Agricultural Research Reports
https://journals.pagepal.org/index.php/ARR
ISSN (Online), 3106-003X; (Print), 3106-0021
https://doi.org/10.54219/arr.01.01.2023.314

Unraveling Extinction: Causes and Cascading Effects on Ecosystem

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Article Info

Keywords:
Biodiversity, extinction, habitat destruction, climate change, ecosystem, environment

Date:
Received: 8 April 2023
Accepted: 20 July 2023
Published: 30 December 2023

Volume: 04 (02), 2023

Abstract

The ongoing global biodiversity crisis is characterized by an alarming rise in extinction rates, primarily driven by anthropogenic activities, including habitat destruction, climate change, overexploitation, and the introduction of invasive species. This review critically examines the multifaceted causes of species extinction and highlights the cascading effects that can result from the loss of a single species, ultimately leading to widespread ecological disruption. Secondary extinctions, or extinction cascades, occur through complex trophic and mutualistic interactions, which destabilize community dynamics and ecosystem functions. The article explores both structural and dynamical perspectives of extinction risk, highlighting the importance of network position, interaction strength, and functional redundancy—the existence of several species that carry out comparable ecological tasks, protecting ecosystem services against the extinction of particular species. Case studies from terrestrial and marine ecosystems illustrate the real-world implications of these patterns. Additionally, emerging modeling tools and predictive frameworks are discussed, such as compensatory perturbation theory, which calls for calculated actions to counteract the consequences of species loss and stabilize ecosystems. Addressing the extinction crisis requires an integrated, interdisciplinary approach that combines ecological theory, advanced modeling, and inclusive conservation policy. This review underscores the urgency of protecting interconnected species networks to safeguard ecosystem resilience and long-term environmental stability.

1 Introduction

Evolution and natural selection are regular processes that include extinction. A series of secondary extinctions, for instance, might result from a species' extinction in complex ecological ecosystems where animals display a wide range of trophic and competing tactics (Borrvall *et al.,* 2000; Dunne *et al.,* 2002; Ebenman *et al.,* 2004; Koh *et al.,* 2004; Montoya *et al.,* 2006; Paine, 1966; Petchey *et al.,* 2004; Pimm, 1980; Sole and Montoya, 2001). These secondary extinctions happen when a primary extinction makes a community dynamically unstable or impractical (a consumer can have no prey). A process of relaxation (loss or alteration of an organism's ecological niche or lifestyle that results in the loss of previously necessary structures, functions, or selective limitations, particularly when reverting to a simpler or more ancestral way of existence) (Altermann, 2012; Pocheville, 2014) known as secondary extinctions produces a viable and long-lasting colony. The removal of the keystone sea star Pisaster ochraceus from intertidal zones led to the domination of mussels and the local extinction of several other species (Paine, 1966). Similarly, the disappearance of sea otters from kelp forest ecosystems caused trophic collapse and loss of

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biodiversity (Springer *et al.,* 2003). In both cases, the extinction of one species led to a significant change in the composition of the community, which included the extinction of numerous other species. One of the main causes of biodiversity loss both now and in the future may be these "secondary extinctions," also known as "coextinctions," which can follow a primary extinction (Koh *et al.,* 2004; Montoya *et al.,* 2006).

Extinction cascades can result from both top-down (predator loss) and bottom-up (primary producer disruption) pathways, and are strongly influenced by ecosystem traits such as species richness, functional diversity, and trophic structure (Fowler, 2010). The existence of several species in an ecosystem that perform comparable ecological functions is known as functional redundancy, and it contributes to the stability of the ecosystem even in the event that some species become extinct (Royalty and Steen, 2021). Conversely, compensatory perturbation theory outlines a modeling framework that stabilizes ecological networks by reducing the cascading impacts of an initial extinction through the intentional removal or suppression of additional species (Sahasrabudhe and Motter, 2011). Extinction vortices are self-reinforcing population decline processes in tiny, isolated populations where the probability of extinction is accelerated by interactions between genetic, demographic, environmental, and stochastic factors. A downhill spiral toward extinction results from detrimental effects such inbreeding depression, loss of genetic diversity, decreased reproductive success, and greater susceptibility to random events that intensify as population size declines (Blomqvist *et al.,* 2010). The recent widespread declines in insect diversity and abundance further emphasize the urgency of this issue, as their loss threatens the long-term functioning and stability of entire ecosystems (Kehoe *et al.,* 2021). Thus, there is a need to study extinction cascades for the management of ecosystems and the conservation of environment.

With an emphasis on extinction cascades and the underlying mechanisms behind them, this review attempts to investigate the main causes and ecological effects of species extinction. The review emphasizes how interconnected species networks react to early perturbations by looking at both natural and anthropogenic influences. In order to lessen the loss of biodiversity, it also highlights the significance of prediction models and coordinated conservation methods, as well as the existing research gaps.

2 Primary Causes of Extinction

The extinction is controlled by a decline in biological variety due to habitat loss, with the resulting fragmentation of the remaining habitat. Because separate gatherings of individuals will vanish much as populations in an interconnected network. A species' regional decline in the face of habitat degradation and fragmentation might simulate a collapse of metapopulation dynamics (McCallum and Dobson, 2002; Simberloff, 1995). Dominant species are frequently exempt from threat of species extinction, due to their abundance in the undisturbed remnants left over after destruction (Tilman *et al.,* 1994). The primary causes of extinction are outlined in Table 1.

2.1 Anthropogenic Factors

The main cause of extinctions in the modern era is still anthropogenic pressures. These include the introduction of invasive species, overexploitation, habitat degradation, and climate change.

2.1.1 Invasive species

The consensus among ecologists, environmental biologists, and managers is that non-native species invasions constitute a major factor in the recent extinction of species (Fritts and Rodda, 1998; Wilcove *et al.,* 1998). Since invasive organisms are changing terrestrial and aquatic populations all over the world, the spread and introduction of non-native species has turned into a global ecological and conservation crisis. Extinction of species and biodiversity loss are both significant continuing crises. Many environmentalists and academics think that invasions along with extinctions are closely related since native species reductions frequently happen concurrently and in the same location as non-native species invasions (Gurevitch and Padilla, 2004).

2.1.2 Overexploitation

A species' extinction may happen suddenly and directly if habitat damage or population overexploitation is extreme (Brook *et al.,* 2008). By influencing species richness, abundance, and extinction order, habitat loss seems to impair ecosystem functioning. Rapid functional loss was a result of large-bodied bee and beetle species being the most

Table 1. Extinction, primary cause, and its effects on ecology

Extinction cause	Type of extinction cause	Example	Impact on ecology	Geographic scope	References
Species invasion	Anthropogenic	Cane toads, Zebra mussels,	Introduce new illnesses and predators and compete with the native population	Global	(Chinchio *et al.*, 2020; Feit and Letnic, 2015)
Overexploitation	Anthropogenic	Overhunting, overfishing	Direct population Decline has an impact on community balance and reproductive potential	Global/Local	(Hogue and Breon, 2022; Rosser and Mainka, 2002)
Degradation of habitats	Anthropogenic	Deforestation, agriculture, urbanization	Decreases population size, separates species, and messes with the dynamics of meta-populations	Global	(Tian *et al.*, 2011; Hanski, 2011)
Changing climate	Anthropogenic	Ocean acidification, Global warming	Changes the ranges of species, interferes with reproduction, and modifies trophic relationships	Global	(Change, 2022; Harrington *et al.*, 1999)
Natural Disasters	Natural	Volcanic outbreaks, asteroid effects, cyclones	Unexpected habitat loss and population declines	Local/Regional	(Hussain *et al.*, 2020)
Infectious diseases	Natural/ Anthropogenic	Chytridiomycosis in amphibians, DFTD in Tasmanian devils	Host population collapse and changed community dynamics	Global/Local	(Daszak *et al.*, 2000; Lederberg, 1993)

functionally efficient and prone to extinction (Larsen *et al.*, 2005).

