences the impact of land-use change on this species. The Spix's macaw´s habitat was a gallery woodland formed by *Tabebuia caraiba* trees used as the bird´s nest sites (Barnett and others, 2014); these trees occurred exclusively in three seasonal watercourses in that region of Brazil (Juniper and Yamashita, 1991). Studies indicate that as the numbers of *Tabebuia caraiba* trees decreased, the Spix's macaws did as well (Juniper and Yamashita, 1991), showing a strong relationship between these two species and a resulting risk of co-extinction. Since colonizers settled in this particular area in Brazil 300 years ago, the *Tabebuia caraiba* trees have been intensely cut and replaced by maize crops, leading to the loss of the Spix's macaw in the wild.

3.1.2 Atmospheric/ocean warming

Increasing temperatures around the world have not only affected human populations but also animals and plants, comprising one of the main drivers for species extinctions (IPBES, 2019). As global surface and sea temperatures continue to increase with climate change (Bardan, 2022), future global extinction risk is predicted to increase and accelerate (Urban, 2015). For example, a study from 2020 with data from 538 terrestrial plant and animal species that focuses on the likelihood of local extinctions due to atmospheric warming suggests the local extinction of up to 30 per cent of these species by 2070 with potential global consequences (Román-Palacios and Wiens, 2020), increasing the likelihood of co-extinctions and cascading extinctions.

Negative impact of deforestation. © Jason Ondreicka / iStock

Increasing temperatures contribute to species extinction in several ways as when temperature exceeds the species' physiological tolerance. This is especially challenging for species with no or limited mobility. The wild tulips *(Tulipa spp.)* are, for instance, cold-adapted organisms originally from Central Asia that cannot move further up on the mountain slope to protect themselves from rising temperatures due to climate change. Heat stress combined with overgrazing, urbanization and overharvesting have been pushing the wild tulips towards extinction. Currently, due to increasing temperatures, around 50 per cent of the 63 wild tulip species across Central Asia are classified as threatened (Wilson, 2022). Eleven of these tulip species are found in Kyrgyzstan, making them the country's most endangered flora and fauna (Knight, 2021). Warming temperatures are bad news for wild tulips and for the grassland ecosystem they are a part of, as they are one of the main providers of resources for wild pollinators, which support crops and local food systems (Wilson and others, 2021).

Other species could be forced to leave their original habitat and move to a new one where temperature conditions are more favourable for them. However, in the new habitat, they may encounter new predators or become a threat for local organisms. For example, crabs conquered the Antarctic seafloor where molluscs and echinoderms have evolved without a protection for that type of predator (Aronson and others, 2015; Pecl and others, 2017).

3.1.3 Pollution

Pollution of air, water and land poses a serious threat to biodiversity and has been identified as one of the five main drivers of extinction by IPBES (IPBES, 2019). Pollution is generated by a number of human activities such as agricultural practices, industrial processes and transportation. All of these factors can affect the natural environment and all living organisms in different and compounding ways. Pollution leads to the presence of agents or substances that threaten species, either by altering their habitats or harming them directly (Chu and Karr, 2017), and can, either alone or in combination with other drivers, lead to accelerating extinctions. For example, chemical pollutants, such as sulphur dioxide, can damage forest soil, compromising trees' abilities to absorb nutrients and, therefore, their ability to grow (Agrawal, 2003) and to support other species. In a study conducted in north-west Germany, it was found that the presence of sulphur dioxide and other harmful pollutants in the forest soil has affected not just the trees, but also other dependent species like the epiphytic lichen, a marker of forest health, whose diversity has declined significantly since the nineteenth century, with at least 54 per cent going extinct in this region (Hauck and others, 2013).

Pollution that threatens species mainly originates from agriculture and aquaculture, but it also comes from industrial and domestic waste, which has been listed as one of the main drivers of forest mangrove decline around the world (Bhowmik and others, 2022). Around 50 per cent of the world's mangroves have disappeared in the last 50 years (Aaron and others, 2021), and currently 11 of 69 assessed species are threatened with extinction (two classified as critically endangered) (Polidoro and others, 2010; Bhowmik and others, 2022). As the mangroves are a unique type of ecosystem that provides habitats for multiple aquatic (e.g. fishes, crustaceous), terrestrial (e.g. mammals, reptiles) and aerial (e.g. birds, insects) species, the threat of pollutants represents a major concern for the ecological interactions linked to this ecosystem. Pollutants can, for example, smother mangrove roots and alter the physiology of trees, flowers and leaves, increasing their susceptibility to diseases or reducing their robustness to absorb external stressors (e.g. storms). This change can consequently impact any living organism depending on them and also compromise the other important ecosystems services our global community relies on (Friess and others, 2019).

3.1.4 Invasive alien species

Invasive alien species are defined as animals, plants or other organisms that are non-native to a particular ecosystem but have been introduced as a result of human activity (either intentionally or by accident) and have successfully established and spread a population that has a negative impact on the ecosystem itself and/or species dependent on it, including human well-being (IUCN, 2021a; IPBES, 2023). Invasive alien species are one of the biggest drivers of biodiversity loss and species extinction (IPBES, 2019) and can irreversibly change ecosystems by, for example, altering the structure and properties of water, soil or ecosystem networks, and consequently the ecological interactions of multiple species. A recent assessment shows evidence that invasive alien species have contributed to 60 per cent of global extinctions, 90 per cent of those occurring on islands, and are the only driver of at least 16 per cent of recorded extinctions (IPBES, 2023).

A well-known example of an invasive alien species contributing to accelerating extinctions is the case of the brown tree snake *(Boiga irregularis).* The snake is native in the southern Pacific islands of New Guinea and Solomon and also north Australia. This snake was introduced by accident in the island of Guam, most likely unintentionally as part of the cargo arriving to the island around the 1940s, and is responsible for the extinction of at least 13 forest bird species (of the 18 native ones) and 3 species of lizard (Savidge, 1987; David and others, 2017; HISC, 2022). This snake preyed not only on bird and reptile eggs, but also small rodents and bats in its natural habitat, and it became a threat for Guam's native species as it preyed on eggs of native birds without any predators, competitors or diseases (HISC, 2022), spreading successfully in this new environment. One of the species that went extinct due to this invasive snake is the small Guam flycatcher *(Myiagra freycineti)*, a native species of the island that was last seen in 1983, and whose natural habitat was invaded by the brown tree snake. The nesting behaviour of the flycatcher was not adapted for the unfamiliar threat, and became an easy prey for the new predator (Savidge, 1987; Wiles and others, 2003). In general, flycatchers play an important role not only in controlling the insect population that can affect the forest ecosystem health but also for crop productivity. As such, the loss of this flycatcher in Guam probably also had an impact on other species and the ecosystems, contributing to the dramatic loss of biodiversity documented in the Island in the last 100 years that is mostly linked to invasive alien species (Fritts and Rodda, 1998).

3.1.5 Lack of information

While a lack of information also contributes to primary extinctions, its role is likely even higher in the context of co-extinctions, as scientific information is currently evolving, and the number of empirical studies is still relatively low. Parasites are a good example of how a lack of information contributes to species losses, as parasitism is oftentimes overlooked although it is one of the most common types of associations among species (Dunn and others, 2009; Farrell and others, 2015; Bay Kruse Thomsen, 2022). Frequently seen as a negative relationship, or associated with disease outbreaks or unhealthy environments, parasitism plays an important role in ecosystems (Farrell and others, 2015). Parasites form a strong relationship with their host which basically provides either habitat or nourishment (or both), key aspects for the parasite to exist in the first place. As such, some parasites even specialize to only certain hosts, reinforcing a very intimate and close relationship with them, which at the same time makes them extremely susceptible to any threat to the host (Carlson and others, 2020; Bay Kruse Thomsen, 2022). However, parasite extinction is currently underreported and not well understood (Carlson and others, 2020), which increases the potential risk of cascading extinctions. For example, parasites have unique roles in the food web by shaping host population dynamics (e.g. consumer-resource interactions) (Dunne and others, 2013), or they can also modify community composition and organization by altering the energy flow among hosts (e.g. making hosts more susceptible to predators) (Hudson and others, 2006).

3.1.6 Insufficient future planning

Healthy ecosystems and biodiversity underpin human well-being in many different ways (Naeem and others, 2016; Díaz and others, 2018). In contrast, the rapid increase in numbers of animal and plant extinctions in the last few decades represents a threat to humanity and life as we know it (Fisher and others, 2023). As a consequence, safeguarding biodiversity should be incorporated in future planning. The lack thereof is partially attributable to a lack of awareness of both our dependence on biodiversity for our well-being, and for the severity of the current species extinction (Bernardo and others, 2021). This is not a new issue but rather has been historically present and left a strong imprint due to a widespread disturbance of the habitat of many species around the world (Jiménez-Franco and others, 2022).

One example of this is the case of the Javan tiger *(Panthera tigris sondaica),* native to the Indonesian island of Java in the Western Pacific Ocean. This tiger was very abundant in the 1800s to the point that it was considered "a pest" (Gerstein and Hernandez, 2022). At that time, the human population of Java was around 28 million. However, the human population increased to 85 million people by 1975, along with stark changes in land cover and land use. The last Javan tiger was seen in its original habitat in 1976, when only 8 per cent of its native habitat remained (Seidensticker, 1986; Seidensticker, 1987). In addition to the habitat loss, one of its' food sources, the Rusa deer, was also disappearing due to hunting, habitat loss and diseases, which had an impact on the remaining Javan tigers, pointing to a process called co-endangerment. Clearly, there was no plan in place to secure the habitats for either the deer or the tiger for the future. Human expansion and overhunting did not consider the habitats of the tiger and the deer and did not identify their survival as a planning target, accelerating the disappearance of the Javan tiger and leading to their declaration as extinct by IUCN in 2003 (Jackson and Nowell, 2008). Furthermore, as the primary predator at the top of the food chain, these tigers used to play an important role in their ecosystem to control the population of wild boar and Rusa deer, in addition to being an important symbol of the island's folklore in relation to shamans and ancestral spirits (Wessing, 1995). However, lack of awareness and insufficient future planning contributed to their disappearance (Gerstein and Hernandez, 2022).

