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REVIEW

Strategies to prevent the new infectious diseases from an ecological perspective

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Background: The coronavirus problem is an ecological problem stemming from a sudden change in the relationship between parasites and hosts. Ecologists judge organisms that are established out of their original territory as exotic species. Unlike in their original habitat, these exotic species become very aggressive in their newly settled habitat. Coronavirus infection damage was bigger in Europe or the United States than that in the country of its origin, China, and its neighboring countries. Therefore, coronavirus infection damage resembles the damage due to the invasive species.
Results: Exotic species are found in places with similar environmental conditions to those of their origin when introduced to other ecological regions. However, there are few ecological ill effects in their place of origin, while the damage is usually severe in the ecological regions in which it is introduced. According to historical records, exotic infectious diseases, such as European smallpox and measles, also showed a similar trend and caused great damage in newly established places. Therefore, it is expected that measures to manage exotic species could be used for the prevention of exotic infectious diseases such as the coronavirus.
Conclusions: Prevention comes first in the management of exotic species, and in order to come up with preventive measures, it is important to collect information on the characteristics of related organisms and their preferred environment. In this respect, ecosystem management measures such as exotic species management measures could be used as a reference to prevent and suppress the spread. To put these measures into practice, it is urgently required to establish an international integrated information network for collecting and exchanging information between regions and countries. Furthermore, a systematic ecosystem-management strategy in which natural and human environments could continue sustainable lives in their respective locations may serve as a countermeasure to prevent infectious diseases.

Keywords: coevolution, conservation, coronavirus, exotic species, population interaction

Introduction

In an interview article (Jeong 2021), Professor Jonna Mazet, an expert on viral infectious diseases, estimated the number of zoonotic viruses that can be transmitted from the wild to humans to be about 500,000 species. Among them, only 0.2% of them were found by the research team. This means that there are undoubtedly many viruses that we do not know. Therefore, the question is not whether or not another virus infection will come, but when and where it will break out. In this regard, she emphasized the importance of preventing another pandemic (infectious pandemic) that will occur, although it is important to end the coronavirus problem now (Jeong 2021).

Infection disease experts of the research team led by Professor Jonna Mazet say, "The virus does not spread, but humans do." In other words, they believe that viruses have long existed in their own natural areas and have not had much impact on humans, as they have been in different areas from humans. However, the rapid industrialization, urbanization, and climate change caused the destruction of natural ecosystems, disrupting biodiversity, and viruses that remained in their natural domain are moving to humans, new hosts, to adapt to environmental changes. The climate plays a leading role in determining the distribution of organisms. As the climate is changing rapidly now, the range of life and the interaction system are faltering. They see this change in the environment as the background for the spread of the virus (Jeong 2021). It is the same as the view of an ecologist.

She also predicted that virus infections will affect us more often and more strongly in the future as viruses tend to become more aggressive when they meet other hosts (Jeong 2021). Ecologists judge organisms that are established out of their original territory as exotic species (Lockwood et al. 2013). Unlike in their original habitat, these exotic species become very aggressive in their newly settled habitat. Therefore, experts in this field view the spread of exotic species as one of the most serious environmental problems and also consider it a major contributor to the biodiversity loss (Linders et al. 2019). Viruses that become more aggressive when they meet other hosts resemble characteristics of these exotic species. Even in this respect, it could be confirmed that the views of infectious disease experts and ecologists are not different.

Infection scientists, including Professor Jonah Mazet, believe the cause of the coronavirus infection may have been due to the indiscriminate access of human to the bats' living environment and activity byproducts, and the meat-consumption process. In other words, they are looking for a background for infection in changes in biological interactions. On the issue of removing intermediate hosts that some are raising, she warns that their removal could lead to a deadlier spread of the virus, given the various ecological service functions they exert. Furthermore, she suggests a way for humans to coexist in their respective domains without invading the bat's territory as a way to prevent virus infections. She says that as a human survival environment, protecting the natural ecosystem and responding to climate change are ways to help prevent the spread of the virus, and that everyone should be together (Jeong 2021).

She and other viral infectious disease experts do not see the cause of the outbreak of infectious diseases as the virus itself but as a matter of the relationship between humans and viruses or the living areas of viruses. They see the fundamental countermeasures against viral infectious diseases as restoring natural systems that have been damaged by human social and economic activities so that humans and viruses can coexist separately. For example, she advises that restoring the devastated forest by investing only 2% of each country's expenses for a year with the COVID-19 pandemic could reduce the outbreak of "Infection Disease X (future epidemic)" by 40% (Jeong 2021).

