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Keywords: Species extinction; Climate change; Habitat loss and fragmentation; Introduced species; Chains of extinction; Infectious disease; Overexploitation; Pollution

1 **A critical evaluation of the species extinction by human influence**

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9 **Abstract**

10 Currently, biodiversity conservation is an indispensable work in many countries. In biodiversity
11 conservation, species extinction is one hot research topic. This paper started with the extinction theory
12 and literature analysis, then it examined the main reasons for the species extinction (climate change,
13 habitat loss and fragmentation, introduced species, chains of extinction, infectious disease,
14 overexploitation, and pollution). This paper can enhance people's understanding of species extinction
15 and the importance of biodiversity conservation.

16 **Keywords**

17 Species extinction; Climate change; Habitat loss and fragmentation; Introduced species; Chains of
18 extinction; Infectious disease; Overexploitation; Pollution

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20 **Introduction**

21 Species extinction is caused by various problems around the world (e.g., an unstable ecosystem). In
 22 recent years, there has been an increasing trend with respect to species extinction. As a result, examining
 23 the reasons for species extinction is important. This will help scientists and policymakers to develop
 24 better conservation management plans and protect species at risk of extinction.

25 More and more species are facing the risk of extinction. To examine the main reasons for such increases,
 26 previous studies have outlined several human activities that may be contributing to species extinction:
 27 (1) climate change (1), (2) habitat loss and fragmentation (2, 3), (3) introduced species (2), (4) chains of
 28 extinction (2), (5) infectious disease (4), (6) overexploitation (2), and (7) pollution (5). The above factors,
 29 including human and non-human factors, have had a huge impact on the extinction of species.

30 Species extinction was analysed via the analysis via the VOSviewer (Fig 1) and many papers reported
 31 that human factors played an important role during the extinction process. By reviewing 500 most recent
 32 extinction-related papers from the Web of Science, we summarized that top-two human factors that play
 33 an important role during the species extinction process were climate change (16.2%) and habitat loss and
 34 fragmentation (7.8%). Introduced species, overexploitation, chains of extinction, pollution, and
 35 infectious disease also played a significant role (see Table 1).

36 *Table 1 Estimation of human factors leading to species extinction via bibliographic studies.*

Topics	Number of publications	Percentage
Climate change	81	16.2%
Habitat loss and fragmentation	39	7.8%
Introduced species	36	7.2%
Chains of extinction	26	5.2%
Infectious disease	21	4.2%
Overexploitation	13	2.6%
Pollution	5	1.0%
Human factors total	221	44.2%

37 As a basis for further species extinction studies, Deborah Rabinowitz examined the causes of species
 38 threats and summarised three important factors that might affect species survival: habitat specificity,
 39 geographic range and population size (6). If the habitat specificity is wide, the geographic range is large
 40 or the population size is large, the species will face less extinction pressure. If the habitat specificity is

41 narrow, the geographic range is small or the population is rare, the species might become extinct. Most
 42 of the analysis in this essay on the reasons for species extinction is based on Rabinowitz's theory (human
 43 behavior affecting the population size, habitat specificity, and geographic range).

44
 45 **Fig 1.** The bibliographic studies of 500 extinction-related papers via VOSviewer, showing human factors
 46 (e.g., climate change, habitat fragment, and invasive species with purple arrow) leading to species
 47 extinction.

48 Climate change

49 Climate change has been a major factor affecting species survival. After the industrial revolution, there
 50 was a significant global warming trend. Due to rapid industrialisation and excessive carbon dioxide
 51 emissions, the average temperature increased by around 1°C from 1880 to 2010. (7). Significant efforts
 52 have been made by scientists and policymakers to control global warming trends. For example, the
 53 Intergovernmental Panel on Climate Change (IPCC) established the goal of 1.5°C of global warming
 54 above pre-industrial levels (8).

55 However, the results of these efforts are still limited because people in many developing countries have

56 relatively lower standards of living, and they may have to focus on industrial development. As a result,
 57 developing countries have released more and more carbon dioxide, thus exacerbating the trend of global
 58 warming. The estimated temperature might increase around 2–3°C in the tropics and around 4–5°C in
 59 the Arctic areas without proper control in the near future (9). In this process, various species (especially
 60 the species living in the Arctic region) might face a different living environment in the future, and thus
 61 they might be under the stress of possible extinction.