The gopher tortoise, an ecosystem architect, is a vulnerable species that digs burrows that are used by more than 350 other species. © Paulbr / iStock

3.1.7 Lack of regulations/enforcement

Loss of biodiversity and species extinction are major concerns that have been debated for decades in different international agreements. For example, goal 15 of the 2030 agenda for Sustainable Development — "Life on land" — recognizes, among other aspects, the irreversible impact of human activity on accelerated species extinction, and aims to halt biodiversity loss by 2030 (UNSD, 2020). Additionally, some international agreements govern specific drivers of the extinctions such as the Convention on International Trade in Endangered Species of Wild and Flora (CITES), which aims to ensure that international trade dynamics do not further harm threatened species (CITES, 2023). The Treaty of the High Seas aims, among other goals, to protect marine biodiversity (UN, 2023a). The declaration of UNESCO World Heritage sites provides a sanctuary for species at the brink of extinction (UN, 2023b). However, international agreements are not always followed and goals are not always achieved. For example, target 12 from goal C in the Aichi biodiversity targets aimed to prevent the extinction of known threatened species to improve the status of biodiversity (CBD, 2020a), but it was not achieved as species continued to advance on the extinction path (CBD, 2020b).

At the local level, depending on the government and specific dynamics of each country, there are also agreements and frameworks in place to protect biodiversity and avoid species extinctions, but similar to the international agreements, they are not necessarily always implemented or adhered to as expected. This could be linked to some root causes of extinction not properly addressed such as *Insufficient risk management* (see **Chapter 3.2.2**) and *Undervaluing environmental costs* (see **Chapter 3.2.1**). Therefore, ecosystems that should be protected are instead being degraded, and species that are classified as vulnerable keep losing their habitats, or are illegally poached without consequences from authorities, increasing the likelihood of accelerating extinctions.

For example, the lack of regulations and enforcement have contributed significantly to the decline of the endangered vaquita *(Phocoena sinus)* (UNU-EHS, 2022), a marine mammal that can only be found in the north of the Gulf of California. Although the vaquita has been listed as "threatened with extinction" by the CITES since 1976 and classified as "critically endangered" by IUCN since 1996, a recent study confirmed that there are only an estimated 10 individuals left in the wild (Taylor and Rojas-Bracho, 2023). For years, there have been several initiatives to ban the use of gillnets as fishing gear — the main threat to the vaquita's population. However, these nets are not used to capture vaquitas but to catch the also endangered totoaba fish *(Totoaba macdonaldi)* that is hunted for the illegal trade of its swim bladders (Crosta and others, 2018; Sanjurjo-Rivera and others, 2021). Therefore, international and local organizations have pushed for regulations to reverse the decline of vaquitas, yet, among other reasons, the Mexican government's poor enforcement of the law regarding gillnet use and illegal totoaba fishing has hindered its implementation (O'Connor and others, 2022). As such, though the vaquita and totoaba do not share an ecological connection, their ecological persistence is connected via a socioecological connection with human activities (Crosta and others, 2018; Ben-Hasan and others, 2021). The shared risk driven by lack of regulation enforcement illustrates how accelerating extinctions can also take place even among species that do not share a direct ecological link but are connected through their habitat and the pressures on it.

Sea otter in kelp forest, Glacier Bay National Park, Alaska. © Gerald Corsi / iStock

3.2 Root causes

3.2.1 Undervaluing environmental costs

Every driver discussed so far in relation to biodiversity loss and accelerating extinctions, can be linked to the root cause of *Undervaluing environmental costs*. This root cause links all our choices and actions (or inactions) which prioritize economic or development goals without consideration of the environment. For example, the unprecedented conversion of natural areas for human use (see **Chapter 3.1.1**), the lack of awareness and risk perception around the resulting impacts (see **Chapter 3.1.5**) and the lack of sustainable planning to account for these impacts and conserve natural processes (see **Chapter 3.1.6**) has led to intense fragmentation and degradation of habitats, and the dramatic plummeting of our ecosystem health and species' well-beings.

Similarly, all the examples stated above about species already extinct or critically endangered could also be part of this root cause. Most likely all the listed species have a story about how environmental costs were not considered. The Steller's sea cow *(Hydrodamalis gigas)* was an herbivore (algivorous) that fed on the kelp forest in the region of the North Pacific Ocean (Alaska-Russia) and was last seen in 1768. Though the primary target was sea otters *(Enhydra lutris),* people hunted the sea cows to extinction mostly for their oil and fur, but also as a source of food (Turvey, 2009). Research on the Steller's sea cow indicates that they could have played an important role within the kelp forest ecosystem as their behaviour and feeding routine allowed more light to enter the kelp forest to allow more opportunities for it to expand and grow (Bullen and others, 2021; Bullen, 2020). Additionally, it seems the Steller's sea cows had a mutualistic relationship with some local seabirds that used to perch feed from a parasite on their backs, so when the Steller's sea cow disappeared, this relationship likely disappeared as well, with an unknown impact on the local seabird (Bullen and others, 2021). Finally, it seems that once the Steller's sea cow was extinct, the hunting of sea otters intensified which influenced their local extinction in California between the eighteenth and nineteenth century (Estes and others, 2016; Gullixson, 2019). This case is a good example of the likelihood of cascading extinctions, as the sea otters help control the population of sea urchins which feed on the kelp forest. Without otters, the urchins overgraze the kelp, creating "urchin barrens" or patches where the kelp forest has been invaded and essentially wiped out. The shelter, food and protection provided by kelp would be lost for over 1,000 species, including sharks, turtles, seals, whales, birds, fish and more (USNPS, 2023; Bridge, 2020).

3.2.2 Insufficient risk management

The current decline in biodiversity that has contributed to the accelerating extinctions of multiple species around the world has a deep root cause in the lack of risk management over the last two centuries. In particular the lack of perception and awareness, as discussed in **Chapter 3.1.6**, has often led to inaction and lack of management. For example, although we have some estimations about the total number of species in the planet (e.g. 5.3 million [Costello and others, 2013], 8.7 million [Mora and others, 2011]), there is much regarding biodiversity that is still undiscovered (Moura and Jetz, 2021). Consequently, we are also not aware of all the potential ecological interactions we could be losing when one of those unknown species disappears, highlighting the shortcomings of our current risk management strategies to mitigate extinctions. As such, we should proceed more in-line with the precautionary principle, which encourages us to resist performing actions of which the effects are unknown (Cooney, 2004)

However, *Insufficient risk management* encompasses more than perception and awareness. It also relates to execution and performance. In this sense, some management strategies to stop accelerating extinctions could be seen as either lacking or unsuitable. In 1987 when the California condors almost became extinct (with only an estimated 22 individuals remaining in the wild), a conservation program led by the United States government focused on bringing them back from the brink of extinction (Colwell and others, 2012). In this process, however, it was decided to rid the condors of their parasites, and as a consequence, the *Colpocephalum californici*, an avian chewing louse with roles not fully understood yet, went extinct as its only host was this specific condor (Koh and others, 2004; Dunn and others, 2009). This episode is an example of a conservation-induced extinction (Bay Kruse Thomsen, 2022). The misconception that all parasites are bad, or what some call the "ick" factor (Patel, 2006), stems from a lack of information and an absence of the precautionary principle, and it also shows insufficient risk management to assess potential consequences of such a decision. As mentioned in **Chapter 3.1.5**, parasites are more important than believed and could provide information about the evolutionary history of a species (Whiteman and Parker, 2005), which can be particularly unique for rare hosts or endangered species like the California condor (Lyman Kirst, 2012).

3.2.3 Human-induced greenhouse gas emissions

The consequences of increasing greenhouse gas emissions and climate change have driven plants, animals and other organisms to extinction in several ways (Cahill and others, 2013). These include the consequences of heat-avoidance behaviour like range shifts (see Chapter 3.1.2), the limited physiological tolerance to extreme temperatures (Somero, 2011), the loss of pollinator or host in ecological networks (Schleuning and others, 2016; Gérard and others, 2020) and climate-induced advantages favouring competitors and pathogens (Tylianakis and others, 2008) to name a few. The impacts of climate change also go beyond single organisms, and can impact entire ecosystems. For example, as most of the excess greenhouse gas emissions in the atmosphere is absorbed by the oceans (Lindsey and Dahlman, 2023), critical ecosystems for risk management like corals have been thermally stressed and bleached in the last 20 years (Janzen and others, 2021).

Furthermore, another consequence of increasing human-induced greenhouse gas emissions and their connections with warmer oceans, was found recently in a study linking climate change and the reproduction and survival rate of polar bears (Amstrup and Bitz, 2023). Polar bears are a vulnerable species that are forced inland, away from their natural habitats; as the ice layers melt, they are food-deprived and depend on their fat reserves for sustenance. As climate change accelerates, ocean temperatures rise, in turn, accelerating ice melt, which gives the polar bears less time to feed and accumulate the fat that they need to properly function; this is especially critical for mother bears who feed polar bear cubs. If the cubs do not get enough milk, they will not survive, consequently triggering a decline in their population (Orie, 2023; Amstrup and Bitz, 2023). In this sense, human-induced greenhouse gas emissions directly affect the survival of polar bears. If we lose polar bears, we would also be losing the connections they have among other species. As predators, they are important to keep other species' populations in balance that contribute to the food network. Polar bears prey on seals, so without polar bears, seal populations will increase which will also increase competition among other species (including humans) for food such as crustaceans and fish. These species might then either need to hunt something else, or perish as well (Chen, 2022)

3.2.4 Global demand pressures

Since the 1950s, the world has seen an acceleration in human population growth and resultant demands for water, energy, food and land, with severe consequences for the Earth system (Steffen and others, 2005). During this "Great Acceleration" period, the increasing demand for natural resources has led to habitat fragmentation and overexploitation of species which have contributed to biodiversity loss and the increasing rate of species extinctions (IPBES, 2019). Additionally, in some cases, global demand pressures influence a lack of regulations or enforcement (see Chapter 3.1.7), as highly profitable illegal trading of species and overexploitation of resources can take place when demand pressure is high (Mozer and Prost, 2023).