In areas and places where exotic species are spreading, most of them are exposed to excessive human interference, losing their ecological balance and failing to maintain their health. Therefore, ecologists consider ecological restoration as the best way to curb the spread of exotic species (Guo et al. 2018; Lee et al. 2010). The view on how to curb the spread of viruses and exotic species is also evidence of the same of infectious disease experts and ecologists. This is also in line with the UN's plan to set the 10 years from 2021 to 2030 as a damaged-Earth treatment period and to solve the environmental problems facing mankind by promoting large-scale ecological restoration projects (https://www.decadeonrestoration.org/about-un-decade).

As mentioned earlier, I view the coronavirus crisis as an ecological problem caused by the sudden change in the relationship between living things. While introducing the background here, I will review the strategy for preventing the spread of the virus from an ecological perspective.

Results

Interaction of two populations associated newly produces severe detrimental effect

Ecology is a science that addresses the relationship between organisms or between organisms and their surroundings (Odum and Barrett 2005). The coronavirus problem, which is now threatening our lives, is a problem stemming from an abnormality in the relationship between organisms that are very familiar in ecology. In other words, this problem is an ecological problem stemming from a sudden change in the relationship between parasites and hosts. When populations interacting in the relationship between organisms have evolved together over a long period of time in a stable ecosystem, the adverse effects are not as significant and few as in the case of the coronavirus (Odum and Barrett 2005).

First of all, we can find such a relationship in our body. Many microorganisms in our bodies live together without causing any significant damage to our health, such as *E. coli*. However, when *E. coli* living in other organisms suddenly enters our bodies, it causes serious problems such as the pathogenic *E. coli* O157, which caused food poisoning and threatened our health years ago. This is because the interrelationship between organisms has suddenly changed (Ameer et al. 2022).

The coronavirus is known to have been transmitted from virus-hit wild animals in the process of using wild animals as food. Whether the animal that possessed the virus becomes a bat (*Chiroptera blumenbach*) or a pangolin (*Manis pentadactyla*), the relationship maintained between them has been co-evolved for a long time, so there has been no problem, but it is causing such great damage to us, the suddenly changed host (Hassanin et al. 2021; Maurin et al. 2021). Thus, as mentioned earlier, the coronavirus crisis is an ecological problem caused by sudden changes in the relationship between organisms.

Predation and parasitism are familiar examples of interactions between two populations in an ecosystem. In these interactions, the negative effects tend to be quantitatively small when the interacting populations have had a common evolutionary history in a relatively stable ecosystem. In other words, natural selection tends to lead either to a reduction in detrimental effects or to the elimination of the interaction altogether, as the continued serve depression of a prey or host population by the predator or parasite population can only lead to the extinction of one or both populations. Consequently, a severe impact of predation or parasitism is most frequently observed when the interaction is of recent origin (when two populations have just become associated) or when large-scale or sudden changes have occurred in the ecosystem (as might be produced by humans). In other words, over the long term, parasite–host or predator–prey interactions tend to evolve to coexistence. If any, negative interactions become less negative with time if the ecosystem is sufficiently stable and spatially diverse to allow reciprocal adaptation (Odum and Barrett 2005).

Parasite–host or predator–prey populations introduced into experimental microcosms or mesocosms usually oscillate violently, with a certain probability of extinction. Violent oscillations occur when a host, such as a house fly (*Musca domestica*) and a parasitic wasp (*Nasonia vitripennis*), are first placed together in a limited culture system. When individuals selected from cultures that had managed to survive the violent oscillations for two years were then re-established in new cultures, it was evident that, through genetic selection, an ecological homeostasis had evolved in which both populations could now coexist in a much more stable equilibrium (Pimentel and Stone 1968).

In the real world of humans and nature, time and circumstances may not favor such reciprocal adaptation by new associations. There is always the danger that the negative reaction may be irreversible, in that it leads to the extinction of the host. The chestnut blight in America is a case in which the question of adaptation or extinction hangs in the balance (Odum and Barrett 2005). From the extensive damage caused by the coronavirus infection, we could confirm the principle of this ecological interaction again.

Coronavirus infection damage resembles the damage due to the invasive species

Coronavirus infection damage was bigger in the United States and Europe than that in China and its neighboring countries (Fig. 1). These intercontinental differences in coronavirus damage clearly resemble exotic species damage. In fact, applying the ecological concept, this is damage due to exotic species. Oftentimes, exotic species are found in places with similar environmental conditions to those of their origin when introduced to other regions. However, there are a few ecological ill effects in their origin, while the damage is usually severe in the regions in which it is introduced (Lockwood et al. 2013). Therefore, the adverse effects are widely known. We could identify such damages from various examples. In terms of biodiversity loss, it is known to have a major impact after habitat destruction. It is also known as a lasting and pervasive threat because even though the introduction of alien organisms stops, the existing aliens do not disappear completely, but can sometimes continue to spread and consolidate. Therefore, considering their continuous potentiality, some say it is the most serious environmental problem (Almond et al. 2020; UNEP and CBD 2022; Fig. 2).