62 Most protected areas might have different environmental conditions during the global warming process.
 63 Some species in the original areas might not be able to adapt to the new conditions (e.g., higher
 64 temperatures). If these species cannot move to another new suitable area (especially some plants or
 65 animals with weak mobility), they might become extinct.

66 Fig 2 shows a simplified example of extinction due to global warming. Before global warming, the
 67 species range was concentrated at the foot of the mountain (the 14°C to 20°C area in this example). After
 68 global warming, the average temperature of the mountain increased (the 14°C to 20°C area shifted uphill
 69 in this example). As a result, many species within that range needed to move uphill (right side in Fig 2).
 70 Consequently, some species without good mobility on the warm edge were vulnerable to extinction.

71
 72 **Fig 2.** Schematic illustration showing a geographic range shift associated with global warming. After
 73 global warming, the average temperature of the mountain increased. As a result, the overall species' range
 74 was shifted uphill in the mountain area, leading to warm-edge local extinction. The figure idea and

information were obtained from (10) and replotted by the author of this essay.

Similar to the uphill example above, scientists have also found many species moving poleward due to global warming. For example, Rachael Hickling et al. examined latitudinal shifts in northern range margins in the United Kingdom (11). In the 16 taxonomic groups, Rachael Hickling et al. found dragonflies, soldier beetles, spiders, woodlice, millipedes, and aquatic-bugs significantly moving northward (50 km to 100 km). Carabids, fish, lacewings, longhorn-beetles, butterflies, grasshoppers, birds, and mammals also moved northward (25 km to 50 km). The harvestmen did not move, and the herptiles moved southwards (around 50 km). Species originally within the southern distribution of the United Kingdom may gain suitable climate space in the north, and species originally within the northern distribution of the United Kingdom may lose suitable climate space. In this case, some species within the northern distribution might have been vulnerable to extinction, and such changes will cause ecosystem problems.

Due to global warming, many species have had to move to a new suitable place for living. However, fragmented and converted landscapes might also hinder this movement (12). In such cases, some species cannot move to new habitats and might become extinct. By rough estimation, around 15%-37% of Earth will be extinct by 2050 if global warming continues along its current path (13). After species extinction, the ecological balance will be destroyed (e.g., the extinction of natural enemies will lead to the increase of pests). As a result, the resulting extinction will ultimately affect human life.

Climate change leads to species extinction and ecosystem problems (Fig 3). Briefly, climate change might lead to significant temperature increases in some places. Some species with good adaptability might be able to acclimate to the higher temperature. Some species with weak adaptability will have to move. In the latter case, species with good mobility can move to a new habitat, whereas species with low mobility might be vulnerable to extinction. If some species become extinct, the ecosystem could be imbalanced (e.g., the number of some species will increase with natural enemy extinction), which could cause further ecosystem problems.

Fig 3. Schematic illustration showing how climate change might affect species survival and lead to ecosystem problems. The illustration has been simplified by the author as the real situation is much more complicated.

One recent study demonstrated that climate-related local extinctions are already widespread (10). Wiens summarised 27 studies to document local extinctions related to climate change. In many cases, there were range shifts of protected areas due to global warming. However, not all species had sufficient mobility to migrate to a new suitable habitat. As a result, many local species faced more stress and possible extinction, including the Zygaenidae (Lepidoptera) (14).

Coral reefs function as the ‘rainforests of the sea’ in the marine ecosystem. Shallow coral reefs form some of Earth’s most diverse ecosystems. In 1995, coral reefs occupied less than 1% of the world’s ocean area and contained at least 25% of all marine species (15). Lisa Wedding et al described the main ecosystem services provided by coral reefs as: (1) coastal protection, (2) blue economy and (3) food source (16, 17).

Due to global warming, coral bleaching occurs when coral reefs are stressed by warmer than normal waters. Coral bleaching has devastated reefs, thus posing the most severe threat to coral reefs related to global warming. A large number of corals have died, and the mortality rate has even exceeded 16% in some areas. Coral bleaching might negatively affect the ecosystem services provided by coral reefs and the lives of around 500 million people. As a result, the biodiversity conservation of coral reefs is critical,

and scientists and policymakers should act as soon as possible (16, 17).

