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Review Article

Biodiversity, a review of the concept, measurement, opportunities, and challenges

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Abstract

Biodiversity is a crucial part of nature's precious assets that provide many human needs and insures against environmental disasters. Scientists have not yet reached a consensus on the definition of biodiversity; therefore, we will discuss various interpretations. Most biodiversity studies have focused on species diversity, but biodiversity has a more comprehensive aspect. Due to the extinction of plant and animal species, climate change, air pollution, advances in technology and industry, development of agricultural and urban lands, and changing human attitudes toward species, ecosystems, and landscapes, biodiversity has become a more attractive topic for researchers over the last decade. When diversity is being measured, a precise taxonomic classification of the subject must be made. Although many diversity indices and models have been proposed to quantify diversity, many of them confuse researchers. The use of new approaches, such as considering functional and genetic characteristics (functional diversity and phylogenetic diversity, respectively) has revealed hidden functions, services, and sustainability of ecosystems. These valuable measures have also created new issues. The variety of introduced indices and the multidimensionality of ecosystem services, and the different roles of species in other ecosystem functions have raised new questions and numerous complexities. Therefore, researchers have tended to use multidimensional and trans-ecosystem approaches. In this review article, the definitions and concepts of biodiversity and its historical background are presented, and then new ideas, challenges, and opportunities are discussed.

Keywords: Biodiversity, diversity indices, ecosystem functions, living organisms

Introduction

Biodiversity encompasses various life forms on earth, including a variety of genes, species, ecosystems, and ecological processes (Agapow *et al.* 2004, Rathoure and Patel 2020). It is one of the key concepts in ecology and environmental protection that sustainable development depends on its efficient conservation (Wunder and Wertz-Kanounnikoff 2009, Haines-Young and Potschin 2010, Williams *et al.* 2020). At the United Nations Conference on Environment and Development (UNCED), 'Biological diversity' was defined as the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems (Parminter 1992, Sundriyal 1996, Eschwilk 2006).

However, scientists have not yet reached a consensus on the definition of biodiversity, and therefore a variety of explanations have been proposed. For example, in another description of biodiversity, scales taken into account and biodiversity are defined as the transformation of ecosystems and its components, which generally make into account alpha, beta and gamma diversity. Alpha, beta, and gamma diversity means diversity within habitats (local scale), among habitats and in landscape-scale, respectively (Lust and Nachtergale 1996, Ress and Juday 2002, Ishida *et al.* 2005). In most studies of biodiversity, alpha and beta diversity have been considered (Pitkanen 1998, Erfanzadeh *et al.* 2015, Heydari *et al.* 2017).

Ecologists categorized biodiversity in three primary levels, including genetic diversity, species diversity, and ecosystem diversity. The genetic diversity referred to all the different genes that may be contained in all individual animals, plants, fungi, and microorganisms and allow them to adapt over time to environmental changes (Whittaker 1972, Peet 1974). On the other hand, species diversity is defined as the differences within and between populations of species and among different species or the mathematical expression of the variety that use three components of community structure, i.e., 1. species richness 2. abundance, and 3. evenness (Hamilton 2005). However, genetic diversity usually applies to intra-species differences, while species diversity usually applies to inter-species disputes. Finally, ecosystem diversity contains all the different habitats, biological communities, ecological processes, and variation within individual ecosystems (Whittaker 1972, Peet 1974, Hamilton 2005, Jurasinski *et al.* 2009, Tuomisto 2010). These divisions will help answer many ecologists' questions. For example, assessing the impact of climate change on biodiversity requires evaluating and measuring diversity at national, international, and even worldwide scales (Colwell *et al.* 2017).

One of the controversial dimensions of biodiversity is its definition that may be related to different ecology branches. For example, in taxonomy, a taxonomist defines a list of species or taxa as diversity; in genetics, allelic diversity is a functional expression of the variety. However, for a plant sociologist, records of species, their distribution, and types of vegetation are defined as diversity.

Diversity plays an essential role in providing ecosystem services (e.g., Tahmasebi *et al.* 2017). Ecologists believe there is a positive relationship between biodiversity and ecosystem functioning and sustainability (Widdicombe *et al.*, 2002; Penuelas *et al.*, 2020). Although contradictory results have been reported in the past decades, this perspective reveals a positive relationship between biodiversity and ecosystem functioning and sustainability after the conference held in Paris, France, in December 2000, entitled Biodiversity and ecosystem functioning.

