



## Review Article

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## Hitchhiking microbes: Declining biodiversity &amp; emerging zoonoses

Gurudas Nulkar<sup>1</sup>, Madhura Bedarkar<sup>2</sup>, Ketaki Ghate<sup>3</sup> & Sakshi Nulkar<sup>4</sup>

<sup>1</sup>*Symbiosis International University*, <sup>2</sup>*Symbiosis Institute of Business Management*, <sup>3</sup>*Oikos for Ecological Services* & <sup>4</sup>*Intern and wildlife researcher, Ecological Society, Pune, Maharashtra, India*

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The connection between nature conservation and human wellbeing is well known, however, the role of declining biodiversity and emerging diseases is relatively less studied. The presence of a thriving biological diversity is known to have therapeutic effects on human health. On the other hand, human economic activities have contributed to a sharp decline in species, resulting in poor ecosystem health. Several studies have shown how microorganisms have switched from animals to humans, leading to novel diseases. This review describes studies on zoonotic diseases and biodiversity, with examples from India. It is argued that conservation of biodiversity and ecosystems and changes in economic activities must be made to ward off new diseases, and why cooperation between ministries is critical to restrict the decline of biological diversity in a megadiverse country like India.

**Key words** Biodiversity - coronavirus - ecosystems - One Health - zoonoses - zoonotic diseases

### Introduction

The International Union of Geological Sciences terms the current period on earth as the Holocene epoch<sup>1</sup>. This period in earth's history began nearly 11,700 years ago, after the last major ice age. However, it is often called the Anthropocene, which indicates the dominance of *Homo sapiens* on the planet. Since man embraced settled agriculture, the ecological footprint of humanity, on the planet's resources<sup>2</sup> has been continuously increasing. While bestowing a more secure and comfortable life for ourselves, the consequences of this lifestyle upon the living and non-living entities of the biosphere, have largely been ignored. The 7.6 billion humans represent just 0.01 per cent of all living organisms by weight, but the agricultural and economic activities required to

maintain the population have led to the loss of 83 per cent of all wild mammals and half of all known plants<sup>3</sup>. This decline in biodiversity has had multiple consequences, some immediately noticeable, like species extinction, and others which could manifest in the long run. The alarming rise in the incidence of novel diseases, specifically the recent COVID-19 pandemic, is one such short run consequence.

The Stockholm Conference of 1972 was termed as the 'birth of the green generation'<sup>4</sup>, as it created a consensus among nations that the loss of biodiversity and degradation of ecosystems are national and global problems. These issues are captured in the Sustainable Development Goals (SDG) as critical to sustainable development. Fiona Harvey<sup>5</sup> is optimistic that the signatories to the Conference of Parties (COP) will

work on the nationally determined commitments, leading to pollution reduction, species conservation and ecological restoration. It is expected that these would keep a check on climate change and improve ecological services on the planet. However, in light of the current pandemic, research showing the interconnectedness of declining biodiversity and the occurrence of novel pathogen in humans, is offering compelling arguments for conservation of natural systems.

### **Humans and biodiversity: a crucial relationship**

By definition the biodiversity is the variability among living organisms on the planet. It includes diversity within species, between species and of ecosystems<sup>6</sup>. It is a critical element in earth's life support system, and determines the sustenance of human societies<sup>7,8</sup>. India hosts a rich biological and physical diversity, being home to eight per cent of the world's living organisms. The diversity of natural ecosystems ranges from forests, mountains, wetlands, estuaries and mangroves, grass lands, swamps, deserts and glaciers. The Western Ghats and the Eastern Himalayas are enlisted in the global 25 hotspots of biodiversity on the earth. The country hosts a population of rare animals and nearly 2.9 per cent of world's threatened species<sup>9</sup>.

Much like the external environment, the human body is also an ecosystem of microbes, and comprises bacteria, archaea, fungi, protozoans and viruses<sup>10,11</sup>. They inhabit human organs and our body provides them with food<sup>12</sup>. From an evolutionary perspective, Rook<sup>13</sup> has proposed that any organism that has survived a significant part of mammalian evolution might have been 'written into' the mammalian genome. Many relatively harmless microorganisms have been present throughout mammalian evolution. Human body recognizes them as harmless friends and this is poetically referred to as the 'Old Friends Hypothesis'<sup>14</sup>. Their metabolism inside human body, has an important function in human health.