Habitat loss and fragmentation

Habitat loss is considered to be an important cause of species extinction (2, 3). In an early landmark paper, Deborah Rabinowitz (1981) indicated that there are seven kinds of rarity, and within this construct, habitat loss is considered as one of the most important factors leading to species extinction.

In some cases, human behaviour, whether it be intentional or unintentional, leads to habitat loss and threatens species survival. For example, with rapid human population growth after the industrial revolution, trends emerged such as urban expansion, agricultural development, mining and construction (18). These trends have resulted in the loss of habitats all over the world (19), and in particular, such changes have been the result of the following regional patterns:

(1) Amazonia facing the dual threats of deforestation, leading to the habitat loss for many species (20);

(2) Industrial development and urban expansion in East Asia, leading to environmental pollution and habitat loss (21);

(3) Conversion a large number of forests into croplands or farmlands in Southeast Asia to facilitate agricultural development, causing significant habitat loss (22, 23).

In all of the above examples, the tropical area, an important habitat, is a large expanse of land that deserves special attention. Grainger reported that the habitat loss of the tropical moist forest area in 63 countries was around 100–200 million hectares (ha) from 1980 to 1990 (24). Based on the tropical conservatism hypothesis (25), tropical areas have three important components relevant to biodiversity conservation: (1) A cradle, meaning that there is greater time and area for more speciation; (2) A museum, implying that there with more time and area, there is less extinction; and (3) tropical species find it is difficult to survive outside of the tropics since the environmental condition is different. As a result, there is a large number of species living in tropical areas. If the species lose their habitat in the tropical area, they might become extinct. For the above reasons, scientists and the policymakers need to control habitat loss in tropical areas to protect biodiversity.

Besides habitat loss, habitat fragmentation also plays an important role in contributing to increased rates of species extinction (26). Habitat fragmentation is defined as the process through which a large continuous area of habitat turns into many smaller patches. Habitat fragmentation might be due to many reasons such as habitat loss, deforestation, climate change, or road construction. Habitat fragmentation threatens species via three main transformations:

(1) After fragmentation, each habitat is comprised of smaller areas. Smaller areas have less of a population. If the population is less than the minimum viable population (MVP), a species might become extinct (27). Even the population is higher than the MVP, the smaller area might not benefit the reproduction or continuous survival of the species.

(2) Habitat fragmentation negatively affects a species' activities, limits genetic exchange, and reduces genetic diversity. In the road construction, the original habitat was fragmented. As a result, the animals in different patches with lower mobility could not mate any longer given that there was a road in the middle separating the smaller areas. This adversely affected the population and genetic exchange.

(3) Habitat fragmentation causes an edge effect. Again, in the case of the road construction example, an increased edge around each respective area emerged, and the species were consequently more vulnerable to pressure from invasive enemies and humans. The invasive species had more edges to invade, and obviously this affected the survival of local species and the balance of the ecosystem.

A recent study examined habitat fragmentation and its impact on the ecosystem (28). In this paper, the authors stated that around 70% of forest land all over the world is within 1 km of the forest's edge. As a result, an increased edge within an area due to fragmentation significantly affects the habitat in forests worldwide. In fact, habitat fragmentation was estimated to reduce biodiversity by 13–75% over a 35-year period and greatly impaired ecosystem services. This paper recommends certain requirements to improve landscape connectivity (e.g., growing certain plants in fragmentation areas) and conserve biodiversity, which would reduce the extinction rate and enhance the available ecosystem services.

The relationship between the number of species and the area has been discussed in an earlier foundational paper (29). Briefly, one of the most used methods to determine the number of species has been

extrapolated from a classic island species-area relationship is the following: Number of species = $c \times \text{Area}^z$ ($S = c \times A^z$, where the common practice is to assume a slope z of 0.25).

On the one hand, a larger habitat area generally leads to a higher number of species. In such a case, the relationship between species is more complicated, and the ecosystem is more stable. On the other hand, habitat fragmentation reduces the area of a single habitat, thus seriously impacting the number of species in the habitat along with ecosystem stability. As a result, a large continuous habitat area is better than multiple small, fragmented habitat areas.