Take the example of Chestnut blight (*Cryphonectria* [*Endothia*] *parasitica*) (Fig. 3). Asian chestnut trees were introduced to the United States in the early 1900s. Both American chestnut (*Castanea dentata*) and Asian chestnut (*Castanea mollissima*) have maintained the interactive relationships with their respective fungi for a long time. This relationship is a common phenomenon in both Asian chestnut trees and American chestnut trees. However, the species are different. In both American and Asian chestnuts, the relationship between the parasites and their hosts has a long history of interrelationships, and they have lived without any problems, like *E. coli* in our body. However, the damage was severe when fungi parasites on Asian chestnut trees moved to the USA were transferred to the

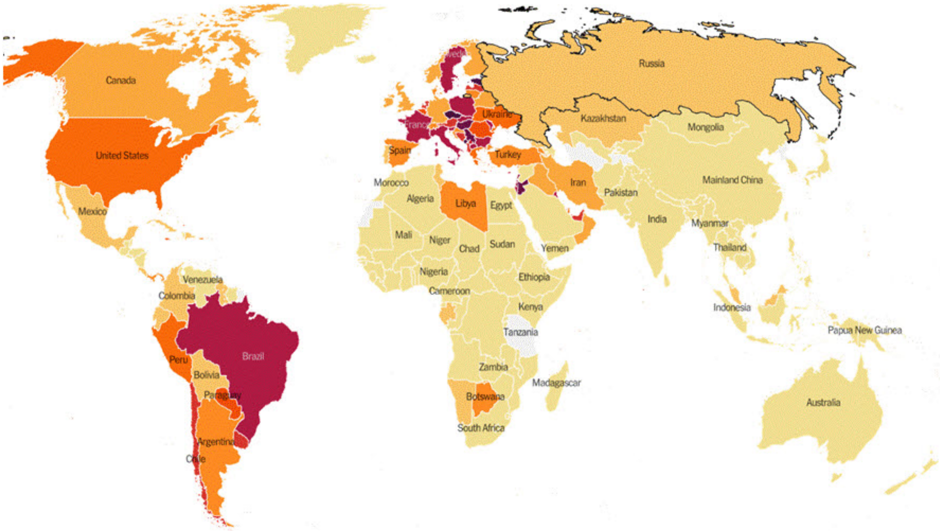

Fig. 1 A map showing the population size of who was infected by Coronavirus (COVID-19) around the world (https:///www.nytimes.com/interactive/2021/world/covid-cases.html). The darker the color, the higher the number of infections.

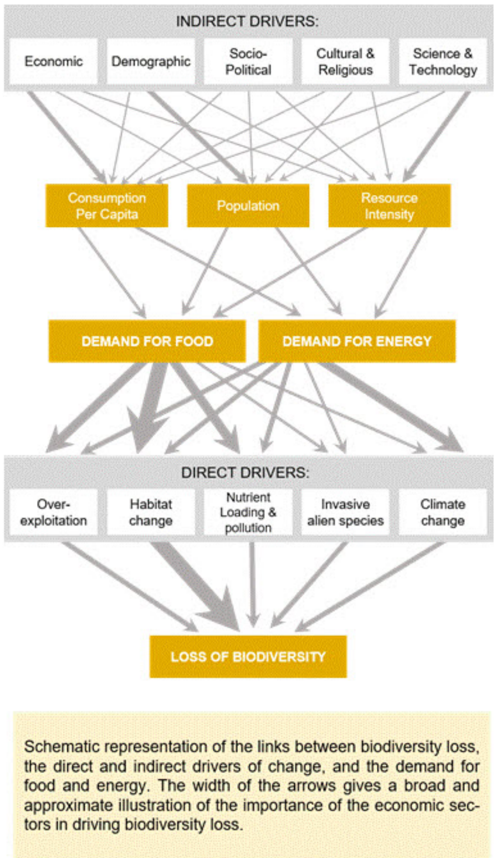

Fig. 2 Major threats to biodiversity (redrawn from UNEP and CBD 2022).