Depending on the demand pressures, ecosystems can be affected in different ways. For example, in freshwater ecosystems, the increasing global demand for energy and water consumption has led to an increase in the number of hydroelectric dam projects around the world: in 1950 there were only 5,000 dams located in North America and Europe; by 2000 the number was around 45,000 spread around 140 countries (Richter and others, 2010). Without proper risk management and accounting for environmental costs, this kind of risk-intensifying land use has resulted in the extinction of freshwater species, like the Chinese paddlefish (UNU-EHS, 2021; Narvaez and others, 2021).

Global demand pressures also relate to global markets and their effect on wildlife trade dynamics, with connections between market-driven overexploitation practices (e.g. overfishing, overhunting, indiscriminate logging) and the likelihood of different species going extinct (Hinsley and others, 2023). For example, the Chilean sandalwood *(Santalum fernandezianum),* a very aromatic tree native to the Juan Fernandez Island in Chile, was harvested to extinction due to demand for the use of its valuable aromatic oil in various products (Harbaugh and Baldwin, 2007; Humphreys and others, 2019).

A degraded mangrove habitat in Malindi in the Kenyan coastal region in 2007. Industrial development and pollution have caused havoc on important ecosystems and eradicated a buffer against typhoons and hurricanes. © TONY KARUMBA / AFP

3.2.5 Colonialism

Almost every territory in the world has been or once was colonized by humans, with important implications for accelerating extinctions. Namely, the so-called "Western Colonization" of non-European territories began in the 1460s, establishing new sea routes around Africa, Asia and America that allowed some countries to attempt to expand their territory (Ertan and others, 2016). The "new" territories were seen as places of infinite resource extraction with little regard for their local communities or for the long-term consequences of the indiscriminate use of resources. Consequently, natural habitats were destroyed mainly through deforestation and mining, overexploitation of species by unsustainable hunting, fishing, logging, indiscriminate trading of species, and by the intended or unintended introduction of invasive alien species across the world, pushing away native endemic species (Winter and others, 2009; Sodhi and others, 2009; McQuade, 2019; Lenzner and others, 2022).

Island territories, in particular, were severely transformed after colonizers arrived. Islands are often considered "reserves of biodiversity", as they harbour around 20 per cent of Earth's species (Fernández-Palacios and others, 2021). However, as mentioned previously, islands have been severely affected by species extinctions, particularly those driven by the introduction of invasive species (see **Chapter 3.1.4**) (IPBES, 2023). For instance, the extinction of the dodo bird *(Raphus cucullatus)*, a gigantic pigeon-like native of the island of Mauritius was assumed to have gone extinct in the seventeenth century after the arrival of Portuguese and Dutch sailors (Kitchener, 1993). According to some historians, the dodo did not have any known predator, so the first explorers to the island became an unfamiliar threat for the dodo (Rijsdijk and others, 2015). Furthermore, colonizers destroyed the dodo's natural habitat and brought with them pigs, cats, dogs, rats and other animals that may have fed from dodo nests and most likely became competitors for the same sources of food (Kitchener, 1993). Additionally, this example also illustrates a potential co-extinction link: although 400 years have passed without the dodo, researchers believe that there are still consequences of its extinction, particularly for native plants that depended on the dodo for the seed dispersion of their fruits (Albert and others, 2021). Currently, only 28 per cent of the plants on Mauritius are native, and 7 per cent of those have seeds that are too big for seed dispersal by other animals on the island, indicating that only the dodo was able to eat them. Now that the dodo is gone and many of these native plants are critically endangered, scientists think that the plants may have lost the capacity to rely on animals for seed dispersal and will soon go extinct as well (Albert and others, 2021; Ashworth, 2023).

3.3 Influences

As we live in an interconnected world, reaching a tipping point might influence another one. In the case of accelerating extinctions, losing a species also implies losing ecological interactions among strongly connected species which can lead to either co-extinctions or cascading extinctions in the ecosystem. This could affect ecosystem functions and services to the point that the ecosystem itself could collapse and affect other depending systems. For example, the accelerating extinctions risk tipping point has a direct effect on reaching a risk tipping point for an **Uninsurable future**, as losing species impacts biodiversity and ecosystem functions (IPBES, 2019), which consequently affects ecosystem health. Healthy ecosystems are essential for reducing exposure and vulnerability of people against extreme events such as storms, floods and droughts (Walz and others, 2021). Therefore, a degraded or collapsed ecosystem could forever lose this unique ability, and the incurred damages from extreme events will be greater (Dong and Klug, 2023), further exacerbating the precarious situation with insurance coverage and reaching the **Uninsurable future** risk tipping point.

Accelerating extinctions can also be influenced by other risk tipping points. In the case of **Unbearable heat**, many animals, in particular mammals, share similar thermal limits as humans, and thus similar health risks above the 35°C wet-bulb temperature threshold (Sherwood and Huber, 2010). Even if the primary extinction was set in motion as a result of natural evolutionary processes, the resulting reduced diversity will reduce the number of ecological interactions between species and raise the risk of cascades should an extinction take place (Dunne and Williams, 2009; Kehoe and others, 2021).

Similarly, the tipping points of **Mountain glaciers melting** and **Groundwater depletion** can accelerate extinctions, as changes in aquatic and terrestrial ecosystems will threaten ecosystem conditions and ecological interactions among species that could lead to accelerating extinctions. For example, local extinctions are predicted to follow glacier retreat, particularly in cold-adapted plant and aquatic invertebrate species, which have already seen their habitats shrink in recent years (Giersch and others, 2017; Anthelme and others, 2022). In addition, the change of habitats of organisms living in underground aquifers vulnerable to shocks (Devitt and others, 2019), and the depleting groundwater will further impact biodiversity on the surface as river and lake habitats literally dry up.

4. Where are we headed? Current and future impacts

4.1 Livelihood loss

Species' extinctions and the resulting loss of biodiversity and ecological interactions compromise ecosystem health and therefore the delivery of ecosystem services that are critical for the livelihood and income of millions around the world (Valiente-Banuet and others, 2015; Díaz and others, 2018). The conversion of natural landscapes, the depletion of raw materials and exploitation of species has a direct impact on communities which depend on natural resources or agriculture, as they might not be able to carry out the activities that sustain their livelihood. For example, coastal communities that depend on mangrove forests benefit from the crustaceans, fish, honey or wood the forests provide, for both consumption and income in addition to the cultural services, such as recreation and tourism which also generates sources of employment for the community (IUCN, 2021b). However, as explored in **Chapter 3.1.3**, some mangrove species are at risk of extinction like the critically endangered *(Bruguiera hainesii)* native of Malaysia.

4.2 Food & water insecurity

Similarly, to the loss of livelihoods, the availability of food and water is also directly affected by the impacts that biodiversity loss and species extinction have on the ecosystem's health. In terms of food insecurity, accelerating extinctions have impacted many agricultural systems by the loss of genetic diversity and the disappearance of varieties and breeds of animals and plants which are fundamental for not just locals but also for global nutrition (IPBES, 2019). In addition, the ongoing decline in diversity, distribution and density of pollinators due to human activities, mostly reflected by the extinction of many species of insects and birds, may compromise food production to the point that some field crops, vegetables and fruits are at risk of disappearing from our diets, as around 75 per cent of the world's crops heavily depend on pollinators (Garratt and others, 2014; IPBES, 2019; Mancini and others, 2023). The extinction of wild tulips discussed in **Chapter 3.1.2** illustrates the potential extinction of a species in connection to pollinators.

Water insecurity on the other hand, shares a key connection with healthy freshwater ecosystems, as around 2 billion people rely on rivers for drinking water (WWF, 2021). However, the pressures on species also compromise the quality of the water supply. As such, the pollution of streams and wetlands, overfishing and other unsustainable extractive practices has damaged these ecosystems to the extent that they have one of the highest numbers of species threatened with extinction (CBD, 2015; WWF, 2022), and has also compromised global water security (Vörösmarty and others, 2010).

Pollinators like bees are important for our food systems. © Susanne Schulz / iStock

4.3 Ecosystem damage and biodiversity loss

As we progressively lose species, we lose more biodiversity and ecological interactions along the way. This is why we talk about a chain reaction to ecosystem collapse. When we lose species, we are losing genetic diversity which can compromise an ecosystem's functions and services. However, ecosystems may not disappear entirely but will most likely transition into a new state (Miller, 2013; Bland and others, 2017; BGCI, 2021). Therefore, extinction's cumulative damage to our natural systems is difficult to assess and oftentimes irreversible. The chain reaction also has a snowball effect: the more species we lose, the more extinctions we trigger, which makes stopping the chain reaction more and more challenging. In addition, damages to ecosystems also means a loss of resilience which reduces not just the amount of ecosystem services in terms of providing food and water, but also the ability of our ecosystems to protect us from harm. For example, the loss of corals reduces coastal protection against storms and the impacts of sea level rise. Therefore, the damage to this ecosystem due to climate change and other human pressures such as pollution and the loss of biodiversity (see **Chapter 3.2.3**) also reduces the coastal protection for nearly 200 million people (Ferrario and others, 2014; Janzen and others, 2021)

4.4 Loss of opportunities

Because of accelerating extinctions, we are losing various opportunities for the advancement of society we either already know and use or are yet unknown. As such, we might be losing the possible “drugs of the future” in terms of medicinal plants or fungi that could help cure diseases, such as cancer or heart disease (Howes and others, 2020; Latham, 2021). Other species provide learning opportunities about evolutionary process and the unique functions of species and especially the “rare species” (Leitão and others, 2016). From the extinction of the Chilean sandalwood *(Santalum fernandezianum)* discussed in **Chapter 3.2.4**, we forever lost the opportunity to explore the unique insights about the evolution of the island of Juan Fernandez. Every example of extinctions discussed in this report is an example of the loss of opportunities.