2.1.3 Degradation of habitats

With little regard for the environmental services that have disappeared as a result, some irrevocably, the majority of rivers have been completely restructured, the oceans have been drastically changed and exhausted, coral reefs are on the verge of becoming non-functional ecosystems, and more than half of the land is used for crop and livestock agriculture. Our ecosystem base will be disrupted in new ways by climate change, which is mostly caused by human-generated greenhouse gas emissions. The behaviors of species are changing and upsetting long-standing mutualisms (Mooney *et al.*, 2009; Trisos *et al.*, 2020).

The primary driver of species extinction is habitat degradation (Tilman *et al.*, 1994). The main causes of habitat loss and the threats to the survival of the greatest number of species listed by the International Union for the Conservation of Nature (IUCN) are agricultural growth, commercial and residential development (roads, housing, etc.), and forest loss (Veach *et al.*, 2017). Wildlife populations, particularly those of mammalian carnivores, are seriously threatened by urbanization (Riley *et al.*, 2003). The major threat to penguin populations is pollution, which comes from industrial processes and agricultural runoff (Trathan *et al.*, 2015). An extinction vortex is created when poaching, habitat fragmentation, and a lack of enough habitat combine negatively (Burkey and Reed, 2006). Anthropogenic climate change will have a significant role in the extinction of species. Studies demonstrating the effects of climatic oscillations and those demonstrating declines in abundance linked to climate change both revealed strikingly comparable trends. Documented population losses and extinctions linked to climate change are largely caused by shifting species relationships (Cahill *et al.*, 2013; Sattar *et al.*, 2021).

Apart from decreasing the amount of habitat, fragmentation separates populations into smaller, disjointed areas, limiting gene flow and resulting in genetic bottlenecks (Fahrig and systematics, 2003). These isolated populations experience a decline in genetic diversity and a rise in inbreeding depression over time, which can limit their ability to adjust to changing environments, diminish reproductive fitness, and make them more susceptible to disease (Spielman *et al.,* 2004). Small populations may be driven into an extinction vortex by this genetic degradation. Studies on landscape ecology have shown how important habitat connectedness is to preserve genetic exchange across populations. For instance, corridors and matrix quality have a major impact on species dispersal and long-term survival, according to metapopulation models and landscape resistance assessments (Baum *et al.,* 2004). Therefore, it is crucial to combine genetic conservation and spatial planning to reduce the danger of extinction in fragmented ecosystems.

2.1.4 Global climate change

Ecosystems, biological communities, and species worldwide are being impacted by the changing global climate. Numerous environmental changes linked to a warming global climate, such as higher average and potentially extreme temperatures, intense dry and wet spells, lower ocean pH, and changed salinity dynamics in estuaries, may make organisms more vulnerable to chemical toxicity. Furthermore, chemical exposures may make it more difficult for species to adapt to the shifting climate and its changing environmental conditions (Noyes and Lema, 2015). Potential losses in freshwater fish species in terms of greenhouse gas emissions are caused by several variables (Hanafiah *et al.,* 2011).

Climate and biodiversity are related to one another. Human activity is the primary source of climate change. The greenhouse effect is caused by an increase in greenhouse gases due to human activity. Thermal optima move towards high latitudes and high altitudes as the atmosphere's temperature rises. Increases in global precipitation have an impact on wildlife as well. Through trophic interaction, biomass production, and hydrological balance, climate change disrupts the dynamic state. The behavior, reproduction, movement, and foraging of wildlife are all directly impacted by changing climate regimes (Sattar *et al.,* 2021).

Additionally, ecological feedback loops triggered by climate change amplify its own effects. For example, rising temperatures and protracted droughts are causing wildfires to occur more frequently and with greater intensity, which not only obliterates native vegetation but also disturbs the landscape and makes it more vulnerable to invasion by exotic species. In a reinforcing cycle, these intruders frequently outcompete local plants and animals, further diminishing biodiversity and changing fire regimes. Furthermore, the absorption of excess atmospheric CO_2 into saltwater results in ocean acidification, which lowers pH levels and interferes with the creation of calcium carbonate, which is necessary for the survival of many marine creatures, including corals, mollusks, and certain plankton (Fabry *et al.,* 2008; Hoegh-Guldberg *et al.,* 2007). Marine food webs are weakened, biodiversity is decreased, and ecosystem services like fisheries and carbon sequestration are hampered by this chemical change. These feedback loops collectively show how interrelated and self-reinforcing mechanisms in climate change increase the likelihood of extinction.

2.2 Natural Factors

2.2.1 Geological events

The impact of the changing climate on biodiversity in the future has been the subject of numerous research (Bellard *et al.,* 2012). Spatially localized processes like cyclones and deforestation pose a serious threat to the extinction of every species with a very limited range (Simberloff, 1995). The frequency of hurricanes is rising, and there are more significant precipitation and temperature anomalies, indicating that extreme weather conditions are happening more frequently. All living things will be significantly impacted by such harsh climatic conditions since they will increase the likelihood of failure to reproduce and decrease adult survival (Moreno and Møller, 2011; Parmesan *et al.,* 2000). Habitat destruction and deforestation have been attributed to a variety of sources. Forest fires, droughts, floods, exotic animal populations, and climate change are all examples of natural causes of deforestation (Bodo *et al.,* 2021).

2.2.2 Disease outbreaks

Theoretically, invasive infectious illnesses have the potential to wipe out host populations, especially if there are reservoir species or if the disease spreads according to frequency. Few ancient extinctions can be conclusively attributed to disease, but a number of contemporary outbreaks, like Tasmanian devil facial tumor disease (DFTD) and chytridiomycosis in amphibians, represent serious extinction concerns. Importantly, anthropogenic factors including habitat loss, climate change, and the global wildlife trade frequently contribute to the formation and spread of these diseases, even though they are caused by naturally occurring viruses. For example, although having a fungal origin, chytridiomycosis is thought to have spread throughout the world due to human-mediated amphibian migration. This blurring of the lines between man-made and natural environments emphasizes how intricately human activity increases the risk of disease-driven extinction (Daszak *et al.,* 1999; McCallum, 2012). Unusually high rates of infectious disease outbreaks are occurring in wildlife populations (Epstein, 2001; Harvell *et al.,* 1999; Harvell *et al.,* 2002). Emerging infectious diseases (EIDs) are caused by parasites and pathogens that have lately become more common, occupied host species, or spread geographically; they may also be caused by newly developed agents or newly found parasites and pathogens (Daszak *et al.,* 2000; Lederberg, 1993). Considerations that disease transmission may be a major factor in the extinction of species have been raised by the variety of EIDs that affect wildlife and the worry that outbreaks would become more frequent in the future (Daszak *et al.,* 2000; Harvell *et al.,* 2002; Holmes, 1996). Infectious diseases can reduce host ranges, influence community dynamics, and spread to local populations (Daszak *et al.,* 1999; Lafferty, 2003; McCallum and Dobson, 1995; Walsh *et al.,* 2003). According to epidemiological theory, a species should only become extinct due to infectious diseases in certain situations, most frequently when the pre-epidemic population size is tiny, or reservoir hosts are present, in an abiotic environment (De Castro and Bolker, 2005).