Our relationship with other life forms is carried into the external environment. Our needs of food, water, clean air and benign climatic conditions are fulfilled through the ecosystem services. These services arise from the exchange of matter and energy between the living organisms and their surroundings. This interaction begets the life sustaining ecological services, on which human societies rely on for their existence. On the planet, only plants produce their own food and other organisms live off the surplus food that they produce. There is mutualism and competition in

this relationship, which is the backbone of ecosystem productivity. Many studies show that the resilience of the ecosystems increases with a larger functional biodiversity<sup>15,16</sup>.

Biodiversity offers not just cultural and spiritual values, but is also critical in human agriculture. Diversity of birds, insects, reptiles and amphibians keep a check on crop diseases while microorganisms in the soil break down minerals into usable form for crops. This assistance from other life forms enables agricultural production, maintenance of livestock and provisioning of insects for pollination or disease control. When aiming for a robust and sustainable farming system, it is essential to preserve, support, use and promote biodiversity<sup>17</sup>.

Human health, as defined by the World Health Organization (WHO) is "a state of complete physical, mental and social well-being and not merely the absence of disease" or infirmity<sup>18</sup>. It has been shown that a proximity to nature and biodiversity has beneficial effects on human health and wellbeing<sup>19,20</sup>. Several studies have demonstrated how a contact with nature, including urban green spaces, can lead to measurable psychological<sup>21</sup>, physiological<sup>22</sup> and health benefits<sup>23</sup>. A brief visit to forests, parks or natural environments has shown to reduce stress and fatigue<sup>24,25</sup> and trigger a positive mood<sup>26</sup>.

Ostfeld and Keesing<sup>27</sup> have suggested that biodiversity provides sources of preventive and therapeutic agents and nutrition. The existence of high species diversity increases the barriers to the transmission of infectious agents. This reduces risk of human disease. Biological and physical diversity and their interactions are critical for social and ecological resilience<sup>28</sup>. Human health and wellbeing is largely dependent on ecosystem functioning and the provision of goods and services that is supported by biodiversity. Ecosystems also render services including food, clean air, fresh water, medicines, climate regulation, pest and disease control and disaster risk reduction. Therefore, biodiversity is considered to be an important determinant of human health and its conservation and sustainable use can support human health<sup>29</sup>. The Convention on Biological Diversity (CBD), ratified by 196 States and the European Union, considers biodiversity as the foundation for human health, as it underpins the functioning of the ecosystems on which we depend for our food and fresh water; aids in regulating climate, floods and disease<sup>30</sup>. Furthermore, it is because of a

healthy biodiversity that we derive recreational benefits and aesthetic and spiritual enrichment<sup>30</sup>.

### Loss of biodiversity and emerging diseases

All living beings in nature have natural predators. Within a landscape, diverse communities coexist and the prey-predator relationship keeps a check on populations. The food chain has evolved in a way that no species can dominate the chain. It is thus critical to conserve and retain the physical and biological diversity in its natural composition. The 'Biodiversity Hypothesis' proposes that contact with natural environments and biodiversity, including microbiota, enriches the human microbiome, promotes immune balance and protects from allergy and inflammatory disorders<sup>31</sup>. The human body is protected with two layers of biodiversity - microbes within human body and those in the environment we live in<sup>32,33</sup>. The outer layer is dependent on the variety of life in soil, waters, plants and animals around us. The inner layer is in the gut, skin and air passages. The inner layer is dependent on colonization from the outer layer<sup>34</sup>. Viruses, bacteria and other types of microbes are capable of inflicting diseases in plants, animals and humans. In a healthy ecosystem, they are usually constrained geographically and seasonally by ecological relationships and the regulatory functions of ecosystem services. Researchers have established an association between biodiversity loss and human health<sup>25,35,36</sup>. Keesing *et al*<sup>37</sup> reported that in several case studies, the species most likely to be lost from ecological communities as diversity declines are those most likely to reduce pathogen transmission.