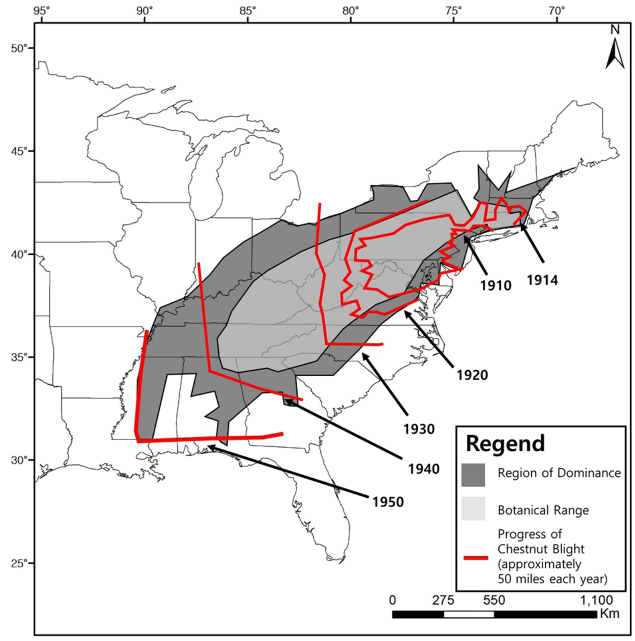

Fig. 3 A map showing the spread of Chestnut blight damage (redrawn from Forest Pathology 2022).

USA chestnut trees. This is the result of a sudden change in biological interaction due to the introduction of exotic species. The tree was a major forest tree species in the eastern United States with a wide geographical and topographical distribution from the northern Maine of the United States to the southern states of Alabama and Mississippi, and from the Feeding Heights to the Ohio Valley. The first infection was discovered in 1904, and almost all of the mature trees disappeared in just 50 years (Odum and Barrett 2005).

Where parasites or predators have long been associated with their respective hosts or prey, the effect is moderate, neutral, or even beneficial from the long-term viewpoint. However, most newly acquired parasites or predators are damaging. In fact, a list of the diseases, parasites, and insect pests that cause the greatest loss in agriculture or forestry would include mostly species that have recently been introduced into a new area, such as the chestnut blight, or that have acquired a new host or prey (Odum and Barrett 2005).

The cinnamon fungus (*Phytophora cinnamomi*) has had a dramatic effect on forest and scrublands of parts of Australia. In contrast to the specificity of chestnut blight, the cinnamon fungus attacks 50–75 percent of the species present in a forest. Because of the impact on so many plant species in a community, dependent wildlife has also been affected (Weste and Marks 1987). There are many other examples of forest devastation by pathogenic invaders (Campbell and Schlarbaum 1994; Lee 1989; Lee et al. 2018). The European corn ear worm (*Helicoverpa zea*), the gypsy moth (*Lymantria dispar*), the Japanese beetle (*Popillia japonica*), and the Mediterranean fruit fly (*Ceratitis capitate*) are just a few introduced insect pests that belong to this category (Odum and Barrett 2005).

There is also an example in Korea. As the fall webworm (*Hyphantria cunea* Drury), pine gall midge (*Thecodiplosis japonensis* Uchida et Inouye), and recent pine wilt nematode (*Bursaphelenchus xylophilus* [Steiner and Buhrer] Nickle) have gradually invaded, pine forests in Korea have been reduced to one-third of the previous levels. All of them are exotic pests outside their original ecological regions (Fig. 4).

Why are exotic species spreading so fast and causing so much damage?

The increased connectivity of the global human population has amplified the frequency and effect of biological invasions and disease outbreaks. New trade routes among previously disconnected countries (Aide and Grau 2004) as well as enhanced transportation technology (e.g., airplanes and barges) have increased both the frequency and magnitude of invasions and potentially deadly disease outbreaks worldwide. In addition, land use and climate change interact with human transportation networks to facilitate the spread of invasive species, vectors, and pathogens from local to continental scales (Benning et al. 2002; Dukes and Mooney 1999; Patz et al. 2004; Sakai et al. 2001; Smith et al. 2007).

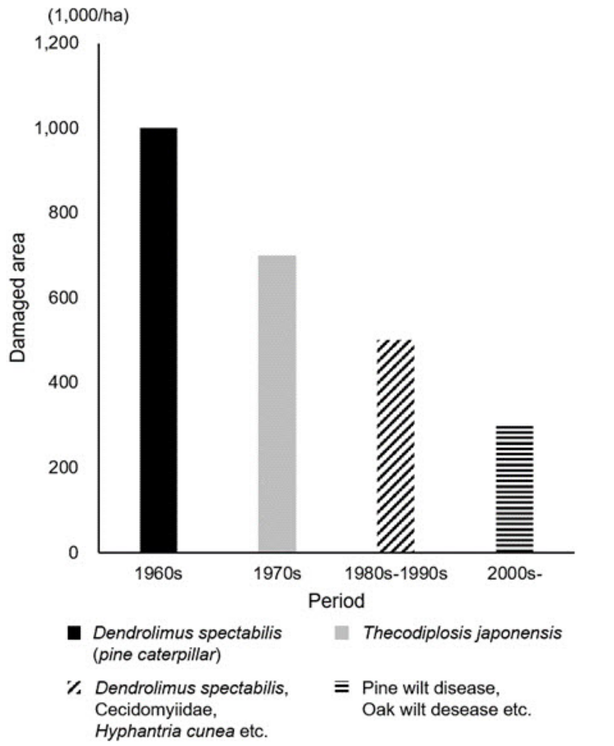

Fig. 4 Status of occurrence of forest pests and damaged areas by the period in Korea.