3 Mechanisms of Extinction Cascades

Conceptual representation of primary drivers of extinction and their consequences on ecosystem function and services are highlighted in Figure 1. Major anthropogenic and natural drivers trigger functional losses such as extinction cascades, trophic imbalances, and mutualistic breakdowns. These disruptions lead to reduced ecosystem services including pollination, decomposition, pest control, and water quality.

Extinction cascades occur when a single species' extinction spreads throughout interdependent ecological networks, upending the structure of communities. In certain situations, the removal or control of particular mitigating species (green node) can stop additional cascading losses, while in other cases, the extinction of a triggering species (red node) can cause the sequential loss of dependent species

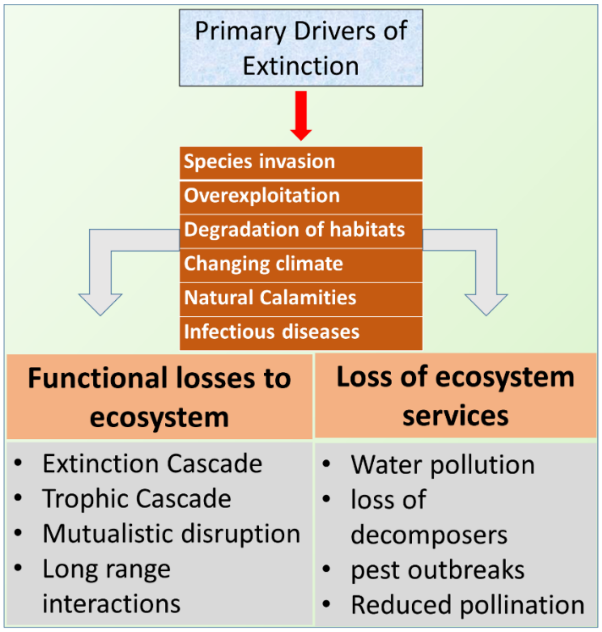

Figure 1. Showing the primary drivers of the extinction cascade (Author's compilation)

(orange nodes), as seen in Figure 2. Whereas dashed arrows show compensating or stabilizing effects within the network, solid arrows show direct trophic interactions. In order to anticipate and lessen secondary extinctions, it is crucial to identify important species and interaction routes, as this network-based perspective emphasizes.

3.1 Trophic cascades

The actions of one native species at the top of the food chain significantly altered the species' composition and physical characteristics. Their activities plus abundance determine the community's integrity and its unwavering persistence across time. These individual populations constitute the foundation of the community's structure (Paine, 1969). Keystone species often drive trophic cascades by exerting significant top-down control on community structure, as evidenced by the removal of the sea star Pisaster ochraceus, which led to mussel overdominance and diminished intertidal biodiversity. When some rocky intertidal predators, like the starfish Pisaster, were experimentally removed, one or two sessile-in-nature species (mussels) almost entirely dominated the substrate, significantly reducing the diversity of species. Two requirements determined the keystone predator's significance in this and other situations (Paine, 1969; Pimm, 1980). The

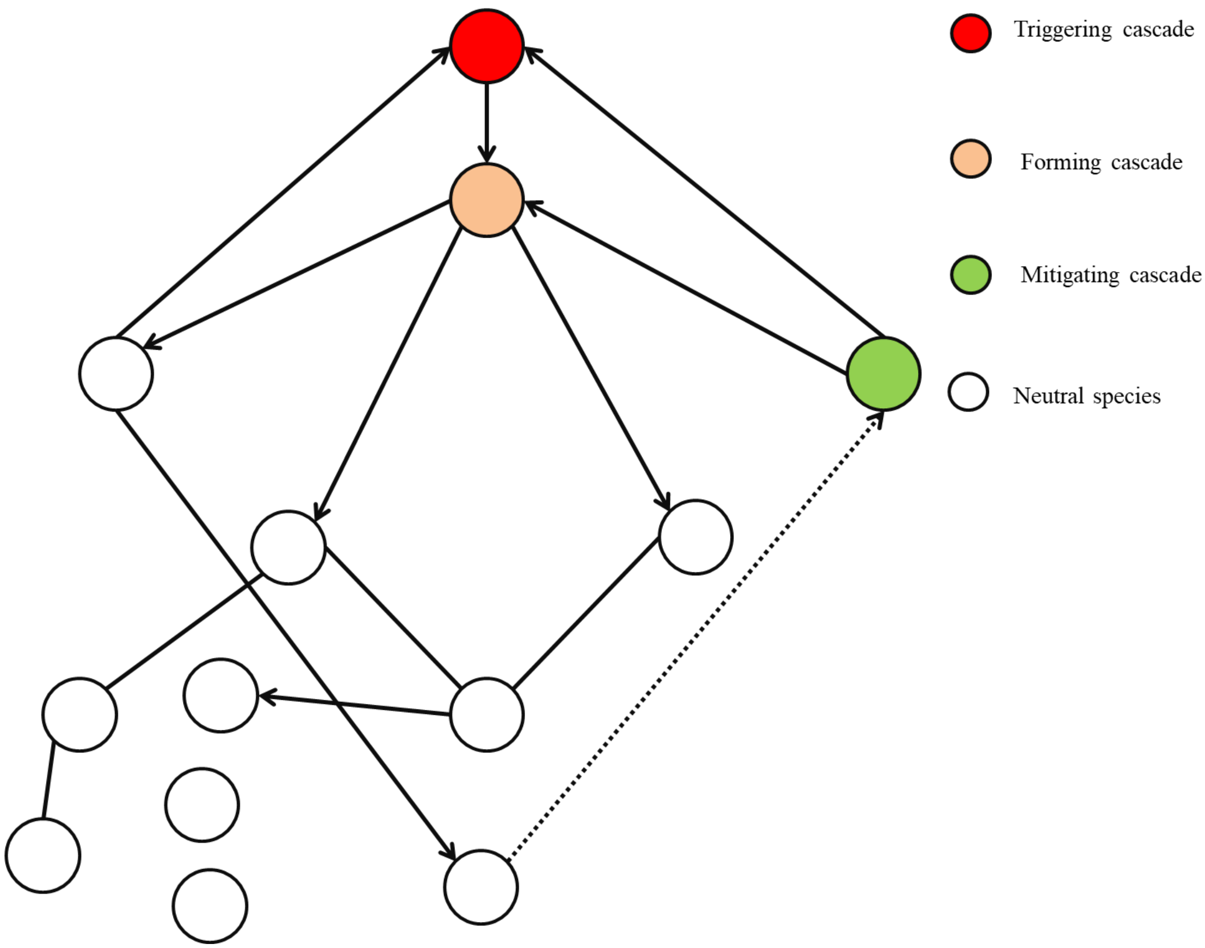

Figure 2. A network diagram demonstrating extinction cascades in food webs of ecology
Adapted from Sahasrabudhe and Motter, 2011

consumer was able to keep other species out of society by either predating or competing with them, and the predator ate selectively and managed the abundance of a primary consumer. Therefore, the early meaning was essential that keystone predator is significant because it regulates the numbers of significant predator species or competitors. It is worthwhile to investigate the apparent contradiction between the keystone-species hypothesis and food-web theory. The two conceptualizations suggest distinct community structure patterns, necessitating distinct conservation approaches. Any attempts to preserve a small number of keystone species will unavoidably fail to protect the majority of species that are of equal significance (Mills *et al.,* 1993).