4.5 Cultural heritage loss

Accelerating extinctions also have an impact on the provision of cultural ecosystem services such as recreation, cultural identity and spiritual experience (Cave, 2022). For many communities around the world, the surrounding nature of mountains, rivers, forests and species of plants and animals have cultural value, either as part of traditional knowledge, religious practices or folklore legends (Clark and others, 2014). Consequently, the disappearance of species and their ecological interactions represents a cultural heritage loss as for each species that goes extinct, there is an intangible value that we are also losing. This was illustrated with the example of the Javan tiger in **Chapter 3.1.1**. Before its extinction, the Javan tiger was an important figure in the folklore of Java as a symbol for shamanism and traditional ancestral spirits (Wessing, 1995).

5. The future we want to create

To assess solutions for avoiding risk tipping points, we must consider these key questions: Does the solution attempt to prevent negative system changes or target adaptation to them? Does the solution work within the current system or drive a fundamental reimagining of the system? Answering these questions is critical for understanding how different actions advance risk reduction goals and yield varied outcomes, including potential consequences and trade-offs. To navigate this, we have developed the ADAT2 framework, which classifies solutions into four categories: Adapt-Delay, Adapt-Transform, Avoid-Delay, and Avoid-Transform — see the **main report** for details.

5.1 Adapt

Adapt actions reduce exposure to the impacts of a tipping point and help to prepare for sustainable living within the new system. Species can avoid falling victim to co-extinction when a species they are connected to goes extinct, if they are able to find ways to adapt to the change in time. The mechanisms involved are: i) establishment of new connections with other persisting species, either in-situ or in a new location if migration is an option, or ii) the strengthening of a pre-existing interaction with another species to compensate for the lost link (Baumgartner and others, 2020). Human intervention can help or hinder species adapt to new conditions after the extinction of a strongly connected species. Protecting and restoring habitat connectivity, for example, facilitates species movements and allows range shifts, thereby facilitating new interactions and the potential replacements for the lost interaction partners (Brodie and others, 2014). Elements of connectivity, such as green corridors, are key to preserving and supporting species populations and ecological functions in an increasingly fragmented and changing world (Pörtner and others, 2021). Assisted colonization or migration, which is the deliberate movement of plants or animals to another habitat outside of their historical range, is seen as a potential tool for the management and conservation of endangered species (Pörtner and others, 2021). One specific example of assisted colonization is the introduction of species to specifically restore species interactions such as by restoring fruit-bearing trees if a fruit-eating animal is endangered. However, this method is controversial given the lack of research and the potential risk of introducing invasive alien species (Griffiths and others, 2011). Human interventions, which support genetic heterogeneity within populations of endangered species, is an additional important strategy to support species' adaptive potentials in their recovery (Crow and others, 2021; CBD, 2022).

Solutions aiding species to establish new interspecies connections in order to adapt to crossing the risk tipping point of losing a strongly connected species can help to delay the worst impacts of species loss. However, these solutions will always have their limits unless the underlying drivers and root causes of the original extinction are addressed. New connections will remain vulnerable unless we change and reverse course from losing nature and biodiversity towards restoring and substantially increasing the area of natural ecosystems.

5.2 Avoid

While species have some options and capabilities to adapt to the extinction of strongly connected species, the more connections disappear, the more constrained the adaptations will become. In the long term, avoiding extinctions and co-extinctions will be the only way we can save ourselves because we are part of nature. Otherwise, if one species after another goes extinct, it is only a matter of time before humans are next.

Species and ecosystems themselves have several capabilities and characteristics that help prevent co-extinction. Understanding these traits helps to create more impactful interventions to avoid extinctions. Phenotypic plasticity, for example, is a mechanism that helps to prevent extinction and co-extinction (Greenspoon and Spencer, 2021) through the ability of an organism to change in response to environmental stimuli. Conservation can support phenotypic plasticity if it considers ways to preserve key ecological processes (Donelson and others, 2023; Reed and others, 2011). Plant-pollinator interactions can be dynamic over time through interaction rewiring (CaraDonna and others, 2017), a reassembly of interactions between species that can be supported by the diversity of flowering plants. Trophic redundancy, and biodiversity overall, can also reduce the risk of co-extinction by increasing options and thus resilience (Borrvall and others, 2000; Sanders and others, 2018). Persistence can also be achieved through evolutionary rescue, which occurs when evolutionary adaptation leads to the avoidance of extinction. Evolutionary rescue is more likely to occur with a higher level of standing genetic variation (Greenspoon and Spencer, 2021).

More broadly, actions taken by humans can help species threatened with extinction or co-extinction to avoid crossing the risk tipping point. To be successful, these measures must be implemented proactively and in accordance with the precautionary principle. Preventing species from going extinct often requires active and species-specific conservation actions such as “ex-situ conservation” (conservation outside their natural habitats), “species reintroduction” (re-establishment of a viable population of a species within its original range), or “species recovery” (restoration of natural processes and the genetic, demographic or ecological parameters of a species). While such species-specific conservation actions have been shown to be essential for the recovery of many currently threatened species (Bolam and others, 2023), they need to be combined with different types and larger scale interventions to prevent species extinction. Threatened species have been shown to benefit from the implementation of: i) spatial planning measures to conserve existing ecosystems, ii) restoration of degraded ecosystems and iii) designation of protected areas to conserve terrestrial and marine areas, especially those of high biodiversity value (Bolam and others, 2023).

Another concern is that human encroachment may further decrease suitable habitats for species and thus will further drive extinctions. An approach to facilitate human-nature coexistence is that of a multifunctional approach across land, freshwater and marine biomes, including: i) large, intact wilderness spaces, ii) shared spaces and iii) anthromes dominated by humans (Pörtner and others, 2021). Shared spaces are a mosaic of intact natural habitats with corridors of natural habitats to facilitate the migration of species. The concept aims to achieve human habitability, self-sustaining biodiversity and good quality of life for all kinds of beings while still separating and compartmentalizing nature and humans to some degree.

Focusing specifically on the risk of co-extinctions, we recognize that co-extinction is rarely addressed explicitly in conservation planning (Brodie and others, 2014). Specific conservation considerations to reduce the risk of co-extinction could include: i) placing more emphasis on species that provide strong benefits to other species (e.g. fruit-eating, seed-dispersing animals or animals that provide shelter for other species), ii) supporting ecological processes such as pollination or iii) proactively protecting species where their extinction is expected to lead to co-extinction

(Brodie and others, 2014). Applying the precautionary principle can help to avoid co-extinctions. Interventions that support gene flow in an area within a species' range have also the potential to reduce extinctions by supporting evolutionary rescue (Greenspoon and Spencer, 2021). Transforming the way we approach the conservation and restoration of species and ecosystems will help us to avoid risk tipping points and specifically address co-extinction risk. However, they will only act to delay accelerating extinction if they do not also address root causes and drivers.

5.3 From Delay to Transform

While the above solutions can help to prevent co-extinction or may help species adapt to the loss of interspecies relationships they have relied on, a sustained reduction of extinction risk will only occur if human behaviour and actions that are currently driving biodiversity loss fundamentally change. For example, biodiverse habitats, such as wetlands, can be restored to support biodiversity and prevent extinction, but the efficacy of the intervention depends on many technical and non-technical factors. Restoration success is undermined if changes are implemented only on a small scale while large-scale stressors, such as those acting on a catchment scale, are not removed (Brettschneider and others, 2023). Success is also less likely if the surrounding communities do not accept the change, or more generally, the collective values of society do not align with the change process. For example, in a river restoration process, acceptance of the project by inhabitants was enhanced by the accessibility of transparent information and the preservation of the benefits provided by the former status and land use of the area (Heldt and others, 2016). While information and transparency are key, people often form ideas and attitudes toward restoration based on their own experiences of being outside or by interacting with others (Scholte and others, 2016).

Transformative change that benefits nature and biodiversity, however, needs a reimagining of our relationship with nature and a fundamental change of how we see and treat other beings on the planet. The separation of humans from nature has led to the exclusion, exploitation and extinction of many species on the planet. We delineate conservation areas where nature is allowed to exist while the rest of the planet is seen as belonging to humans to take, alter, pollute or destroy. Indeed, even using the world "natural resources" supports an assumption that Earth is subject to human ownership and use (Crist and others, 2021), ignoring the fact that humans and human well-being fundamentally depends on other species to exist, for the air we breathe, the food we eat and the water we drink (MEA, 2005). There cannot be fully separate spaces for humans and nature, because humans are part of nature. A paradigm shift is needed towards respecting the needs and well-being of nature and the global-scale system of interconnected pieces of which we as humans are one. Considering this oneness opens the opportunity to overcome the dichotomy between humans and nature. Indeed, many societies have lost an understanding of what it means to be part of nature, and we will need to relearn and reimagine how to speak and think about nature, how we research ecology and what biodiversity conservation means (Kurle and others, 2023).

This shift also means that exploitative use of nature needs to end, which can only be achieved if societal priorities and values change. Currently, more than 90 per cent of biodiversity loss occurs from the extraction and processing of natural resources (IRP, 2019). Clearing land for agriculture or settlements, widespread pollution of air, soil and water, and overhunting or harvesting the species themselves all lead to habitat loss (Ellen MacArthur Foundation, 2021). Indeed, changes in land and sea use and the exploitation of organisms are the largest direct causes of change in nature (IPBES, 2019). Reducing resource use is thus fundamental to stop extinctions. Zero-waste strategies and transitioning to a circular economy challenge the way we use our resources. This includes redesigning our systems to keep materials in circulation by reusing or recycling them (Valenzuela-Fernández and Escobar-Farfán, 2022), eliminating waste and pollution and regenerating the environment. The concept has been around since the 1960s, but implementation is, so far, limited by some technical but mainly cultural barriers particularly stemming from a lack of interest and awareness by consumers as well as a hesitant company culture to scale up implementation (Kirchherr and others, 2018).

Indeed, circular economy is understood as a fundamental systemic change instead of tweaking the status quo (Kirchherr and others, 2017), so the cultural change needs to happen in all parts of the society. Embarking on such a journey can start with small yet significant steps such as our word choices. Using words like “fish stocks” represents how we currently value fish. A “stock” of tuna identifies the animals as commodified objects rather than as individual subjects entitled to partake in the web of life. The logic of extractive use of resources renders fish as assets for possession and trade (Telesca, 2017). To stop exploitative use, we could stop viewing the living and non-living beings in our world as resources, and instead view them as partners and gifts based on mutual respect and reciprocity like many indigenous peoples do. This would also mean accepting a humbler role in the way we interact with the rest of the planet and recognizing that humans are one with nature.