The contiguous existence of humans with domesticated and wild animals, happens through food, shared landscapes and companionship. This enables the transmission of microbiota to humans. The diseases such as rabies, leptospirosis, plague, scrub typhus, Nipah virus, Kyasanur forest disease, Japanese encephalitis, and various types of influenza are causing small and consistent outbreaks in animal and human populations across India. The sharp rise in industrialized domestication of animals offers increasing opportunities for pathogens to pass to humans, through the biophysical environment. This has resulted in a worldwide increase in outbreaks of potentially epidemic-causing zoonoses. Around 60 per cent of all infectious diseases and 75 per cent of all emerging infectious diseases<sup>18</sup> in humans are zoonotic.

Hammen and Settele<sup>38</sup> have noted that some of major global changes that have developed, including

deforestation and climate change, are able to impact the biodiversity-human health relationship. Ostfeld and Keesing<sup>27</sup> state that biodiversity provides sources of preventive and therapeutic agents and nutrition. Sandifer *et al*<sup>23</sup> have suggested that humanity is at a key juncture, as biodiversity loss increases with population growth, climate change and uncontrolled development. They examined the existing research on the relationship between human health benefits and nature and biodiversity and developed an extensive list of documented health effects.

Human interventions in landscapes alter the species composition and population sizes, resulting in reduced ecosystem productivity and the ensuing ecosystem services. Interventions alter the natural influencers on infectious agents range and activity<sup>39</sup>. Economic activities release toxic substances which harm ecosystems at local levels; and accelerate climate change at the global level. The resource consumption of seven billion individuals has changed the structure and functioning of the planet's ecosystems. There has been an irreversible loss of species leading to an accelerated decline in ecosystem services. Over time, the complexity of the ecosystem is compromised and organisms are forced to seek out new habitats. Some of the potentially pathogenic microbes hitchhike on newer animal hosts from their original habitats and enter human ecosystems giving rise to new diseases<sup>40</sup>. How many of these novel, potentially pathogenic microbes are able to reach humans, is influenced by climatic and micro-environmental conditions. The 2016, United Nations Environment Programme (UNEP) report has suggested that the risk of new diseases and their "amplification increases with the intensification of human activities surrounding and encroaching into natural habitats". This enables pathogens in wildlife reservoirs to spill over to livestock and humans. Ecological disturbances such as agricultural intensification and human settlement, or encroachments into forests and other habitats<sup>41</sup> can trigger the spill over. The World Economic Forum<sup>42</sup> has attempted to quantify the loss of species on the planet. The numbers, while shocking, reveal what human interventions have done to the biological diversity of the planet.

### Change in biodiversity and zoonoses in India

The deadly Kyasanur forest disease (KFD), is an example of such spill-over case in India. KFD is caused by the KFD virus identified in 1957. The virus was isolated from a sick monkey from the Kyasanur

forest in Karnataka State of India. Since then, about 400-500 human cases per year have been reported. Hard ticks (*Hemaphysalis spinigera*) are the reservoir of KFD virus and once infected, remain so for life<sup>43</sup>, contributing to disease transmission. Rodents, shrews, and monkeys are the other common hosts for KFDV. These animals share landscapes and food with people, and thus enable the passage of the pathogen into human species.

Rabies, another disease with a 100 per cent fatality rate, is not an emerging infectious disease, but has existed for a long time. As a rabies-endemic country<sup>44</sup>, India is estimated to have 20,000 rabies deaths every year, among 20 million dog bite cases a year. Nearly 36 per cent of the world's rabies deaths occur in India every year. This disease has the potential to spill-back into healthy populations of wild canids, small mammals and bat species through dog bites, as free-ranging dogs are increasingly found to have conflicts with wild animals<sup>44</sup>.