Alien pathogens are also spread via ballast waters (Carlton 2002), a well-known pathway of invasive alien species introduction, which creates a long-distance dispersal mechanism for human pathogens, which also explains the recent finding of enteric bacteria in the Antarctic (Takahashi et al. 2008). Ballast waters are important for the epidemiology of waterborne diseases, such as *Vibrio cholerae* (Ruiz et al. 2000). It reached Europe from South Asia and East Africa through Russia and the Balkans around 1830 and caused several infectious diseases through the routes of warships visiting various ports in Northern Europe. In 1991, in Peru, it killed more than 10,000 people (Bright 1998). Since 1992, it has been found in ballast tanks of South American cargo ships anchored in several North American ports (Takahashi et al. 2008). In ballast water tanks, biofilm matrices also provide 'protective refugia' for microorganisms including pathogens (Decho 1990; Drake et al. 2005). Harmful algal blooms increase in intensity and frequency in the Mediterranean Sea, significantly threatening ecosystems as toxin producers and agents of anoxic conditions (Streftaris and Zenetos 2006). Many diseases can spread through human-to-human contact and cause great damage worldwide: in addition to the most common pathogens, such as HIV (AIDS), *Neisseria gonorrhoeae* (gonorrhea), *Treponema pallidum* (syphilis), fungal pathogens (e.g., *Candida* spp.) can be transferred from person to person (David et al. 1997). Invasive species drive ecological dynamics at multiple spatial scales and levels of organization, through local and regional extinctions of native species (e.g., chestnut blight; Mack et al. 2000) and entire communities, shifts in native species richness and abundance (Parker et al. 1999), and altered fire regimes, water quality, and biogeochemical cycles (Bohlen et al. 2004; D'Antonio and Vitousek 1992; Strayer et al. 1999; Vitousek et al. 1996). Invasive species are the second leading cause (after human population growth and associated activities) of species extinction and endangerment in the USA (Pimentel et al. 2005). Because climate change and land use can exacerbate the spread and effects of invasive species across scales (Dukes and Mooney 1999; Simberloff 2000), identifying invasion and curtailing the spread of invaders is an enormous ecological and societal challenge (Lodge et al. 2006).

Invasive alien species are one of the major factors of human-accelerated global change. They threaten biodiversity, alter the ecosystem structure, functions, and services, incur enormous economic costs, and cause serious health problems to humans. The impacts on human health are indeed a big problem and also cause significant costs, but surprisingly, very few studies have analyzed this topic (Kumar and Singh 2020; Mazza et al. 2014).

Four categories were identified: invasive species (1) causing diseases or infections; (2) exposing humans to bite wounds/pain, bio-toxins, allergens, or toxic substances; (3) promoting diseases, injuries, or death; and (4) influencing other negative effects on human life. Invasive species affect human health in many ways, i.e., as alien pathogens and invaders that bring or promote parasites or produce toxins. Others cause denutrition/malnutrition or exert displaced or deferred impacts. Their negative effects are expected to intensify in the near future due to the increased opportunities of invasions related to climate change, the increased introduction pathways, and the synergic effects of climate change. It is essential to improve our understanding of the arrival routes, biological patterns, and mechanisms of influence of invasive species affecting human health. This is because all of this information is essential to develop more effective and rigorous policies to prevent and mitigate the negative effects of these species (Mazza et al. 2014).

It has been postulated that one reason why invasive species are so successful when entering a new biogeographic area is because they escape from their natural enemies. This is undoubtedly the case in many cases, but experimental evidence has not been well developed. Some people assume that running away from predators makes organisms much more successful by allowing them to invest more resources in competitiveness (Blossey and Notzold 1995). These relationships indicate that the ultimate success of the invaders is related not only to the nature of their habitat at the time of the invasion but also to the relationship that develops later. It has been suggested that over time, the invaders will achieve a new balance with the environment, and the population will stabilize. In some cases, these relationships develop rapidly, and others develop over long periods of time. An excellent example of the early lack of predators on invaders is *Eucalyptus* spp. (native to Australia) in California. *Eucalyptus* species were first introduced into California in 1850. Plantings were so extensive that one could drive for miles and miles and never lose sight of an individual of this genus. Although trees of this genus have had a large impact on their new environment (Robles and Chapin 1995), they actually have not spread much from where they were originally planted. One never saw damage to leaves of these trees by herbivores because evidently none of the local fauna could overcome the abundant natural defense compounds that Eucalyptus trees produce, whereas in their native habitat, herbivory is extensive.