Some countries such as Bolivia and Ecuador assigned all of nature a legislative standing. There are some signs that this world view might get increasing recognition also in other parts of the world. The Whanganui River in New Zealand was granted legal personhood rights in 2017 and has since been followed by the Klamath River in the U.S. and the Magpie River in Canada. In all three cases, the change was a result of the influence of local Indigenous people (Darlymple, 2022). This change does not mean that these rivers are free from harm, but defending the rights of the river becomes easier if a case is brought to the court of law as the river is seen as a person and not just a resource (Darlymple, 2022).

A monarch butterfly lands on the shoulder of a child during an awareness event on Washington, D.C., United States, in 2018. The event was an effort to alert the public of the declining monarch butterfly population. © Drew Angerer / Getty Images / AFP

6. Conclusion

The current rate of species extinction shows an increase compared to natural background rates. Human actions and inactions related to land-use change, overexploitation of species, climate change, pollution and invasive alien species in the last 500 years have been pushing us to a tipping point of accelerating extinctions. Part of the issue also lies in our lack of understanding of the complex process behind extinctions. As a result, most of the attention has been placed on a particular species disappearing and not on the ecological interactions at risk. This exposes ecosystems to the risk of chain reactions of cascading extinctions that could trigger irreversible changes, all of which is detrimental to us as we crucially depend on them for life-supporting services.

There are multiple, interconnected drivers and root causes pushing us towards risk tipping points of accelerating extinctions around the world. Against this dire backdrop, we still have a window of time for effective action. We need to understand that the risk posed by extinctions is much more than just “one species” disappearing at a time. There is a whole realm of possible interconnected implications we are perilously unaware of. Every species on Earth plays a role in the complex web of life, no matter their size, appearance or the importance of the role we assign them. Every species counts.

When a strongly connected species disappears and the tipping point is crossed, human actions can help co-dependent species to adapt by protecting and restoring habitats so that species can find new connections among them. We can also help avoid crossing the risk tipping point by following the precautionary principle and focusing on conservation measures for identifying and preserving ecosystems’ functions to protect vulnerable species. However, as our actions that degrade the natural world are the main underlying driver of the accelerating extinctions tipping point, the only way we can achieve effective preservation and restoration of nature is to change. Only transformational change away from our business-as-usual way of thinking and doing things will save species from extinction, and us from the consequences of those losses. This invites us to reimagine our relationship with nature in a transformative way, in which it will be necessary to create a new way of seeing and treating other beings on the planet.

7. References

Aaron, Jacqueline, and others (2021). Mangroves: The Roots of an Ecosystem. Extinction Stories. Available at https://pressbooks.pub/extinctionstories/chapter/mangroves/

Agrawal, M. (2003). Plant Responses to Atmospheric Sulphur. In *Sulphur in Plants.* Abrol, Yash P. and Altaf Ahmad, eds. Dordrecht: Springer Netherlands. DOI: 10.1007/978-94-017-0289-8_15

Albert, Sébastien, and others (2021). 109131. *Biological Conservation*, vol. 257, art. 109131. pp. 1–10. DOI: 10.1016/j.biocon.2021.109131

Amstrup, Steven C., and Cecilia M. Bitz (2023). Unlock the Endangered Species Act to address GHG emissions. *Science*, vol. 381, No. 6661, pp. 949–51. DOI: 10.1126/science.adh2280

Anthelme, Fabien, and others (2022). Novel plant communities after glacial retreat in Colombia: (many) losses and (few) gains. *Alpine Botany*, vol. 132, No. 2, pp. 211–22. DOI: 10.1007/s00035-022-00282-1

Aronson, Richard B., and others (2015). No barrier to emergence of bathyal king crabs on the Antarctic shelf. *Proceedings of the National Academy of Sciences*, vol. 112, No. 42, pp. 12997–3002. DOI: 10.1073/pnas.1513962112

Ashworth, James (2023). Extinctions on the island of the dodo are pushing plants towards extinction. Available at https://www.nhm.ac.uk/discover/news/2023/march/extinctions-island-dodo-pushing-plants-towards-extinction.html

Bardan, Roxana (2022). NASA Says 2022 Fifth Warmest Year on Record, Warming Trend Continues. Available at https://www.nasa.gov/press-release/nasa-says-2022-fifth-warmest-year-on-record-warming-trend-continues

Barnett, Juan M., and others (2014). Te avifauna of Curaçá (Bahia): the last stronghold of Spix's Macaw. *Revista Brasileira de Ornitologia*, vol. 22, No. 2, pp. 121–37. DOI: 10.1007/BF03544241

Baumgartner, Matheus T., Mário Almeida-Neto, and Luiz C. Gomes (2020). A novel coextinction model considering compensation and new interactions in ecological networks. *Ecological Modelling*, vol. 416, art. 108876. pp. 1–8. DOI: 10.1016/j.ecolmodel.2019.108876

Bay Kruse Thomsen, Søren (2022). Unwelcome Guests – Coextinction of Parasites. Available at https://www.theextinctions.com/articles-1/unwelcome-guests-coextinction-of-parasites

Ben-Hasan, Abdulrahman, and others (2021). China's fish maw demand and its implications for fisheries in source countries. *Marine Policy*, vol. 132, art. 104696. pp. 1–11. DOI: 10.1016/j.marpol.2021.104696

Bernardo, Fátima, Isabel Loupa-Ramos, and Joana Carvalheiro (2021). Are biodiversity perception and attitudes context dependent? A comparative study using a mixed-method approach. *Land Use Policy*, vol. 109, art. 105703. pp. 1–10. DOI: 10.1016/j.landusepol.2021.105703

Bhowmik, Avit K., and others (2022). Global Mangrove Deforestation and Its Interacting Social-Ecological Drivers: A Systematic Review and Synthesis. *Sustainability*, vol. 14, No. 8, art. 4433. pp. 1–24. DOI: 10.3390/su14084433

Bland, L. M., and others (2017). *Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria.* Gland: International Union for Conservation of Nature

Bolam, Friederike C., and others (2023). Over half of threatened species require targeted recovery actions to avert human-induced extinction. *Frontiers in Ecology and the Environment*, vol. 21, No. 2, pp. 64–70. DOI: 10.1002/fee.2537

Borrvall, Charlotte, Bo Ebenman, and Tomas J. Tomas Jonsson (2000). Biodiversity lessens the risk of cascading extinction in model food webs. *Ecology Letters*, vol. 3, No. 2, pp. 131–36. DOI: 10.1046/j.1461-0248.2000.00130.x

Botanic Gardens Conservation International (2021). State of the World's Trees. Available at https://www.bgci.org/wp/wp-content/uploads/2021/08/FINAL-GTAReportMedRes-1.pdf

Brettschneider, Denise J., and others (2023). Much effort, little success: causes for the low ecological efficacy of restoration measures in German surface waters. *Environmental Sciences Europe*, vol. 35, No. 1, pp. 1–22. DOI: 10.1186/s12302-023-00736-1

Bridge, Tyee (2020). The hidden life of kelp: How sea otters, urchins and starfish make ocean forests. Available at https://www.nationalobserver.com/2020/10/27/features/kelp-sea-otters-urchins-starfish-ocean-forests

Brodie, Jedediah F., and others (2014). Secondary extinctions of biodiversity. *Trends in Ecology & Evolution*, vol. 29, No. 12, pp. 664–72. DOI: 10.1016/j.tree.2014.09.012

Bullen, Cameron D. (2020). A marine megafaunal extinction and its consequences for kelp forests of the North Pacific. Master of Science, University of British Columbia. Available at https://open.library.ubc.ca/media/stream/pdf/24/1.0391881/4

Bullen, Cameron D., and others (2021). The ghost of a giant – Six hypotheses for how an extinct megaherbivore structured kelp forests across the North Pacific Rim. *Global Ecology and Biogeography*, vol. 30, No. 10, pp. 2101–18. DOI: 10.1111/geb.13370

Cahill, Abigail E., and others (2013). How does climate change cause extinction? *Proceedings of the Royal Society B: Biological Sciences*, vol. 280, No. 1750, art. 20121890. pp. 1–9. DOI: 10.1098/rspb.2012.1890

CaraDonna, Paul J., and others (2017). Interaction rewiring and the rapid turnover of plant-pollinator networks. *Ecology Letters*, vol. 20, No. 3, pp. 385–94. DOI: 10.1111/ele.12740

Carlson, Colin J., and others (2020). A global parasite conservation plan. *Biological Conservation*, vol. 250, art. 108596. pp. 1–12. DOI: 10.1016/j.biocon.2020.108596

Cave, Claire (2022). Climate Change and World Heritage: An Introduction. In *50 Years World Heritage Convention: Shared Responsibility -- Conflict & Reconciliation*. Albert, Marie-Theres, and others, eds. Cham, Switzerland: Springer. DOI: 10.1007/978-3-031-05660-4_17

Ceballos, Gerardo, and others (2015). Accelerated modern human-induced species losses: Entering the sixth mass extinction. *Science Advances*, vol. 1, No. 5, art. e1400253. 1-6. DOI: 10.1126/sciadv.1400253

Ceballos, Gerardo, Paul R. Ehrlich, and Peter H. Raven (2020). Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction. *Proceedings of the National Academy of Sciences,* vol. 117, No. 24, pp. 13596–602. DOI: 10.1073/pnas.1922686117

Chen, Jasmin (2022). Impacts of Sea Ice Loss on Polar Bear Diet, Prey Availability, Foraging Behaviors, and Human-Bear Interactions in the Arctic. Master's Projects and Capstones.1350, University of San Francisco. Available at https://repository.usfca.edu/capstone/1350

Chu, Ellen W., and James R. Karr (2017). Environmental Impact: Concept, Consequences, Measurement. *Reference Module in Life Sciences*, pp. 1–22. DOI: 10.1016/B978-0-12-809633-8.02380-3