Nipah virus (NiV) which causes severe acute febrile encephalitis in humans, is another emerging infectious disease. This virus is known to be shed in the faeces and urine of bats (predominantly of genus *Pteropus*). The NiV is speculated to have emerged in Malaysia owing to two important reasons, firstly, deforestation and planting of fruit orchards thus enabling increased interactions of fruit bats and humans, and secondly, the growth of industrialized pig farms where pigs act as reservoirs of the virus, enabling the persistence of the virus. Following the first outbreak in Malaysia<sup>40</sup>, seroprevalence studies in bats showed prevalence of antibodies to NiV and other closely related viruses of the family *Paramyxoviridae* across most of Southeast Asia. Studies of transmission patterns of Nipah in North-East India showed a higher and easier chances of virus spill over from bats to human population<sup>45</sup>. Studies in Bangladesh showed the transmission of NiV from bats to human through date palm sap collection<sup>46</sup>. The sap is harvested from an incision in the tree trunk. The sap oozes out into an open clay pot. Studies using infrared camera have shown that *Pteropus giganteus* bats frequently visit date palm sap trees and lick the sap during collection<sup>47</sup>. NiV can survive for days on sugar-rich solutions such as fruit pulp<sup>48</sup>. As some of the palm is consumed a fresh juice, a pathway to enter human systems<sup>46</sup> opens up for the virus.

### **Growing economy, increasing consumption: Drivers of biodiversity change and emerging diseases**

Jones *et al*<sup>40</sup> studied disease records from United Kingdom in the period between 1940 to 2004 and found an increase in the rate of emerging infectious disease during this period. Of the 335 documented events, 60.3 per cent were zoonotic and 71.8 per cent of the zoonoses originated in wildlife. Loss of biodiversity and ecosystem productivity have been negative externalities of the global economic system<sup>49</sup>. Changing land use for economic reasons has resulted in the loss of habitat, fragmentation and reduced food availability to non-human organisms. As production of goods and services rises, the industries which feed the growth, consume more resources. The economy is fed with minerals, many of which come from open cast mines. Increasing mining has led to a sharp decline in natural forests, which has forced out apex predators and increased human-animal conflicts. This has denuded millions of hectares of forests all over the world. Nearly 10 per cent of the deforestation in the Brazilian Amazon between 2005 and 2015 was due to mining activities<sup>50</sup>. The Indian government, in 2019, released 1.7 lakh hectares of forest land in Chhattisgarh for open cast coal mining<sup>51</sup>. Economic growth requires infrastructure. Roads, railways, airports and dams have caused severe deforestation. Three major infrastructure projects sanctioned in 2020 in Goa, will go through the Mollem National Park, diverting over 250 hectares of forest land for commercial purposes. Of this, 170 hectares falls within protected areas. Mollem is host to a large biodiversity and several threatened species are found here<sup>52</sup>. The proposed Hubballi-Ankola rail project in North Karnataka will divert 727 hectares of pristine forests and 2.2 lakh trees will be fallen. This is part of the ecologically fragile Western Ghats, home to rare and endangered flora and fauna<sup>53</sup>. Severe deforestation in Chhattisgarh has pushed herds of elephants to areas where people are not used to living with them<sup>54</sup>. Without extensive surveillance for potentially pathogenic microbes in wildlife, scientists cannot predict which pathogen will be displaced in these assaults on their habitats.

The majestic Himalayan mountain range is the provider of fresh water to people, farms, and estuarine ecosystems. For millions of years, the rivers originating here have brought alluvial soil onto the flood plains.



However, the spate of large dams built on the rivers has nearly stopped the flow of nutrients from the hills to the plains. This has had severe impact on the downstream ecosystems, as is seen from the loss of key riverine species.

Intensification of agriculture and the use of chemicals has stressed insect populations. Large dams built to support intensive farming, have submerged forests and created new breeding grounds for various species of mosquitoes. Urban sprawls have broken wildlife corridors, fragmented habitats and displaced fauna. Moreover, urban sewage comprising of faecal matter and household chemicals have impacted the diversity of riverine ecosystems. Large windmill farms have killed several apex birds and this has contributed to weakening the food chain. Climate change is another factor affecting biodiversity. The most vulnerable terrestrial ecosystems tundra, boreal forest, mountain, and Mediterranean-type ecosystems; mangroves and salt marshes; coral reefs and sea ice biomes are virtually certain (>99% probability) to experience severe impacts<sup>55</sup>. The biodiversity in these regions will decline significantly, displacing new microbes out of their habitats, and could also unlock potential pathogens from deep permafrost as they thaw out. The alarming rise in the frequency of extreme climate events, demands immediate and urgent measures to improve the resilience of ecosystems.