3.2 Mutualistic disruptions

Plants and their pollinators (two tiers of the food web), engage mutually during pollination (Carvalheiro *et al.,* 2008; Chan and Raine, 2023; Jordano, 1987). Significant amounts of pollination services are provided to crops by wild pollinators (Garibaldi *et al.,* 2011), but little is known about the specifics of these connections (such as the diversity or number of pollinators needed to deliver sufficient pollination) (Kovács-Hostyánszki *et al.,* 2017). Global food security is in risk due to pollination deficiencies (Tscharntke, 2021).

3.3 Structural vs. dynamic extinction risks

Compared to species participating in weaker or more dispersed interactions, those directly involved in strong trophic or mutualistic relationships are at a substantially higher risk of going extinct. It's interesting to note that the probability of these indirect extinctions tends to decline with an increase in species interactions (links), indicating that network complexity acts as a buffer. These results show that interactions' structural position and directional flow within the network, as well as their strength, determine extinction risk. These factors can significantly impact a species' susceptibility to cascading extinctions (Jonsson et al., 2006).

3.4 Long-range interactions

Food-web disruptions brought on by invading species, habitat degradation, overexploitation, and climate change frequently result in an initial loss of species that sets off a chain reaction of extinction cascades, making ecosystem conservation efforts extremely difficult. The simultaneous eradication or population reduction of other particular species can frequently make up for the extinction of one species. Long-range interactions that are not apparent from local predator-prey relationships are often involved in these compensating perturbations (Sahasrabudhe and Motter, 2011).

3.5 Historical Examples

Particularly for forest specialists, significant rates of recorded and inferred extinctions were discovered, with the largest percentage of extinct taxa (34–87%) reported in fish, birds, mammals, and butterflies. In vascular plants, phasmids, decapods, amphibians, and reptiles, observed extinctions were typically lower, but inferred losses were frequently higher (5–80%). More than half of Singapore's remaining native biodiversity is currently found in forest reserves, which make up just 0.25 percent of the country's total territory (Brook *et al.,* 2003).

Worldwide population declines are a clear result of chronic overfishing, but the indirect environmental repercussions brought on by predator elimination from oceanic food webs are yet unknown. Over the past 35 years, 12 out of 14 of these prey species have increased in coastal northwest Atlantic habitats, while the abundances of all 11 great sharks that eat other elasmobranchs (rays, skates, and small sharks) have decreased. The cownose ray, whose increased predation on its bay scallop prey was enough to end a century-long scallop fishery, is the first to feel the effects of this community reconfiguration (Myers et al., 2007).

All around the world, systematic harm to sharks and the trade in their fins occurs. While this is bad for each shark's health, it is considerably more harmful to the ecosystems where these keystone species are essential to its survival (Haase, 2022). Human activities like habitat degradation and overhunting have harmed several major apex predator populations worldwide in recent times. The stability of ecosystems and the dynamics of populations and communities can be significantly impacted by the loss or decline of top predator populations, according to studies conducted in a range of habitats. We do not yet fully understand what would happen to coastal areas if huge top predators are exterminated or significantly reduced in number, though, because there are comparatively few research on their involvement in coastal ecosystems (William, 2013).

3.6 Contemporary Examples

During the decline in sea otter density in Prince William Sound, Alaska, during the 1989 Exxon Valdezoil disaster, interactions among sea urchins (Strongylocentrotus droebachiensis), kelp, and sea otters (Enhydra lutris) were examined. The oil disaster decreased sea otter numbers near northern Knight Island, a heavily contaminated section of the sound, by at least 50%. From 1995 to 1998, the quantity was projected to be 66% lower than it was in 1973. Larger sea urchins were found in proportion to lower sea otter concentrations (Dean *et al.*, 2000). Ocean warming worsens kelp forest collapse in addition to trophic disruption by boosting the spread of warm-water herbivores, increasing thermal stress, and decreasing food availability—all of which impair kelp resilience and growth (Wernberg, 2021). Although seagrasses are one of the best ecosystems on Earth for storing carbon, their global decrease puts the carbon that they have acquired over geological eras at danger. Sea urchin overgrazing of seagrass is one factor contributing to this worldwide loss (Carnell *et al.*, 2020). In modern seagrass systems, sea urchins are among the most prevalent seagrass macro-grazers. Their grazing rates can occasionally outpace the rates at which seagrass grow; this is known as overgrazing. Overgrazing has been identified as one of the main risks to tropical and subtropical seagrasses due to the documented rise in overgrazing occurrences that coincide with the loss of seagrass-associated ecosystem services (Eklöf *et al.*, 2008).

The tragic fate of the Northern White Rhinoceros is a striking example of a terrestrial species stuck in an extinction vortex. By the 2020s, there were just two females left, both of whom were unable to reproduce naturally, after the population had fallen from several thousand in the 1960s due to poaching and habitat destruction. Due to a drastically reduced genetic variety brought on by a critically tiny population, the species was unable to adjust to changes in its habitat or threats from illness (Choudhury and Banerjee, 2022).

Once found in southern Oregon and northern California, the Franklin's Bumblebee (*Bombus franklini*) is thought to be extinct because it hasn't been sighted since 2006. Due to the species' incredibly limited distribution, habitat loss, and disease transmission from commercial bees, it is possible that it will go extinct. Its disappearance serves as a reminder of how vulnerable specialized and localized pollinator species are (Franklin, 2014).

The survival of many natural ecosystems as well as the agricultural economy can both profit from the significant ecological service that solitary bees and other wild pollinators provide. However, the populations and ranges of many solitary bees are declining, which is leading to a general loss in pollinator species richness in many regions. Although a number of interrelated variables, such as increased pesticide use, climate change, and infections, have been linked to this decline, habitat loss continues to be one of the main causes. Many bee species now have fewer options for suitable nesting sites and floral diversity due to the extensive conversion of natural habitats into agricultural landscapes (Kline and Joshi, 2020).

4 Predictive Models and Mitigation Strategies

4.1 Network-based approaches

The bulk of secondary extinctions in food webs can be captured by a Bayesian network technique without the requirement to monitor population dynamics. With binary data, where each resource has the same relevance, and quantitative data, where resources are weighted by their importance, the Bayesian network technique can account for various extinction responses. Though they presume fixed, binary linkages and frequently miss uncertainty or variability in species interactions, traditional food-web models offer a simple and intuitive portrayal of ecological interactions. A more adaptable, probabilistic framework that enables the incorporation of uncertainty, indirect effects, and missing data is provided by Bayesian networks, on the other hand. They can facilitate scenario analysis, dynamic learning, and evidence-based decision-making in conservation and ecosystem management, which makes them especially useful in complex or data-poor ecosystems. Bayesian techniques are a significant improvement over static models for comprehending and forecasting food web dynamics as ecological concerns grow more complicated (Eklöf *et al.*, 2013).