Invasive species are not only diseases themselves but also cause diseases or infections

Ancient history provides many examples. Around 3000 years ago, many Hittite soldiers, who had just returned from Egypt, were killed by alien infections acquired from their Egyptian prisoners (Mazza et al. 2014; McMichael and Bouma 2000). Similarly, European smallpox and measles, brought to the New World by Spanish conquerors in the 16th century, reduced Mexico's population from 20 million to 3 million between 1518 and 1568, and in the next 50 years, decreased it to 1.6 million, providing an opportunity for the fall of the Aztec and Incas (Dobson and Carper 1996; Mazza et al. 2014; McMichael and Bouma 2000).

Black Death bacteria caused more than 200 million deaths from the late 19th century to the early 20th century, when rat fleas moved from Mongolia to Europe in the 14th century infected rats and spread them (Carmichael 2014). By the end of the 19th century, the Black Death bacteria, which had been transferred from China to California, still cause 1,500–2,000 victims worldwide every year (Butler 2014). During the last pandemics, the probable vector was the Norwegian rat (*Rattus norvegicus*) that disembarked from ships accompanied by *Xenopsylla cheops* and other fleas (Lounibos 2011). Syphilis in the late 15th and late 16th centuries, measles in Germany, which affected the population decline in the Fiji Islands in the 19th century, and the Spanish flu in the early 20th century, which killed 30 million to 60 million people worldwide, are exotic invasive diseases (Mazza et al. 2014; Simberloff and Rejmánek 2011).

Among them, many exotic virus-derived diseases such as severe acute respiratory syndrome (SARS), Nile encephalitis, Ebola virus, Dengue fever, microcephaly-causing virus, avian influenza, and acquired immunodeficiency syndrome (AIDS) are particularly feared (Pyšek and Richardson 2010). Their global spread is attributed to many factors, including the human colonization of most ecosystems, the increased number of domesticated animals and contact with them, and the global network of dispersal vectors created by humans traveling around the world (Smith et al. 2007). About 61% of more than 1,400 infectious human diseases also infect animals (zoonotic diseases), and 72%–75% of the emerging human diseases are zoonotic (Jones et al. 2008; Taylor et al. 2001). Some zoonotic diseases may spread in new regions, both due to the introductions of infected animals and, more generally, to human migrations.

Modern medicine has reduced the impact of such diseases, but there is still a need to be concerned because of the many opportunities for disease organisms to move quickly around the world, including many people with immunity to antibiotics and damaged immune systems (Baker et al. 2022; Saker et al. 2004).

What measures should we prepare to solve these problems?

What should we prepare to prevent the spread of the coronavirus? It is necessary to apply exotic-species management measures. Prevention comes first in the management of exotic species, and measures such as extermination and control are required according to the diffusion phase (Fig. 5). To prepare with preventive measures, the characteristics of the relevant creature should first be identified, and the environmental conditions preferred by the relevant creature should be identified. We then synthesize and organize such information and prepare it for the target local

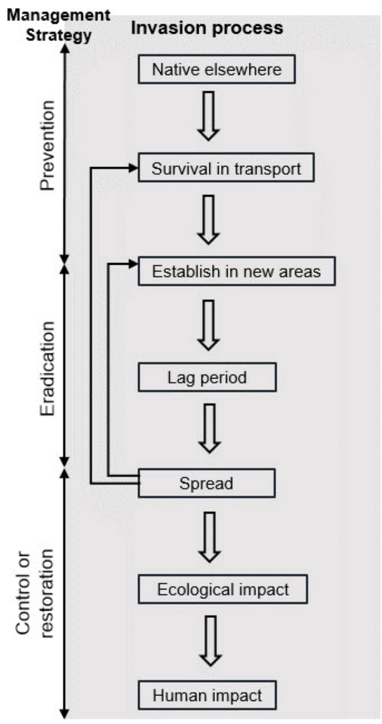

Fig. 5 The process of introduction, settlement, and diffusion of exotic species and management strategies for each stage (redrawn from Lockwood et al. 2013).

environment to anticipate and prepare for the possibility of entry, proliferation, or intrusion. These arrangements are often carried out by obtaining information in areas where exotic species invade and cause problems. Therefore, information obtained from the initial origin is important. The information needs to be collected and shared accurately and systematically. In particular, in today's worldwide-connectivity environment, rapid collection and sharing of such information are urgently needed, and in this regard, the establishment of cyber infrastructure for international information sharing is desperately needed. In addition, the local or national government shall prioritize prevention rather than post-processing and thoroughly prepare for it. To this end, it is essential not to look at the disease itself, but to secure a wide view of the background of the disease, especially the ecological background (Crowl et al. 2008; Lockwood et al. 2013).