Clark, Natalie E., and others (2014). Biodiversity, cultural pathways, and human health: a framework. *Trends in Ecology & Evolution*, vol. 29, No. 4, pp. 198–204. DOI: 10.1016/j.tree.2014.01.009

Colwell, Robert K., Robert R. Dunn, and Nyeema C. Harris (2012). Coextinction and Persistence of Dependent Species in a Changing World. *Annual Review of Ecology, Evolution, and Systematics*, vol. 43, No. 1, pp. 183–203. DOI: 10.1146/annurev-ecolsys-110411-160304

Convention on Biological Diversity (2015). Water and Biodiversity: Summary of the findings of the Fourth Edition of the Global Biodiversity Outlook as they relate to water. Montreal. Available at https://www.cbd.int/gbo/gbo4/gbo4-water-en.pdf

__________ (2020a). Aichi Biodiversity Targets. Available at https://www.cbd.int/sp/targets/

__________ (2020b). Global Biodiversity Outlook 5 - Summary for Policymakers. Available at https://www.cbd.int/gbo/gbo5/publication/gbo-5-spm-en.pdf

__________ (2022). Kunming-Montreal Global Biodiversity Framework. CBD/COP/DEC/15/4. Available at https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

Convention on International Trade in Endangered Species of Wild Fauna and Flora (2023). What is CITES? Available at https://cites.org/eng/disc/what.php

Costello, Mark J., Robert M. May, and Nigel E. Stork (2013). Can we name Earth's species before they go extinct? *Science*, vol. 339, No. 6118, pp. 413–16. DOI: 10.1126/science.1230318

Crist, Eileen, and others (2021). Protecting Half the Planet and Transforming Human Systems Are Complementary Goals. *Frontiers in Conservation Science,* vol. 2, art. 761292. pp. 1–9. DOI: 10.3389/fcosc.2021.761292

Crosta, Andrea, and others (2018). Operation Fake Gold: The Totoaba Supply Chain- From Mexico's Tototaba Cartels to China's Totoaba Maw Wholesalers - An Illegal Trade Killing the Vaquita. Los Angeles, Californa: Elephant Action League. Available at https://earthleagueinternational.org/wp-content/uploads/2018/07/EAL-Operation-Fake-Gold-Final.pdf

Crow, Taylor M., and others (2021). Implications of genetic heterogeneity for plant translocation during ecological restoration. *Ecology and evolution,* vol. 11, No. 3, pp. 1100–10. DOI: 10.1002/ece3.6978

Darlymple, Sarah (2022). Are humans separate from nature? Available at https://www.britishecologicalsociety.org/are-humans-separate-from-nature/

David, P., and others (2017). Impacts of Invasive Species on Food Webs: A Review of Empirical Data. In *Networks of Invasion: A Synthesis of Concepts.* Bohan, David A., and others, eds., Academic Press. DOI: 10.1016/bs.aecr.2016.10.001

De Vos, Jurriaan M., and others (2015). Estimating the normal background rate of species extinction. *Conservation Biology,* vol. 29, No. 2, pp. 452–62. DOI: 10.1111/cobi.12380

Devitt, Thomas J., and others (2019). Species delimitation in endangered groundwater salamanders: Implications for aquifer management and biodiversity conservation. *Proceedings of the National Academy of Sciences,* vol. 116, No. 7, pp. 2624–33. DOI: 10.1073/pnas.1815014116

Díaz, Sandra, and others (2018). Assessing nature's contributions to people. *Science,* vol. 359, No. 6373, pp. 270–72. DOI: 10.1126/science.aap8826

Donelson, J. M., and others (2023). Putting plasticity into practice for effective conservation actions under climate change. *Nature Climate Change,* vol. 13, No. 7, pp. 632–47. DOI: 10.1038/s41558-023-01706-4

Dong, Cody, and Arne P. Klug (2023). Underwriting the Biodiversity Crisis. Available at https://www.msci.com/www/blog-posts/underwriting-the-biodiversity/03731924115

Dunn, Robert R., and others (2009). The sixth mass coextinction: are most endangered species parasites and mutualists? *Proceedings of the Royal Society B: Biological Sciences,* vol. 276, No. 1670, pp. 3037–45. DOI: 10.1098/rspb.2009.0413

Dunne, Jennifer A., and others (2013). Parasites affect food web structure primarily through increased diversity and complexity. *PLoS biology,* vol. 11, No. 6, art. e1001579. 1-17. DOI: 10.1371/journal.pbio.1001579

Dunne, Jennifer A., and Richard J. Williams (2009). Cascading extinctions and community collapse in model food webs. *Philosophical Transactions of the Royal Society B: Biological Sciences,* vol. 364, No. 1524, pp. 1711–23. DOI: 10.1098/rstb.2008.0219

Ellen MacArthur Foundation (2021). The Nature Imperative: How the circular economy tackles biodiversity loss. Available at https://ellenmacarthurfoundation.org/biodiversity-report

Ertan, Arhan, Martin Fiszbein, and Louis Putterman (2016). Who was colonized and when? A cross-country analysis of determinants. *European Economic Review,* vol. 83, pp. 165–84. DOI: 10.1016/j.euroecorev.2015.10.012

Estes, James A., Alexander Burdin, and Daniel F. Doak (2016). Sea otters, kelp forests, and the extinction of Steller's sea cow. *Proceedings of the National Academy of Sciences of the United States of America,* vol. 113, No. 4, pp. 880–85. DOI: 10.1073/pnas.1502552112

Farrell, Maxwell J., and others (2015). The path to host extinction can lead to loss of generalist parasites. *The Journal of animal ecology,* vol. 84, No. 4, pp. 978–84. DOI: 10.1111/1365-2656.12342

Fernández-Palacios, José M., and others (2021). Scientists' warning - The outstanding biodiversity of islands is in peril. *Global Ecology and Conservation,* vol. 31, art. e01847. 1-19. DOI: 10.1016/j.gecco.2021.e01847

Ferrario, Filippo, and others (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications,* vol. 5, No. 1, art. 3794. pp. 1–19. DOI: 10.1038/ncomms4794

Fisher, J. C., and others (2023). Human well-being responses to species' traits. *Nature Sustainability,* pp. 1–9. DOI: 10.1038/s41893-023-01151-3

Florida Fish and Wildlife Conservation Commission (2023). Gopher Tortoise Commensals. Available at https://myfwc.com/wildlifehabitats/wildlife/gopher-tortoise/commensals/

Friess, Daniel A., and others (2019). The State of the World's Mangrove Forests: Past, Present, and Future. *Annual Review of Environment and Resources,* vol. 44, No. 1, pp. 89–115. DOI: 10.1146/annurev-environ-101718-033302

Fritts, Thomas H., and Gordon H. Rodda (1998). The Role of Introduced Species in the Degradation of Island Ecosystems: A Case History of Guam. *Annual Review of Ecology and Systematics,* vol. 29, No. 1, pp. 113–40. DOI: 10.1146/annurev.ecolsys.29.1.113

Fumy, Florian, and Thomas Fartmann (2021). Climate and land-use change drive habitat loss in a mountain bird species. *Ibis,* vol. 163, No. 4, pp. 1189–206. DOI: 10.1111/ibi.12954

Garratt, M. P., and others (2014). Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agriculture, ecosystems & environment,* vol. 184, No. 100, pp. 34–40. DOI: 10.1016/j.agee.2013.10.032

Gérard, Maxence, and others (2020). Global warming and plant-pollinator mismatches. *Emerging Topics in Life Sciences,* vol. 4, No. 1, pp. 77–86. DOI: 10.1042/ETLS20190139

Gerstein, Julie, and Daisy Hernandez (2022). 23 Extinct Animals We've Lost in the Past 150 Years. Available at https://www.popularmechanics.com/science/animals/g201/recently-extinct-animals-list/

Giersch, J. J., and others (2017). Climate-induced glacier and snow loss imperils alpine stream insects. *Global change biology,* vol. 23, No. 7, pp. 2577–89. DOI: 10.1111/gcb.13565

Greenspoon, Philip B., and Hamish G. Spencer (2021). Avoiding extinction under nonlinear environmental change: models of evolutionary rescue with plasticity. *Biology letters,* vol. 17, No. 12, art. 20210459. pp. 1–6. DOI: 10.1098/rsbl.2021.0459

Griffiths, Christine J., and others (2011). Resurrecting extinct interactions with extant substitutes. *Current Biology,* vol. 21, No. 9, pp. 762–65. DOI: 10.1016/j.cub.2011.03.042

Gullixson, Paul (2019). California's sea otter population could triple by recolonizing San Francisco Bay. Available at https://news.ucsc.edu/2019/12/sea-otters.html

Harbaugh, Danica T., and Bruce G. Baldwin (2007). Phylogeny and biogeography of the sandalwoods (Santalum, Santalaceae): repeated dispersals throughout the Pacific. *American journal of botany,* vol. 94, No. 6, pp. 1028–40. DOI: 10.3732/ajb.94.6.1028

Hauck, Markus, Uwe de Bruyn, and Christoph Leuschner (2013). Dramatic diversity losses in epiphytic lichens in temperate broad-leaved forests during the last 150 years. *Biological Conservation,* vol. 157, pp. 136–45. DOI: 10.1016/j.biocon.2012.06.015

Hawaii Invasive Species Council (2022). Brown Tree Snake. Available at https://dlnr.hawaii.gov/hisc/info/invasive-species-profiles/brown-tree-snake/

Heldt, Sonja, and others (2016). Social pitfalls for river restoration: How public participation uncovers problems with public acceptance. *Environmental Earth Sciences,* vol. 75, No. 13, art. 1053. pp. 1–16. DOI: 10.1007/s12665-016-5787-y

Hinsley, Amy, and others (2023). Trading species to extinction: evidence of extinction linked to the wildlife trade. *Cambridge Prisms: Extinction,* vol. 1, art. e10. 1-9. DOI: 10.1017/ext.2023.7

Howes, Melanie-Jayne R., and others (2020). Molecules from nature: Reconciling biodiversity conservation and global healthcare imperatives for sustainable use of medicinal plants and fungi. *Plants People Planet,* vol. 2, No. 5, pp. 463–81. DOI: 10.1002/ppp3.10138