4.2 Compensatory perturbations

A paradoxical consequence that hasn't been studied in complicated food webs is that the extinction of one species can frequently be offset by the simultaneous eradication or population suppression of other specific species. Long-range interactions that are not apparent from local predator-prey relationships are often involved in these compensating perturbations. In many instances, it is discovered that even the early eradication of a species that would later become extinct greatly lowers the number of cascading extinctions. These compensating perturbations only take advantage of the system's resources and show how predictive models and human intervention can be used to manage ecosystems. While they both support ecosystem stability, compensating disturbances and ecological redundancy work in essentially distinct ways. A natural, passive defense based on biodiversity, ecological redundancy allows functionally similar species to protect ecosystems from the extinction of individual species. Conversely, compensating perturbations are proactive, frequently human-mediated measures intended to take advantage of ecological relationships, including trophic cascades or competitive dynamics, in order to bring the ecosystem back into equilibrium after a disruption or unanticipated collapse (Sahasrabudhe and Motter, 2011).

4.3 Restoration strategies

When a keystone predator (*Scylla serrata*) was reintroduced, grazing on a fundamental plant (*Scylla mariqueter*) decreased and its density grew by 360 percent. Consumptive effects that decreased grazer abundance and non-consumptive impacts that prevented grazers from herborizing were the main drivers of Scylla's beneficial effects on Scirpus. These findings show that the restoration of foundation species can be significantly improved by integrating keystone predators in restoration plans, taking into account both their consumptive and non-consumptive impacts (Murie and Bourdeau, 2019). In 1995, gray wolves (*Canis lupus*), which had been extinct for about 70 years, were reintroduced in Yellowstone National Park, marking one of the most well-known keystone species restoration achievements (Nemeth, 2012).

4.4 Challenges in conservation

The conservation of biodiversity in the face of climate change uncertainty poses particular difficulties that need for careful management techniques (Conroy *et al.,* 2011). Numerous mammal, avian, reptilian, and amphibian species are among the distinctive and varied faunal biodiversity found in the Himalayan region. However, a number of modern activities and natural occurrences are posing serious dangers and challenges to this biodiversity. Conservation triage is an essential and strategic change from the idealistic objective of rescuing all species to a pragmatic, impact-driven paradigm of prioritization, despite its emotional and ethical complexity. Triage allows conservationists to maximize ecological returns on limited investments by concentrating efforts on species and habitats that have the highest probability of persisting or that offer disproportionate ecological, cultural, or economic value. This strategy, far from being a sign of surrender, recognizes the gravity and urgency of the situation and seeks to maintain functional biodiversity, stabilize ecosystems, and stop cascade losses in a fast-changing climate. In the face of environmental uncertainty around the world, effective triage provides a way forward for resilient, future-focused conservation when it is driven by open criteria, flexible management, and ethical concern (Wilson and Elizabeth, 2016).

5 Research Gaps and Future Directions

Numerous interrelated factors, such as habitat availability, population dynamics, and ecological interactions, influence how species respond to climate change; nevertheless, existing extinction risk models frequently fall short of capturing these intricacies (Keith *et al.,* 2008). The accuracy of many models is still limited, especially for taxa that are vulnerable to climate change, by their lack of integration with high-resolution, species-specific climate projections. Future studies should concentrate on integrating dynamic climate scenarios, including SSPs and RCPs, into mechanistic models that also take adaptive capacity, phenological shifts, and habitat fragmentation into consideration. This comprehensive method will promote focused conservation efforts and improve the forecasting ability of extinction assessments (Fan *et al.,* 2023).

Despite their critical roles in soil structure, nutrient cycling, and host health, microbial communities are frequently ignored in current extinction-cascade models. There are gaps in our knowledge of the co-extinction hazards of host-associated microbiota, the thresholds of microbial diversity loss, and the feedback loops that may hasten species decline because the majority of research focusses on interactions between plants and animals. Future models should incorporate microbial dynamics using network ecology and meta-omics to increase ecological accuracy and allow microorganisms to be included in multitrophic systems. Microbial keystones can be found through manipulative research, and indicators such as dwindling nitrifier diversity may be used as collapse warning signs. Furthermore, probiotics and soil inoculate are examples of microbiome-based therapies that may present viable methods for reducing extinction cascades in ecosystems that are at risk. The existence of innumerable plant and animal species, many of which are in danger of going extinct, depends on the microbial life in soils. Although frequently disregarded, the decline in microbial diversity and function can hasten the breakdown and collapse of ecosystems. Through the use of meta-omics technologies, researchers and conservationists may identify early indicators of microbial extinction, comprehend the implications for larger ecological networks, and create conservation and restoration plans that are more successful. Meta-omics is thus a vital ally in averting extinction at all levels of life, as well as a window into the secret world of soil microbes (De León *et al.,* 2023).

Large-scale food-web models continue to have limitations despite advancements in computational ecology because of oversimplified assumptions, limited scalability, and inadequate incorporation of important factors such as invasive species and extinction risk. Due in part to data limitations at larger spatial scales, these models frequently lack the dynamic complexity required to represent real-world ecosystems. Future research should concentrate on creating scalable, high-resolution algorithms that integrate extinction risk frameworks with a variety of data sources, including eDNA, trait databases, and remote sensing. Cross-disciplinary methods and adaptive, AI-powered simulations will be crucial for enhancing model accuracy and guiding successful conservation plans.

Even with the increasing amount of ecological research on extinction, there is still a persisting gap between the application of science and policy, particularly in developing and biodiversity-rich areas. Closing the gap between knowledge and policy is crucial in light of the rapidly increasing rate of extinction and biodiversity loss. No matter how solid, scientific knowledge cannot effect change unless it influences and informs policy. It will take intentional, consistent work to strengthen this link: integrating community-based monitoring, strengthening platforms like IPBES, encouraging knowledge co-production, and creating institutional processes that put science into practice. Collaboration between scientists, decision-makers, and local populations leads to more than just better communication; it serves as the cornerstone for inclusive, resilient, and adaptive conservation initiatives. By ensuring that decisions are informed by the best available data, closing the science-policy gap helps to prioritize urgent action, distribute resources efficiently, and eventually stop or reverse extinction trends before they become irreversible. Threats are frequently highlighted in conservation studies, but they are not always translated into scalable, effective frameworks or considered when calculating the economic worth of ecosystem services. Species-level extinction hazards are rarely included in the planning or funding priorities of international programs such as the Sustainable Development Goals (SDGs) and the Convention on Biological Diversity (CBD). Furthermore, the creation of inclusive and successful conservation plans is hampered by the inadequate participation of local communities, indigenous knowledge holders, and other non-scientific players.

The problem of extinction prevention is not just a scientific or technical one; it is also a social and cultural one. In order to preserve species and rebuild ecosystems, community-based conservation and Indigenous knowledge systems provide profound ecological understanding, tried-and-true management techniques, and locally rooted stewardship. We obtain more effective extinction prevention measures as well as a more inclusive, moral, and sustainable future for the protection of biodiversity worldwide by putting communities at the heart of conservation and respecting Indigenous rights and wisdom.