According to the theory of resource availability that accounts for the spread of exotic species, the possibility of exotic species invasion increases as the availability of resources increases (Fig. 6). The availability of resources increases as they move to the right below the equivalent line of supply and absorption in the graph using the X-axis as the resource supply and the Y-axis as the resource absorption volume. According to this theory, resources can be increased by an increase in supply (a→d), a decrease in absorption (a→c), or both, increasing the chances of invasion of exotic species (Davis and Grime 2000). In the case of coronavirus, the resources are human beings.

When reviewing the coronavirus management measures we have been carrying out, there was information from China, the site of the coronavirus outbreak, but the first prevention was not successful due to hesitation in blocking international exchanges. However, it did achieve results for some time in curbing the spread through dedicated efforts

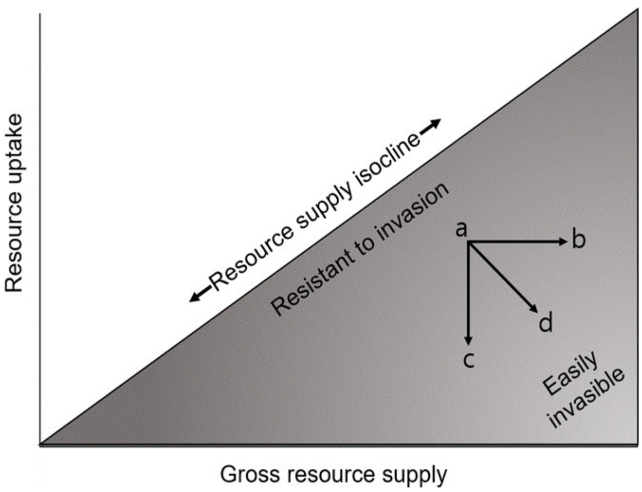

Fig. 6 A schematic diagram showing the theory of resource availability fluctuations and the possibility of exotic species invasion (redrawn from Davis and Grime 2001).

of medical staff and rapid diagnosis and response through public cooperation. But another preventive measure was needed as there was a high possibility of the re-proliferation and mutation of the latent coronavirus after that. The strategy to expose human resources to coronavirus as little as possible by securing information about places where the supply of resources is increasing, that is, places where many people are likely to gather, could be a way to reduce the resource supply and a prevention path to reduce their spread.

Necessity of additive measures: systematic monitoring and information exchange

To adequately address the environmental and societal problems of invasive species and the spread of diseases, such as avian-dispersed H5N1 avian influenza, SARS, COVID-19, and so on, we must develop a continental-scale network to: (1) monitor changes in the local and geographic distributions of invasive species and infectious disease (Drake and Bossenbroek 2004; Peterson et al. 2003); (2) predict the processes and environmental conditions that promote the spread of invasive species and disease vectors from individual sites to regions and the continent (Hufnagel et al. 2004); and (3) understand the long-term ecological and evolutionary responses to ecosystem invasion (Mooney and Cleland 2001; Strayer et al. 2006).

A coordinated cyber-infrastructure, along with improved data portals, would enable more effective integration of databases from information exchange agencies that monitor invasive species or infectious diseases (Crowl et al. 2008). A national database on invasive species and vectors, as well as key environmental features to identify potentially suitable habitats, would help scientists to forecast the spread and effects of invasive species and diseases (Ricciardi et al. 2000). A number of such networks currently exist, including the Global Invasive Species Information Network, the Inter-American Biodiversity Information Network, the Non-indigenous Species Network, and the Non-indigenous Aquatic Species Network (Meyerson and Mooney 2007). Because exotic species and disease spread encompass multiple scales of interacting biotic and abiotic factors, it is necessary to carry out large-scale monitoring while conducting fine-scale experiments and observations. Understanding the transport vectors, the local environmental conditions, autecology, and the population and community ecology of the organisms is required to understand new species and pathogen introductions, and subsequent invasion success requires an understanding as well. This framework can only be successfully employed if it is designed with scale-specific hypotheses and questions (Baker et al. 2022; Crowl et al. 2008).

Invasive species and new diseases pose the same problem; each is a new species with the potential to modify the existing structure and function of ecosystems and the ecosystem services upon which people rely. Furthermore, some new pathogen species can directly impact human health. Thus, the addition of new species (invasive species or diseases) to an ecosystem can affect the well-being of people, whether through economics or health. Many species that are already present influence human well-being positively or negatively, and we must bear in mind that the introduction of new species may result in novel biotic interactions and modify existing ones in the current ecosystems (Crowl et al. 2008).