Hudson, Peter J., Andrew P. Dobson, and Kevin D. Lafferty (2006). Is a healthy ecosystem one that is rich in parasites? *Trends in Ecology & Evolution,* vol. 21, No. 7, pp. 381–85. DOI: 10.1016/j.tree.2006.04.007

Humphreys, Aelys M., and others (2019). Global dataset shows geography and life form predict modern plant extinction and rediscovery. *Nature Ecology & Evolution,* vol. 3, No. 7, pp. 1043–47. DOI: 10.1038/s41559-019-0906-2

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services. Bonn: IPBES secretariat. DOI: 10.5281/zenodo.3553579

__________ (2023). Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. DOI: 10.5281/ZENODO.8314303

International Resource Panel (2019). Global Resources Outlook 2019: Natural Resources for the Future We Want. Nairobi. Available at https://www.resourcepanel.org/reports/global-resources-outlook

International Union for Conservation of Nature (2021a). Invasive Alien Species and Climate Change. Available at https://www.iucn.org/sites/default/files/2022-04/ias_and_climate_change_issues_brief_2021.pdf

__________ (2021b). My Mangroves, My Livelihood. Available at https://www.iucn.org/news/oceania/202107/my-mangroves-my-livelihood

__________ (2023). IUCN Red List of Threatened Species. Available at https://www.iucnredlist.org/about/faqs#What%20are%20the%20Red%20List%20Categories%20and%20Criteria

Jackson, P., and K. Nowell (2008). Panthera tigris ssp. balica. The IUCN Red List of Threatened Species 2008: e.T41682A10510320. DOI: 10.2305/IUCN.UK.2008.RLTS.T41682A10510320.en

Janzen, Sally, Liliana Narvaez, and Jack O'Connor (2021). Technical report: Coral Bleaching in the Great Barrier Reef. Bonn. Available at https://s3.eu-central-1.amazonaws.com/interconnectedrisks/reports/Research/Great_Barrier_Reef_Bleaching_TR_210906.pdf

Jiménez-Franco, María V., and others (2022). Problems seeded in the past: lagged effects of historical land-use changes can cause an extinction debt in long-lived species due to movement limitation. *Landscape Ecology,* vol. 37, No. 5, pp. 1331–46. DOI: 10.1007/s10980-021-01388-3

Johnson, Christopher N., and others (2017). Biodiversity losses and conservation responses in the Anthropocene. *Science,* vol. 356, No. 6335, pp. 270–75. DOI: 10.1126/science.aam9317

Juniper, A. T., and Carlos Yamashita (1991). The habitat and status of Spix's Macaw Cyanopsitta spixii. *Bird Conservation International,* vol. 1, No. 1, pp. 1–9. DOI: 10.1017/S0959270900000502

Kehoe, Rachel, Enric Frago, and Dirk Sanders (2021). Cascading extinctions as a hidden driver of insect decline. *Ecological Entomology,* vol. 46, No. 4, pp. 743–56. DOI: 10.1111/een.12985

Kirchherr, Julian, and others (2018). Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecological Economics,* vol. 150, pp. 264–72. DOI: 10.1016/j.ecolecon.2018.04.028

Kirchherr, Julian, Denise Reike, and Marko Hekkert (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling,* vol. 127, pp. 221–32. DOI: 10.1016/j.resconrec.2017.09.005

Kitchener, Andrew (1993). Justice at last for the dodo. Available at https://www.newscientist.com/article/mg13918884-300-justice-at-last-for-the-dodo/

Knight, Tim (2021). Neglected species – Who cares about Kyrgyzstan's threatened tulips? Available at https://www.fauna-flora.org/news/neglected-species-cares-kyrgyzstans-threatened-tulips-2/

Kupferschmidt, Kai (2022). A wild hope. *Science,* vol. 376, No. 6598, pp. 1148–53. DOI: 10.1126/science.add3235

Kurle, Carolyn M., and others (2023). Considering humans as integral components of "nature". *Ecological Solutions and Evidence,* vol. 4, No. 1, art. e12220. pp. 1–3. DOI: 10.1002/2688-8319.12220

Lang, Jennifer M., and M. Eric Benbow (2013). Species interactions and competition. *Nature Education Knowledge,* vol. 4, No. 4. Available at https://www.nature.com/scitable/knowledge/library/species-interactions-and-competition-102131429/

Latham, Katherine (2021). How biodiversity loss is jeopardising the drugs of the future. *The Guardian*, 10 September. Available at https://www.theguardian.com/environment/2021/oct/09/how-biodiversity-loss-is-jeopardising-the-drugs-of-the-future

Leitão, Rafael P., and others (2016). Rare species contribute disproportionately to the functional structure of species assemblages. *Proceedings of the Royal Society B: Biological Sciences,* vol. 283, No. 1828, art. 20160084. pp. 1–9. DOI: 10.1098/rspb.2016.0084

Lenzner, Bernd, and others (2022). Naturalized alien floras still carry the legacy of European colonialism. *Nature Ecology & Evolution,* vol. 6, No. 11, pp. 1723–32. DOI: 10.1038/s41559-022-01865-1

Lindsey, Rebecca, and Luann Dahlman (2023). Climate Change: Global Temperature. Available at https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Lyman Kirst, Marian (2012). The power and plight of the parasite. Available at https://www.hcn.org/blogs/goat/the-power-and-plight-of-the-parasite

Mancini, Francesca, and others (2023). Invertebrate biodiversity continues to decline in cropland. *Proceedings of the Royal Society B: Biological Sciences,* vol. 290, No. 2000, art. 20230897. pp. 1–11. DOI: 10.1098/rspb.2023.0897

Markes, Sarah (2022). Understanding Species Roles in Ecosystem Survival. Available at https://blog.wcs.org/photo/2022/10/31/understanding-species-roles-in-ecosystem-survival-tanzania/

McQuade, Joseph (2019). Earth Day: Colonialism's role in the overexploitation of natural resources. Available at https://theconversation.com/earth-day-colonialisms-role-in-the-overexploitation-of-natural-resources-113995

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. Washington, D.C.: Island Press. Available at https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Miller, Rebecca M. (2013). Threatened Species: Classification Systems and Their Applications. *In Encyclopedia of Biodiversity.* Levin, Simon A. and Simon A. Levin, eds. Amsterdam, Paris: Elsevier Science. DOI: 10.1016/B978-0-12-384719-5.00415-9

Montoya, José M., Stuart L. Pimm, and Ricard V. Solé (2006). Ecological networks and their fragility. *Nature,* vol. 442, No. 7100, pp. 259–64. DOI: 10.1038/nature04927

Mora, Camilo, and others (2011). How many species are there on Earth and in the ocean? *PLoS biology,* vol. 9, No. 8, art. e1001127. 1-8. DOI: 10.1371/journal.pbio.1001127

Morrison, Beth M. L., Berry J. Brosi, and Rodolfo Dirzo (2020). Agricultural intensification drives changes in hybrid network robustness by modifying network structure. *Ecology letters,* vol. 23, No. 2, pp. 359–69. DOI: 10.1111/ele.13440

Morton, Dana N., and others (2022). Merging theory and experiments to predict and understand coextinctions. *Trends in Ecology & Evolution,* vol. 37, No. 10, pp. 886–98. DOI: 10.1016/j.tree.2022.06.004

Moura, Mario R., and Walter Jetz (2021). Shortfalls and opportunities in terrestrial vertebrate species discovery. *Nature Ecology & Evolution,* vol. 5, No. 5, pp. 631–39. DOI: 10.1038/s41559-021-01411-5

Mozer, Annika, and Stefan Prost (2023). An introduction to illegal wildlife trade and its effects on biodiversity and society. *Forensic Science International: Animals and Environments,* vol. 3, art. 100064. pp. 1–12. DOI: 10.1016/j.fsiae.2023.100064

Naeem, Shahid, and others (2016). Biodiversity and human well-being: an essential link for sustainable development. *Proceedings of the Royal Society B: Biological Sciences,* vol. 283, No. 1844, art. 20162091. pp. 1–10. DOI: 10.1098/rspb.2016.2091

Narvaez, Liliana, Sally Janzen, and Zita Sebesvari (2021). Technical Report: Chinese Paddlefish Extinction. Interconnected Disaster Risks. Bonn: United Nations University – Institute for Environment and Human Security. DOI: 10.53324/ALYR1854

O'Connor, Jack, Oscar Higuera Roa, and Caitlyn Eberle (2022). Technical Report: Vanishing vaquita. Interconnected Disaster Risks. Bonn: United Nations University – Institute for Environment and Human Security. DOI: 10.53324/ATER5245

Orie, Amarachi (2023). Scientists say they've found a direct link between planet-warming pollution and polar bear survival. Available at https://edition.cnn.com/2023/09/01/world/polar-bear-greenhouse-gas-emissions-intl-scli-climate-scn/index.html

Patel, Samir S. (2006). The Value of Small Things. Available at https://web.archive.org/web/20061019214328/http://www.seedmagazine.com/news/2006/08/the_value_of_small_things.php

Pecl, Gretta T., and others (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science,* vol. 355, No. 6332, art. eaai9214. pp. 1–11. DOI: 10.1126/science.aai9214

Pimm, S. L., and others (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, vol. 344, No. 6187, art. 1246752. pp. 1–11. DOI: 10.1126/science.1246752

Poisot, Timothée, and others (2021). Global knowledge gaps in species interaction networks data. *Journal of Biogeography,* vol. 48, No. 7, pp. 1552–63. DOI: 10.1111/jbi.14127

Polidoro, Beth A., and others (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PloS one,* vol. 5, No. 4, art. e10095. 1-10. DOI: 10.1371/journal.pone.0010095

Pörtner, Hans-Otto, and others (2021). Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. Bonn, Germany: IPBES secretariat. DOI: 10.5281/ZENODO.4659158

Reed, Thomas E., Daniel E. Schindler, and Robin S. Waples (2011). Interacting Effects of Phenotypic Plasticity and Evolution on Population Persistence in a Changing Climate. *Conservation Biology,* vol. 25, No. 1, pp. 56–63. DOI: 10.1111/j.1523-1739.2010.01552.x