6 Conclusion

The accelerating rate of species extinctions poses an urgent threat to global biodiversity and ecosystem stability. This review highlights the multifaceted causes of extinction, with anthropogenic pressures, such as habitat destruction, climate change, overexploitation, and invasive species, emerging as primary drivers. In parallel, natural disturbances, disease outbreaks, and geological events contribute to extinction risks, particularly when coupled with anthropogenic stressors. A major insight of this review is the complex nature of extinction cascades, where the loss of one species, especially keystone or highly connected organisms can trigger a chain of secondary extinctions, dramatically altering ecosystem structure and function.

Mechanistically, trophic imbalances, mutualistic disruptions, and long-range network interactions reveal that extinction is not isolated but often systemic. Case studies from marine, terrestrial, and agricultural ecosystems reinforce the real-world consequences of these cascades, such as the collapse of kelp forests, pollinator declines, and overgrazing in seagrass beds. Furthermore, structural network analyses show that the position and strength of species interactions within ecological networks play a critical role in determining vulnerability.

While predictive tools like Bayesian network models and compensatory perturbation frameworks offer new avenues for forecasting and mitigating cascading extinctions, significant research gaps remain. These include the integration of microbial dynamics, climate resilience, and species-specific responses into extinction models. Moreover, current conservation frameworks often fall short in translating scientific findings into actionable policy, particularly in biodiversity-rich regions.

Interdisciplinary cooperation, bringing together ecologists, modelers, policymakers, social scientists, economists, and local communities, is crucial to tackling these issues. Ecosystem management can be strengthened and more equitable, scalable, and sustainable conservation results can be guaranteed by combining behavioral insights, socioeconomic planning, and conservation funding mechanisms. A coordinated global effort is needed to implement science-based conservation strategies, enhance ecological forecasting, and protect both species and the essential services ecosystems provide. To preserve ecosystems from cascading losses and improve long-term biodiversity persistence, practical conservation measures are crucial. These include creating networks of protected areas, controlling invasive species, and creating habitat corridors that are climate-resilient. Without immediate, integrative action, the planet may face irreversible biodiversity losses that compromise ecological resilience and human well-being alike.

7 Funding

No funding was received for this study.

8 Acknowledgment

The authors are grateful to the University for providing seeds and chemicals for the research.

9 Conflict of Interest

The authors declare no conflict of interest.

10 SDGs Addressed

This review addresses SDG 13: Climate Action and SDG 15: Life on Land by emphasizing the urgent need to mitigate human-driven biodiversity loss, while also supporting SDG 14: Life Below Water through its focus on marine ecosystems and conservation of interconnected species networks.

References

Altermann, E. J. F. I. M. (2012). Tracing lifestyle adaptation in prokaryotic genomes. *Frontiers in Microbiology, 3*, 48.

Baum, K. A., Haynes, K. J., Dillemuth, F. P., & Cronin, J. T. (2004). The matrix enhances the effectiveness of corridors and stepping stones. *Ecology, 85*(10), 2671–2676.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters, 15*(4), 365–377.

Belovsky, G. E., Mellison, C., Larson, C., & Van Zandt, P. A. (1999). Experimental studies of extinction dynamics. *Science, 286*(5442), 1175–1177.

Blomqvist, D., Pauliny, A., Larsson, M., & Flodin, L.-Å. (2010). Trapped in the extinction vortex? Strong genetic effects in a declining vertebrate population. *BMC Evolutionary Biology, 10*(1), 33.

Bodo, T., Gimah, B. G., & Seomoni, K. J. (2021). Deforestation and habitat loss: Human causes, consequences and possible solutions. *Journal of Geographical Research, 4*(2), 22–30.

Borrvall, C., Ebenman, B., & Jonsson, T. (2000). Biodiversity lessens the risk of cascading extinction in model food webs. *Ecology Letters, 3*(2), 131–136.

Brook, B. W., Sodhi, N. S., & Bradshaw, C. J. (2008). Synergies among extinction drivers under global change. *Trends in Ecology & Evolution, 23*(8), 453–460.

Brook, B. W., Sodhi, N. S., & Ng, P. K. (2003). Catastrophic extinctions follow deforestation in Singapore. *Nature, 424*(6947), 420–423.

Burkey, T. V., & Reed, D. H. (2006). The effects of habitat fragmentation on extinction risk: Mechanisms and synthesis. *Songklanakarin Journal of Science and Technology, 28*(1), 9–37.

Cahill, A. E., Aiello-Lammens, M. E., Fisher-Reid, M. C., Hua, X., Karanewsky, C. J., Ryu, H. Y., Sbeglia, G. C., Spagnolo, F., Waldron, J. B., & Warsi, O. (2013). How does climate change cause extinction? *Proceedings of the Royal Society B: Biological Sciences, 280*(1750), 20121890.

Carnell, P. E., Ierodiaconou, D., Atwood, T. B., & Macreadie, P. I. (2020). Overgrazing of seagrass by sea urchins diminishes blue carbon stocks. *Ecosystems, 23*, 1437–1448.

Carroll, E. L., Hall, A., Olsen, M. T., Onoufriou, A. B., Gaggiotti, O. E., & Russell, D. J. (2020). Perturbation drives changing metapopulation dynamics in a top marine predator. *Proceedings of the Royal Society B: Biological Sciences, 287*(1928), 20200318.

Carvalheiro, L., Barbosa, E., & Memmott, J. (2008). Pollinator networks, alien species and the conservation of rare plants: *Trinia glauca* as a case study. *Journal of Applied Ecology, 45*(5), 1419–1427.

Chan, S., & Raine, N. E. (2023). Sharing the wealth: Pollen partitioning in a *Cucurbita* crop pollination system with reference to the wild hoary squash bee. *Journal of Pollination Ecology, 34*, 228–238.

Change, C. (2022). *Mitigating climate change. Working Group III contribution to the sixth assessment report of the Intergovernmental Panel on Climate Change*.

Chinchio, E., Crotta, M., Romeo, C., Drewe, J. A., Guitian, J., & Ferrari, N. (2020). Invasive alien species and disease risk: An open challenge in public and animal health. *PLOS Pathogens, 16*(10), e1008922.

Choudhury, M. R., & Banerjee, I. (2022). Brief discussion on the mathematics behind extinctions: A detailed statistical assay on the population density of Northern white rhinoceros.

Commission, N. R. S. S. (1995). *IUCN red list categories*. IUCN.

Conroy, M. J., Runge, M. C., Nichols, J. D., Stodola, K. W., & Cooper, R. J. (2011). Conservation in the face of climate change: The roles of alternative models, monitoring, and adaptation in confronting and reducing uncertainty. *Biological Conservation, 144*(4), 1204–1213.

Daszak, P., Berger, L., Cunningham, A. A., Hyatt, A. D., Green, D. E., & Speare, R. (1999). Emerging infectious diseases and amphibian population declines. *Emerging Infectious Diseases, 5*(6), 735–748.

Daszak, P., Cunningham, A. A., & Hyatt, A. D. (2000). Emerging infectious diseases of wildlife: Threats to biodiversity and human health. *Science, 287*(5452), 443–449.

Daszak, P., Cunningham, A. A., & Hyatt, A. D. (2001). Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta Tropica, 78*(2), 103–116.

De Castro, F., & Bolker, B. (2005). Mechanisms of disease-induced extinction. *Ecology Letters, 8*(1), 117–126.