Traditional epidemiology has often ignored the ecological perspective, but it usually corresponds to host–pathogen or host–vector–pathogen population ecology. Therefore, an ecological understanding of the population interaction of the related organisms is necessary to assess (and reduce) the impacts of invasive species and diseases. We therefore need to examine the problem at a much greater geographical level, using networks of study sites to address a series of questions (Crowl et al. 2008).

First, what causes the variability between locations in the establishment of, impact of, and success of countermeasures against new species? This knowledge will improve our ability to predict which locations will be susceptible to invasion by a particular species, the potential effect on the local ecosystem and people, and what the most effective local countermeasures will be. Detailed ecological study is required at a variety of pre-selected locations to address how specific species characteristics (e.g., growth, reproduction, and survival) under different local driver values (e.g., gradients of temperature, moisture, elevation, and human activities) affect biotic interactions and, thereby, human well-being (Crowl et al. 2008).

Then, how do propagules of new species arrive at a location? This requires knowledge at regional and global scales. Therefore, we can assess how a particular new species becomes available for invasion, what controls invasion rates, and how preventative measures can be developed. Only through observation on a larger scale can invasion fronts and their movements be monitored and studied (Hengeveld 1989). This requires specific biotic information such as species characteristics related to propagule numbers emerging from surrounding populations and vagility, but today, this may largely be a function of external “drivers” such as markets (e.g., plant and animal trades) and transportation systems (e.g., regional connectedness and modes of transportation providing friendly transient environmental conditions for propagules). Compared to the previous question, the network of study sites addressing this question needs to contain a greater number of uniformly distributed sites, because proximity to propagule sources, rather than “driver” differences, is the key factor (Crowl et al. 2008). Consequently, a network designed to address one hierarchical level is useful, but only a slightly greater design effort may allow all hierarchical levels to be addressed and synergistic effects can emerge when cross-hierarchical questions are simultaneously addressed. These considerations will allow network construction to better address issues in invasion and disease ecology, and better enable networks to predict and forecast emerging threats (Crowl et al. 2008). In addition, a more fundamental measure is ecosystem management. Infectious-disease experts expect the possibility of viral infectious diseases to increase in the future. They believe that the background is due to the destruction of the natural ecosystem due to rapid industrialization, urbanization, and climate change caused by humans, and viruses that remained in their areas in nature move to humans, a new host, to adapt to environmental changes. Climate plays a leading role in determining the distribution of organisms. As the climate is changing rapidly, the distribution range and interaction system of organisms are shaking. They see these environmental changes as the background of the spread of the virus (Jeong 2021; UNEP and ILRI 2020).

Infectious-disease scholars believe that humans were infected with the virus in the process of indiscriminately accessing the living environment and activity by-products of bats that have coexisted with the virus and eating the meat. And the cause of the damage is thought to be the sudden change in population interaction as with previous infectious disease damage. Therefore, in order for us to reduce such damage, humans must live without invading natural areas such as bat habitats as much as possible. In other words, protecting the natural ecosystem and minimizing environmental changes, including climate change, and maintaining the natural area well may be the way to suppress the spread of viruses (Jeong 2021; UNEP and ILRI 2020).

Conclusions

It is known that humans were infected with the coronavirus in the process of indiscriminately accessing the habitat of bats that have coexisted with the virus and eating the meat. That is, the coronavirus problem is an ecological problem caused by the sudden change in population interaction. The map showing the intercontinental difference of coronavirus infection degree resembles the spatial distribution of exotic-species damage. In this respect, ecosystem management measures such as exotic-species management measures could be used as a reference to prevent and suppress the spread. Prevention comes first in the management of exotic species, and in order to come up with preventive measures, it is important to collect information on the characteristics of related organisms and their preferred environment. It is time for the establishment of an international integrated information network for collecting and exchanging information between regions and countries to be urgently required.

Viral infectious disease experts do not see the cause of the outbreak of infectious diseases as the virus itself, but as a matter of the relationship between humans and viruses or the living areas of viruses. Therefore, they see the fundamental countermeasures against viral infectious diseases as restoring natural systems that have been damaged by human social and economic activities so that humans and viruses can coexist separately.

On the other hand, they predict that such infectious diseases will increase further in the future in a rapidly changing environment, including climate change. It is time for a systematic ecosystem management strategy that can solve environmental problems and at the same time serve as a countermeasure to prevent infectious diseases to be required. It is possible to assume models in which natural and human environments can continue sustainable lives in their respective locations, such as the multiple use model concept applied to protect biosphere reserves (Jeong 2021; UNEP and ILRI 2020; UNESCO 1996).

Abbreviations
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The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request

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The author declares that they have no competing interests.

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