Richter, B., and others (2010). Lost in development's shadow: the downstream human consequences of dams. Water Alternatives. Available at https://www.semanticscholar.org/paper/Lost-in-development%27s-shadow%3A-the-downstream-human-Richter-Postel/edc322a1a1d0e614c18206ea3fe1fad956465981

Rijsdijk, Kenneth F., and others (2015). A review of the dodo and its ecosystem: insights from a vertebrate concentration Lagerstätte in Mauritius. *Journal of Vertebrate Paleontology,* vol. 35, sup1, pp. 3–20. DOI: 10.1080/02724634.2015.1113803

Román-Palacios, Cristian, and John J. Wiens (2020). Recent responses to climate change reveal the drivers of species extinction and survival. *Proceedings of the National Academy of Sciences of the United States of America*, vol. 117, No. 8, pp. 4211–17. DOI: 10.1073/pnas.1913007117

Sanders, Dirk, and others (2018). Trophic redundancy reduces vulnerability to extinction cascades. *Proceedings of the National Academy of Sciences,* vol. 115, No. 10, pp. 2419–24. DOI: 10.1073/pnas.1716825115

Sanjurjo-Rivera, Enrique, and others (2021). An Economic Perspective on Policies to Save the Vaquita: Conservation Actions, Wildlife Trafficking, and the Structure of Incentives. *Frontiers in Marine Science,* vol. 8, art. 644022. pp. 1–20. DOI: 10.3389/fmars.2021.644022

Savidge, Julie A. (1987). Extinction of an Island Forest Avifauna by an Introduced Snake. *Ecology,* vol. 68, No. 3, pp. 660–68. DOI: 10.2307/1938471

Schleuning, Matthias, and others (2016). Ecological networks are more sensitive to plant than to animal extinction under climate change. *Nature Communications,* vol. 7, art. 13965. pp. 1–9. DOI: 10.1038/ncomms13965

Scholte, Samantha S. K., and others (2016). Public Support for Wetland Restoration: What is the Link With Ecosystem Service Values? *Wetlands,* vol. 36, No. 3, pp. 467–81. DOI: 10.1007/s13157-016-0755-6

Seidensticker, John (1986). Large carnivores and the consequences of habitat insularization: ecology and conservation of tigers in Indonesia and Bangladesh. In *Cats of the World: Biology, Conservation and Management.* Miller, S. D. and D. D. Everett, eds. Washington, D.C.: National Wildlife Federation:

__________ (1987). Bearing witness : observation on the extinction of Panthera tigris balica and Panthera tigris sondaica. Tigers of the World : The Biology, Biopolitics, Management, and Conservation of an Endangered Species, pp. 416–26. Available at https://cir.nii.ac.jp/crid/1570009751320272512

Sherwood, Steven C., and Matthew Huber (2010). An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Sciences of the United States of America,* vol. 107, No. 21, pp. 9552–55. DOI: 10.1073/pnas.0913352107

Sodhi, Navjot S., Barry W. Brook, and Corey J. A. Bradshaw (2009). Causes and Consequences of Species Extinctions. In *The Princeton Guide to Ecology.* Levin, Simon A., ed. Princeton, New Jersey: Princeton University Press.

Somero, George N. (2011). Comparative physiology: a “crystal ball” for predicting consequences of global change. *American Journal of Physiology. Regulatory, Integrative and Comparative Physiology,* vol. 301, No. 1, R1-14. DOI: 10.1152/ajpregu.00719.2010

Steffen, Will, and others (2005). *Global Change and the Earth System: A Planet Under Pressure.* Global Change - The IGBP Series. Berlin: Springer Berlin Heidelberg

Strona, Giovanni (2022). *Hidden Pathways to Extinction.* Fascinating Life Sciences. Cham: Springer International Publishing

Strona, Giovanni, and Corey J. A. Bradshaw (2018). Co-extinctions annihilate planetary life during extreme environmental change. *Scientific Reports,* vol. 8, No. 1, art. 16724. pp. 1–12. DOI: 10.1038/s41598-018-35068-1

Taylor, Barbara, and Lorenzo Rojas-Bracho (2023). Vaquitas continue to surprise the world with their tenacity – IUCN – SSC Cetacean Specialist Group. Available at https://iucn-csg.org/vaquitas-continue-to-surprise-the-world-with-their-tenacity/

Telesca, Jennifer E. (2017). Accounting for Loss in Fish Stocks: A Word on Life as Biological Asset. *Environment and Society,* vol. 8, No. 1, pp. 144–60. DOI: 10.3167/ares.2017.080107

Samuel T. Turvey, ed. (2009). *Holocene extinctions.* Oxford biology. Oxford, New York, Auckland: Oxford University Press

Tylianakis, Jason M., and others (2008). Global change and species interactions in terrestrial ecosystems. *Ecology Letters,* vol. 11, No. 12, pp. 1351–63. DOI: 10.1111/j.1461-0248.2008.01250.x

U.S. National Park Service (2023). Kelp Forest Community Monitoring. Available at https://www.nps.gov/im/medn/kelp-forest-communities.htm

United Nations (2023a). Beyond borders: Why new 'high seas' treaty is critical for the world. Available at https://news.un.org/en/story/2023/06/1137857

__________ (2023b). UNESCO World Heritage Sites often 'last line of defence against extinction'. Available at https://news.un.org/en/story/2023/08/1140267

United Nations Statistics Division (2020). Sustainable Development Goal 15 - Life on land. Available at https://unstats.un.org/sdgs/report/2020/goal-15/

United Nations University – Institute for Environment and Human Security (2021). Interconnected Disaster Risks 2020/2021. O'Connor, Jack; Eberle, Caitlyn; Cotti, Davide; Hagenlocher, Michael; Hassel, Jonathan; Janzen, Sally; Narvaez, Liliana; Newsom, Amy; Ortiz Vargas, Andrea; Schütze, Simon; Sebesvari, Zita; Sett, Dominic; and Yvonne Walz (authors). Bonn: United Nations University - Institute for Environment and Human Security. DOI: 10.53324/NYHZ4182

__________ (2022). Interconnected Disaster Risks 2021/2022. O'Connor, Jack; Eberle, Caitlyn; Narvaez, Liliana; Higuera Roa, Oscar; Oakes, Robert; Sparkes, Edward; Sebesvari, Zita (authors). Bonn: United Nations University – Institute for Environment and Human Security. DOI: 10.53324/USDG7258

Urban, Mark C. (2015). Accelerating extinction risk from climate change. *Science,* vol. 348, No. 6234, pp. 571–73. DOI: 10.1126/science.aaa4984

Valenzuela-Fernández, Leslier, and Manuel Escobar-Farfán (2022). Zero-Waste Management and Sustainable Consumption: A Comprehensive Bibliometric Mapping Analysis. *Sustainability,* vol. 14, No. 23, art. 16269. pp. 1–24. DOI: 10.3390/su142316269

Valiente-Banuet, Alfonso, and others (2015). Beyond species loss: the extinction of ecological interactions in a changing world. *Functional Ecology,* vol. 29, No. 3, pp. 299–307. DOI: 10.1111/1365-2435.12356

Vörösmarty, C. J., and others (2010). Global threats to human water security and river biodiversity. *Nature,* vol. 467, No. 7315, pp. 555–61. DOI: 10.1038/nature09440

Walz, Yvonne, and others (2021). Disaster-related losses of ecosystems and their services. Why and how do losses matter for disaster risk reduction? *International Journal of Disaster Risk Reduction,* vol. 63, art. 102425. pp. 1–16. DOI: 10.1016/j.ijdrr.2021.102425

Wessing, Robert (1995). The Last Tiger in East Java: Symbolic Continuity in Ecological Change. *Asian Folklore Studies,* vol. 54, No. 2, p. 191. DOI: 10.2307/1178941

Whiteman, Noah K., and Patricia G. Parker (2005). Using parasites to infer host population history: a new rationale for parasite conservation. *Animal Conservation,* vol. 8, No. 2, pp. 175–81. DOI: 10.1017/S1367943005001915

Wiles, Gary J., and others (2003). Impacts of the Brown Tree Snake: Patterns of Decline and Species Persistence in Guam's Avifauna. *Conservation Biology,* vol. 17, No. 5, pp. 1350–60. DOI: 10.1046/j.1523-1739.2003.01526.x

Williams, David R., and others (2021). Proactive conservation to prevent habitat losses to agricultural expansion. *Nature Sustainability,* vol. 4, No. 4, pp. 314–22. DOI: 10.1038/s41893-020-00656-5

Wilson, Brett, and others (2021). Central Asian wild tulip conservation requires a regional approach, especially in the face of climate change. *Biodiversity and Conservation,* vol. 30, No. 6, pp. 1705–30. DOI: 10.1007/s10531-021-02165-z

Wilson, Brett (2022). Around 50% of Central Asian tulips are Threatened with extinction. Available at https://tulipconservation.wordpress.com/2022/12/09/around-50-of-central-asian-tulips-are-threatened-with-extinction/

Winter, Marten, and others (2009). Plant extinctions and introductions lead to phylogenetic and taxonomic homogenization of the European flora. *Proceedings of the National Academy of Sciences,* vol. 106, No. 51, pp. 21721–25. DOI: 10.1073/pnas.0907088106

World Wildlife Fund (2021). One-third of freshwater fish face extinction and other freshwater fish facts. Available at https://www.worldwildlife.org/stories/one-third-of-freshwater-fish-face-extinction-and-other-freshwater-fish-facts

__________ (2022). Living Planet Report 2022 - Building a nature positive society. Gland, Switzerland: World Wildlife Fund. Available at https://wwflpr.awsassets.panda.org/downloads/lpr_2022_full_report.pdf

Cover Image Credit: A close-up of a northern sea otter (Enhydra lutris kenyoni) in Kodiak Harbor, Kodiak Island, Alaska. © WWF-US / Keith Arnold

https://doi.org/10.53324/ZQFY4171

e-ISBN:978-3-944535-82-1
e-ISSN: 2304-0467