De León, L. F., Silva, B., Avilés-Rodríguez, K. J., & Buitrago-Rosas, D. (2023). Harnessing the omics revolution to address the global biodiversity crisis. *Current Opinion in Biotechnology, 80*, 102901.

de Manincor, N., Fisogni, A., & Rafferty, N. E. (2023). Warming of experimental plant–pollinator communities advances phenologies, alters traits, reduces interactions and depresses reproduction. *Ecology Letters, 26*(2), 323–334.

Dean, T. A., Bodkin, J. L., Jewett, S. C., Monson, D. H., & Jung, D. (2000). Changes in sea urchins and kelp following a reduction in sea otter density as a result of the Exxon Valdez oil spill. *Marine Ecology Progress Series, 199*, 281–291.

Dunne, J. A., Williams, R. J., & Martinez, N. D. (2002). Network structure and biodiversity loss in food webs: Robustness increases with connectance. *Ecology Letters, 5*(4), 558–567.

Ebenman, B., Law, R., & Borrvall, C. (2004). Community viability analysis: The response of ecological communities to species loss. *Ecology, 85*(9), 2591–2600.

Eklöf, A., Tang, S., & Allesina, S. (2013). Secondary extinctions in food webs: A Bayesian network approach. *Methods in Ecology and Evolution, 4*(8), 760–770.

Eklöf, J., De la Torre-Castro, M., Gullström, M., Uku, J., Muthiga, N., Lyimo, T., & Bandeira, S. (2008). Sea urchin overgrazing of seagrasses: A review of current knowledge on causes, consequences, and management. *Estuarine, Coastal and Shelf Science, 79*(4), 569–580.

Epstein, P. R. (2001). Climate change and emerging infectious diseases. *Microbes and Infection, 3*(9), 747–754.

Fabry, V. J., Seibel, B. A., Feely, R. A., & Orr, J. C. (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science, 65*(3), 414–432.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics, 34*(1), 487–515.

Fan, H., Si, Q., Dong, W., Lu, G., & Liu, X. (2023). Land use change and landscape ecological risk prediction in Urumqi under the shared socio-economic pathways and the representative concentration pathways (SSP-RCP) scenarios. *Sustainability, 15*(19), 14214.

Feit, B., & Letnic, M. (2015). Species level traits determine positive and negative population impacts of invasive cane toads on native squamates. *Biodiversity and Conservation, 24*, 1017–1029.

Fowler, M. S. (2010). Extinction cascades and the distribution of species interactions. *Oikos, 119*(5), 864–873.

Franklin, J. D. (2014). Does history repeat itself? Impact of climate on floral resources for bumble bees then and now. (Doctoral dissertation, University of Missouri-Columbia).

Fritts, T. H., & Rodda, G. H. (1998). The role of introduced species in the degradation of island ecosystems: A case history of Guam. *Annual Review of Ecology and Systematics, 29*(1), 113–140.

Garibaldi, L. A., Aizen, M. A., Klein, A. M., Cunningham, S. A., & Harder, L. D. (2011). Global growth and stability of agricultural yield decrease with pollinator dependence. *Proceedings of the National Academy of Sciences, 108*(14), 5909–5914.

Gurevitch, J., & Padilla, D. K. (2004). Are invasive species a major cause of extinctions? *Trends in Ecology & Evolution, 19*(9), 470–474.

Haase, A. (2022). Soup minus shark: How the shark finning industry continues to cause transboundary environmental harm.

Hanafiah, M. M., Xenopoulos, M. A., Pfister, S., Leuven, R. S., & Huijbregts, M. A. (2011). Characterization factors for water consumption and greenhouse gas emissions based on freshwater fish species extinction. *Environmental Science & Technology, 45*(12), 5272–5278.

Hanski, I. (2011). Habitat loss, the dynamics of biodiversity, and a perspective on conservation. *Ambio, 40*(3), 248–255. https://doi.org/10.1007/s13280-011-0147-3

Harrington, R., Woiwod, I., & Sparks, T. (1999). Climate change and trophic interactions. *Trends in Ecology & Evolution, 14*(4), 146–150.

Harvell, C. D., Kim, K., Burkholder, J., Colwell, R. R., Epstein, P. R., Grimes, D. J., Hofmann, E. E., Lipp, E., Osterhaus, A., & Overstreet, R. M. (1999). Emerging marine diseases: Climate links and anthropogenic factors. *Science, 285*(5433), 1505–1510.

Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S., & Samuel, M. D. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science, 296*(5576), 2158–2162.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., Edwards, A. J., & Caldeira, K. (2007). Coral reefs under rapid climate change and ocean acidification. *Science, 318*(5857), 1737–1742.

Hogue, A. S., & Breon, K. (2022). The greatest threats to species. *Conservation Science and Practice, 4*(5), e12670.

Holmes, J. C. (1996). Parasites as threats to biodiversity in shrinking ecosystems. *Biodiversity and Conservation, 5*, 975–983.

Hussain, M., Butt, A. R., Uzma, F., Ahmed, R., Irshad, S., Rehman, A., & Yousaf, B. (2020). A comprehensive review of climate change impacts, adaptation, and mitigation on environmental and natural calamities in Pakistan. *Environmental Monitoring and Assessment, 192*, 1–20.

Jonsson, T., Karlsson, P., & Jonsson, A. (2006). Food web structure affects the extinction risk of species in ecological communities. *Ecological Modelling, 199*(1), 93–106.

Jordano, P. (1987). Patterns of mutualistic interactions in pollination and seed dispersal: Connectance, dependence asymmetries, and coevolution. *The American Naturalist, 129*(5), 657–677.

Kehoe, R., Frago, E., & Sanders, D. (2021). Cascading extinctions as a hidden driver of insect decline. *Ecological Entomology, 46*(4), 743–756.

Keith, D. A., Akçakaya, H. R., Thuiller, W., Midgley, G. F., Pearson, R. G., Phillips, S. J., Regan, H. M., Araújo, M. B., & Rebelo, T. G. (2008). Predicting extinction risks under climate change: Coupling stochastic population models with dynamic bioclimatic habitat models. *Biology Letters, 4*(5), 560–563.

Kline, O., & Joshi, N. K. (2020). Mitigating the effects of habitat loss on solitary bees in agricultural ecosystems. *Agriculture, 10*(4), 115.

Koh, L. P., Dunn, R. R., Sodhi, N. S., Colwell, R. K., Proctor, H. C., & Smith, V. S. (2004). Species coextinctions and the biodiversity crisis. *Science, 305*(5690), 1632–1634.

Kovács-Hostyánszki, A., Espíndola, A., Vanbergen, A. J., Settele, J., Kremen, C., & Dicks, L. V. (2017). Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. *Ecology Letters, 20*(5), 673–689.

Lafferty, K. (2003). Is disease increasing or decreasing, and does it impact or maintain biodiversity? *Journal of Parasitology, 89*(Suppl), S101–S105.

Larsen, T. H., Williams, N. M., & Kremen, C. (2005). Extinction order and altered community structure rapidly disrupt ecosystem functioning. *Ecology Letters, 8*(5), 538–547.

Lederberg, J. (1993). Emerging infections: Microbial threats to health. *Trends in Microbiology, 1*(2), 43–44.

McCallum, H. (2012). Disease and the dynamics of extinction. *Philosophical Transactions of the Royal Society B: Biological Sciences, 367*(1604), 2828–2839.

McCallum, H., & Dobson, A. (1995). Detecting disease and parasite threats to endangered species and ecosystems. *Trends in Ecology & Evolution, 10*(5), 190–194.