Introduced species

Introduced species sometimes cause extinction problems (30). Introduced species are those organisms that were not originally distributed in the area and were introduced either unintentionally or intentionally by humans. Introduced species may not be able to adapt to the new habitat and disappear quickly, or they may be able to adapt and establish a stable group in the new area. Introduced species have very diverse and unpredictable effects on the ecosystem (e.g., resource competition, behavioural aggression, predation/herbivory, or pathogen hybridisation).

In some cases, introduced species can develop into increasing populations without human intervention. If these new species threaten the local ecosystem balance and become a local hazard to the established biodiversity, they are called 'invasive species'. Clavero and García-Berthou have reported that invasive species are a leading cause of animal extinctions (31).

There is a persuasive example in the literature (32) that can explain the impact of invasive species on local species and ecosystem balance (ultimately leading to species extinction). Lyall's wren (also referred to as the Stephens Island wren) was a local flightless passerine on Stephens Island in New Zealand, and it lived by eating insects. Due to human activities in the late 19th century, the lighthouse keeper's cats (one of which was named Tibbles) were introduced into the area. After that, cats reproduced in large numbers and became wild. The Lyall's wren fell victim to one of the numerous feral cats, and it quickly became extinct after around 20 years.

A famous invasive species is the Asian carp (33). Asian carp eat plankton, aquatic plants, benthic animals

and algae in waterways. The United States introduced the Asian carp with the original purpose of cleaning water in the 1970s (34). However, the Asian carp reproduced quickly and competed with local species for food and living space in the 21st century. As a result, the Asian carp greatly threatened the survival and reproduction of local species and was considered to be detrimental to the environment in the United States. To control the negative impact, the government reintroduced the alligator gar (a ray-finned euryhaline fish feed on Asian carp) to control the Asian carp and keep the ecosystem in balance.

Currently, there are many invasive species which could damage the ecosystem. To control the negative effect of invasive species, scientists and policymakers should eradicate them (35). However, funding and resources are limited. As a result, scientists and policymakers need to determine which invasive species are of the highest priority with respect to eradication. Booy et al. have reported on the negative effects of different invasive non-native species and suggested a means of possible risk management in a previous paper. They used factor analysis risk assessment scores to indicate the risk level of different invasive species. Some invasive species have been determined to be of high priority for eradication in the United Kingdom, such as the broadleaf watermilfoil, the American lobster, and the round goby (35).

Chains of extinction

Chains of extinction are another one of the factors leading to species extinction. Some species have a mutualistic relationship with one another. In such cases, the extinction of one species might lead to the co-extinction of the other species in cases of obligate mutualism. By rough estimation, around 6,300 species are at risk of extinction due to mutualistic relationships (36).

As an example of mutualism, the passenger pigeon is an extinct species of pigeon that was once endemic to North America. The reasons for the passenger pigeon's extinction were overhunting and habitat loss due to human activity. Furthermore, the passenger pigeon was accompanied by the parasitic mite which normally lived on the passenger pigeon. After the passenger pigeon became extinct, the parasite mite was forced into co-extinction with it (37). This is an example of the chains of extinction, where the extinction of one species can lead to the co-extinction of another species.

Infectious disease

Infectious disease is another factor leading to species extinction, and around 4% of species extinctions were due to infectious disease (4). In some cases, widespread pathogens directly threatens species with extinctions (38). When facing pathogens, humans have public health, social media, and vaccines as defence weapons. However, many animals and plants without these defence weapons may go extinct.

One famous extinction example was thylacine (*Thylacinus cynocephalus*). Previously, the thylacine was widely distributed in the mainland Australia and the island of Tasmania, New Guinea. The extinction of thylacine has many reasons. The epidemic disease (marsupi-carnivore disease) spreading quickly was proved to be one most important factor leading to the massive mortality (39).

In some cases, the infectious disease can be transmitted via human-animal interactions. For example, COVID-19 was reported in minks and it can transmit to human body (40). To prevent the human-animal transmission, the Dutch mink farms killed millions of minks and threaten the species survival (41, 42). It is possible that the COVID-19 virus will directly or indirectly lead to species extinction.

Overextrapolation

Overextrapolation is regarded as another significant factor leading to the extinction of species (2, 3). Overextrapolation refers to the continuous and excessive use of harvestable renewable resources, which causes the resource to be exhausted or the species to become extinct. In biodiversity conservation, overextrapolation behaviour includes many activities such as hunting, logging, grazing or fishing.