Scientists from all over the world have warned that maintaining the health and wellbeing of the human population will be increasingly difficult on a planet with polluted resources, deteriorating biodiversity and social instability<sup>56</sup>. Nine out of 14 terrestrial biomes have breached the safe limit of 90 per cent of biodiversity intactness<sup>57</sup>. The juggernaut of economic growth is backfiring on humans, in the form of diseases, social inequalities, crime and wars, all of which go against the concept of welfare. The ecological costs of current lifestyles are being paid by a burgeoning healthcare industry<sup>58</sup>. The Indian healthcare market is expected to have done a business of over US\$ 193 billion in 2020<sup>59</sup>. Beyond human health, scientific evidence around the world shows that biodiversity is critical to sustaining the businesses around the world. The natural environment has a crucial role in the health of a nation's economy and biodiversity provides critical inputs to industry<sup>60</sup>.

### **The way ahead**

Several zoonotic disease outbreaks in the past few decades have highlighted the need to approach

the issue of health across the globe in a holistic way. The need is more urgent in a country like India, which has some of the highest diversity of life forms, with many communities living in biodiverse areas, having a high interface of wildlife, humans and livestock. In a megadiverse country like India, it is prudent to assume that the diversity of potential disease-causing organisms is also greater, only a fraction of which are currently known to science. The zoonotic disease outbreaks in India like Nipah virus, Swine flu, KFD, *etc.* have pointed to a need for continuous surveillance for detecting zoonoses early and initiating timely and efficient management of these diseases. However, the field of studies concerning zoonotic diseases and their implications are largely isolated, institutionally, with studies undertaken by ecologists, public health experts, and agriculturists, all working in isolation and there is hardly any public awareness and engagement seen. National Centre for Disease Control (NCDC) of India has a Division of Zoonotic Diseases Programmes (DZDP). There are three programmes being run through this: Inter-sectoral Coordination for Prevention and Control of Zoonotic Diseases; National Rabies Control Programme and the Programme for Prevention and Control of Leptospirosis<sup>61</sup>. In the recent national budget of 2021-2022, the government has made a provision for establishing The Institute of One Health, to manage endemic and emerging epidemic threats of zoonotic diseases.

The concept of One Health is a holistic approach for combating the emerging global health concerns with transdisciplinary efforts, especially with respect to zoonotic diseases. The One Health approach considers health at three levels, namely, the individual level, the population level and the ecosystem level<sup>62</sup>. It considers the rapidly evolving environments which enable emergence and support the transmission of infectious diseases affecting any living system capable of harboring disease-causing organisms, while allowing the opportunity to use data to visualize predictive models of disease spread and control.

International efforts to control biodiversity loss started off with the formation of The Convention on Biological Diversity (CBD) on December 29, 1993<sup>63</sup>. Currently there are 196 parties. The CBD is comprehensive, but national reporting has not been encouraging. This needs to strengthen as biological diversity knows no national boundaries. Without close cooperation, conservation will not be easy. Many countries are already undertaking species and habitat

conservation. However, this is hardly sufficient. A significant change must be made to reduce the ecological impacts of human economic activities. For this, multiple strategies must be deployed. Reforestation on degraded landscapes, conservation of wetlands, estuaries and mountains, species conservation, dealing with human-animal conflicts, preserving habitat diversity, pollution abatement, programmes to remove non-native and invasive species, native plantations, are just some of the various approaches which can influence improvement in biological diversity. In a diverse country like India, it is not possible just for the Ministry of Environment, Forests and Climate Change (MoEFCC) to carry out this work single-handedly. Concerted efforts and cooperation between multiple Ministries including that of Agriculture, Health, Water resources, Earth Sciences, Fisheries, Animal Husbandry & Dairying, Mining, Commerce and Industries, and others, are critical to the success. This is critical to warding off new diseases. If this urgent need is not recognized, humanity, as a whole must prepare to face the threat of diseases even more lethal than the COVID-19 pandemic. This will undoubtedly lead to an unhealthy society, and also impose a mammoth burden on national economies.

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*For correspondence:* Dr Gurudas Nulkar, Trustee Ecological Society, Adjunct faculty Symbiosis International University, 893 Sadashiv Peth, Pune 411 030, Maharashtra, India  
e-mail: gurudasn@gmail.com