McCallum, H., & Dobson, A. (2002). Disease, habitat fragmentation and conservation. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 269*(1504), 2041–2049.

Mills, L. S., Soulé, M. E., & Doak, D. F. (1993). The keystone-species concept in ecology and conservation. *BioScience, 43*(4), 219–224.

Montoya, J. M., Pimm, S. L., & Solé, R. V. (2006). Ecological networks and their fragility. *Nature, 442*(7100), 259–264.

Mooney, H., Larigauderie, A., Cesario, M., Elmquist, T., Hoegh-Guldberg, O., Lavorel, S., Mace, G. M., Palmer, M., Scholes, R., & Yahara, T. (2009). Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability, 1*(1), 46–54.

Moreno, J., & Møller, A. P. (2011). Extreme climatic events in relation to global change and their impact on life histories. *Current Zoology, 57*(3), 375–389.

Murie, K. A., & Bourdeau, P. E. (2019). Predator identity dominates non-consumptive effects in a disease-impacted rocky shore food web. *Oecologia, 191*(4), 945–956.

Myers, R. A., Baum, J. K., Shepherd, T. D., Powers, S. P., & Peterson, C. H. (2007). Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science, 315*(5820), 1846–1850.

Nemeth, L. (2012). *Grand experiments: A review of five endangered species reintroductions in the US*. Prescott College.

Noyes, P. D., & Lema, S. C. (2015). Forecasting the impacts of chemical pollution and climate change interactions on the health of wildlife. *Current Zoology, 61*(4), 669–689.

Owens, I. P., & Bennett, P. M. (2000). Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences, 97*(22), 12144–12148.

Paine, R. T. (1966). Food web complexity and species diversity. *The American Naturalist, 100*(910), 65–75.

Paine, R. T. (1969). A note on trophic complexity and community stability. *The American Naturalist, 103*(929), 91–93.

Parmesan, C., Root, T. L., & Willig, M. R. (2000). Impacts of extreme weather and climate on terrestrial biota. *Bulletin of the American Meteorological Society, 81*(3), 443–450.

Petchey, O. L., Downing, A. L., Mittelbach, G. G., Persson, L., Steiner, C. F., Warren, P. H., & Woodward, G. (2004). Species loss and the structure and functioning of multitrophic aquatic systems. *Oikos, 104*(3), 467–478.

Pimm, S. L. (1980). Food web design and the effect of species deletion. *Oikos, 35*(2), 139–149.

Pocheville, A. (2014). The ecological niche: History and recent controversies. In T. Heams, P. Huneman, G. Lecointre, & M. Silberstein (Eds.), *Handbook of evolutionary thinking in the sciences* (pp. 547–586). Springer.

Purvis, A., Jones, K. E., & Mace, G. M. (2000). Extinction. *BioEssays, 22*(12), 1123–1133.

Riley, S. P., Sauvajot, R. M., Fuller, T. K., York, E. C., Kamradt, D. A., Bromley, C., & Wayne, R. K. (2003). Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. *Conservation Biology, 17*(2), 566–576.

Rosenblatt, A. E., Heithaus, M. R., Mather, M. E., Matich, P., Nifong, J. C., Ripple, W. J., & Silliman, B. R. (2013). The roles of large top predators in coastal ecosystems:

New insights from long-term ecological research. *Oceanography, 26*(3), 157–167.

Rosser, A. M., & Mainka, S. A. (2002). Overexploitation and species extinctions. *Conservation Biology, 16*(3), 584–586.

Royalty, T. M., & Steen, A. D. (2021). Functional redundancy in ocean microbiomes controls trait stability. *bioRxiv, 2021*, 2006.2018.448980.

Sahasrabudhe, S., & Motter, A. E. (2011). Rescuing ecosystems from extinction cascades through compensatory perturbations. *Nature Communications, 2*(1), 170.

Sattar, Q., Maqbool, M. E., Ehsan, R., & Akhtar, S. (2021). Review on climate change and its effect on wildlife and ecosystem. *Open Journal of Environmental Biology, 6*(1), 8–14.

Schonewald-Cox, C., Chambers, S., MacBryde, B., & Thomas, L. (1983). *Genetics and conservation: A reference for managing wild animal and plant populations*. Benjamin/Cummings.

Simberloff, D. (1995). Habitat fragmentation and population extinction of birds. *Ibis, 137*(Suppl. 1), S105–S111.

Solé, R. V., & Montoya, M. (2001). Complexity and fragility in ecological networks. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 268*(1480), 2039–2045.

Soulé, M. E. (1987). *Viable populations for conservation*. Cambridge University Press.

Spielman, D., Brook, B. W., & Frankham, R. (2004). Most species are not driven to extinction before genetic factors impact them. *Proceedings of the National Academy of Sciences, 101*(42), 15261–15264.

Springer, A. M., Estes, J. A., Van Vliet, G. B., Williams, T. M., Doak, D. F., Danner, E. M., Forney, K. A., & Pfister, B. (2003). Sequential megafaunal collapse in the North Pacific Ocean: An ongoing legacy of industrial whaling? *Proceedings of the National Academy of Sciences, 100*(21), 12223–12228.

Tian, Y., Wu, J., Smith, A. T., Wang, T., Kou, X., & Ge, J. (2011). Population viability of the Siberian tiger in a changing landscape: Going, going and gone? *Ecological Modelling, 222*(17), 3166–3180.

Tilman, D., May, R. M., Lehman, C. L., & Nowak, M. A. (1994). Habitat destruction and the extinction debt. *Nature, 371*(6492), 65–66.

Trathan, P. N., García-Borboroglu, P., Boersma, D., Bost, C. A., Crawford, R. J., Crossin, G. T., Cuthbert, R. J., Dann, P., Davis, L. S., & De La Puente, S. (2015). Pollution, habitat loss, fishing, and climate change as critical threats to penguins. *Conservation Biology, 29*(1), 31–41.

Trisos, C. H., Merow, C., & Pigot, A. L. (2020). The projected timing of abrupt ecological disruption from climate change. *Nature, 580*(7804), 496–501.

Tscharntke, T. (2021). Disrupting plant–pollinator systems endangers food security. *One Earth, 4*(9), 1217–1219.

Veach, V., Moilanen, A., & Di Minin, E. (2017). Threats from urban expansion, agricultural transformation and forest loss on global conservation priority areas. *PLOS ONE, 12*(11), e0188397.

Walsh, P. D., Abernethy, K. A., Bermejo, M., Beyers, R., De Wachter, P., Akou, M. E., Huijbregts, B., Mambounga, D. I., Toham, A. K., & Kilbourn, A. M. (2003). Catastrophic ape decline in western equatorial Africa. *Nature, 422*(6932), 611–614.

Wernberg, T. (2021). Marine heatwave drives collapse of kelp forests in Western Australia. In D. A. Keith & J. E. M. Watson (Eds.), *Ecosystem collapse and climate change* (pp. 325–343). Springer.

Wilcove, D. S., Rothstein, D., Dubow, J., Phillips, A., & Losos, E. (1998). Quantifying threats to imperiled species in the United States. *BioScience, 48*(8), 607–615.

Wilson, K. A., & Law, E. A. (2016). Ethics of conservation triage. *Frontiers in Ecology and Evolution, 4*, 112.

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