Overexploitation occurs in various regions of the world and threatens the survival of species. With respect to this issue, a previous study has examined the case of bushmeat and food security in the Congo Basin (43). A variety of animals were hunted for their meat, which was called 'bushmeat'. Many rural people relied on the bushmeat to live (e.g., for food or income) and hunted a total of 3.4 million tons bushmeat per year. The rural people in this region had an average protein supply of 85 g person⁻¹ day⁻¹ in 2003. Due to overextrapolation and significant reductions in bushmeat availability, the overall protein supply could decrease to 41 g person⁻¹ day⁻¹ in 2050, which is well below the basic daily requirement of 52 g person⁻¹ day⁻¹ recommended by the World Health Organization (WHO). If this happens, the ecological damage caused by overextrapolation will directly threaten people's lives in the future.

Another study has also looked at the hunting of wildlife in tropical areas (44). In the humid tropics (e.g., West Africa, Central Africa, Indonesia, or Peru), overhunting has caused the local extinctions of numerous species. Many rural people have relied on wild meat, and this food/financial source has already depleted or lost. To solve such problems, the authors recommended pursuing a balance between biodiversity conservation and subsistence use. The authors further suggested that striking such a balance requires strong collaboration between rural people, local companies, state government and research institutes.

Another example of extinction due mainly to overexploitation is the case of the Mariana mallard (also referred to as the Oustalet's duck). The now-extinct Mariana mallard was a type of duck previously endemic to the Mariana Islands of Guam (45). In the early 20th century, many people lived on the island and used traps to hunt the Mariana mallard. The Mariana mallard was unwary of the traps, and the number of these birds declined quickly. After World War II, the local gun ban was lifted, and the Mariana mallard faced even more pressure from overhunting. Finally, the Mariana mallard was determined to be extinct in 1981. Although there were other reasons for its extinction, such as the expansion of agriculture and construction, overexploitation was considered to be the most important factor in many studies (45-47).

Pollution

Pollution also causes species extinction. In the process of industrialisation, some developing countries have focused on economic development and ignored environmental protection. Many factories (e.g., chemical factories or mining facilities) have directly discharged wastewater into the waterways without proper treatment (48-50). In such cases, the presence of pollutants (e.g., heavy metals or polychlorinated biphenyls) in the waterways will cause species to face greater stress to survive. Many animals died due to pollution, which can lead to the extinction of species.

For example, the white-rumped vulture (*Gyps bengalensis*) is a large bird native to South Asia and Southeast Asia. There are many developing countries in South Asia and Southeast Asia. The economies of these developing countries are supported by industry (e.g., chemical engineering or mining), which has led to the significant amount of pollution in this area (48-50). Due to diclofenac pollution, the white-rumped vulture suffered under great stress to survive. Based on rough estimations, the white-rumped

vulture populations declined by 99.8% in 25 years (51). Due to the population decline, the vulture has been listed as ‘Critically Endangered’ (CE) on the International Union for Conservation of Nature (IUCN) Red List (52).

Heavy metal pollution might also threaten the survival of species and lead to extinction. For example, Ficken and Byrne have examined the negative effects of heavy metal pollution on anuran species in the wetlands in Victoria, Southeast Australia (53). In their paper, Ficken and Byrne found that the richness and distribution of the eastern common froglet, the spotted marsh frog and the southern brown tree frog were negatively associated with the concentrations of heavy metals (copper). More heavy metals, less anuran species. Ficken and Byrne concluded that heavy metal pollution significantly contributed to global amphibian decline (53), and might further lead to species extinction.

Conclusion

Species extinction might affect the balance of the global ecosystem. As a result, scientists and policymakers should carefully study the reasons for species extinction. Deborah Rabinowitz’s theory emerging out of an analysis based on habitat specificity, geographic range and population size provided a model to examine the reasons for species extinction. Based on current studies, the main reasons for species extinction are: (1) climate change, (2) habitat loss and fragmentation, (3) introduced species, (4) chains of extinction, (5) infectious disease, (6) overexploitation, and (7) pollution.

After the examination of reasons for extinction, scientists and policymakers will have a better understanding of how best to control human activity to protect various species (e.g., by enhancing the connection between habitats, limiting hunting areas or adjusting the boundaries of protection areas). Better policies mean better biodiversity conservation, and a better environment for humans.

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