In recent years, highlighting ecosystem multifunctionality (the ability of an ecosystem to provide multiple functions and services) and various aspects of biodiversity (taxonomic, functional and phylogenetic) (Fig. 1), researchers have been addressing many unanswered questions (Le Bagousse-Pinguet *et al.* 2019, Zirbel *et al.* 2019) that require more extensive research. Also, multidimensional concepts of sustainability (for example, resistance and recovery) have increased the complexity of these relationships (Palmer *et al.* 2016, Kharrazi *et al.* 2016, Gligor *et al.* 2019).

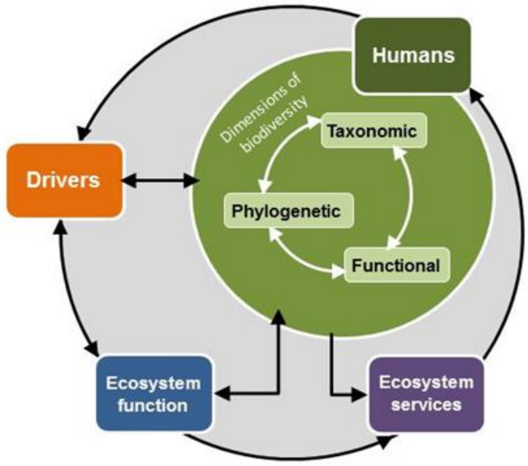

Figure 1. The biodiversity concept diagram (BioDiverse perspective 2013)

Measurement of biodiversity

Quantifying biodiversity was probably first done by Darwin with the registration of 142 species in the meadow around his home in 1855. It was about 100 years ago that Raunkaier who realized the importance of relative abundance of species in the assessment of biodiversity (Magurran and McGill 2011). Fisher *et al.* (1943), Preston (1948), and MacArthur (1957) contributed to the development of the concepts of biodiversity by providing species abundance distributions. Following these studies, there have been many developments in this field.

However, in the late twentieth century, two issues raised attention to biodiversity: 1) a significant reduction in biodiversity was observed, and this encouraged researchers to more study, and 2) the development of mathematical and statistical models along with computer science led to the more accurate evaluation of biodiversity (Piepenburg and Piatkowski 1992). While biodiversity is occasionally treated only as species richness, the relative abundance of species is also an important component that indicates the extent to which a species is dominant or rare in a community (Tilman and Pacala 1993, Sasaki and Lauenroth 2011). When the relative abundance of species is considered, one can see how many species have high (dominant species), medium, and very low abundant (rare species) in a society (Whittaker 1960). Different methods for representing and plotting relative abundance of species according to the type of research and the purpose of the study have been tried, such as simple histogram, Rank-Frequency Diagrams, K-dominance curves, and ABC curves (Magurran 2013).

Species abundance distribution models are often used, and these are divided into two groups: biological models and statistical models (Magurran 2013). In biological models (such as the *niche* apportionment models), the role of species interactions is considered in the distribution of species abundance in a community (Tokeshi and Schmid 2002, Omidipour and Tahmasebi 2017, Moradizadeh *et al.* 2020). However, in statistical models (such as geometric and log series), only statistical assumptions regarding how species are distributed in communities are taken into account (Fisher *et al.* 1943).

The scale is also an essential determinant of biodiversity and can dramatically alter the results of biodiversity assessments (Austrheim and Eriksson 2001, Mutke and Barthlott, 2005, Sfenthourakis and Panitsa 2012, Jouveau *et al.* 2020, Ashrafzadeh *et al.* 2020). Various indices such as alpha (intra-habitat) and beta (among-habitat) indices have been proposed, and these aids to quantify diversity at spatial scales (Laliberté *et al.* 2020). Considering the various additive partitioning and multiplicative partitioning methods and the existence of more than 50 indices for calculation of heterogeneity and dissimilarity of species composition, the complexities will double (Koleff et al 2003, Anderson *et al.* 2011). In this regard, the use of new approaches to biodiversity assessment, such as functional diversity and phylogenetic diversity, has reduced the complexity and revealed hidden angles of biodiversity and its effects (Owen *et al.* 2019, Nadaf and Omidipour 2020). Because these approaches, besides using the abundance and number of species, can examine the functional attributes and genetic characteristics of individuals in each community (Mason *et al.* 2005, Mouillot *et al.* 2005). However, lack of access to all species traits as well as restrictions on measuring the characteristics of all individuals in a community (especially the rare ones) is still a scientific challenge.

Biodiversity hotspots

There are places on earth that are biologically very rich and important, but unfortunately, these areas are severely threatened. Plant and animal species are not evenly distributed across the planet, and certain areas are home to a large number of native species that are not found anywhere else (Mittermeier *et al.* 1999, Myers *et al.* 2000, Habel *et al.* 2019). Many of these species are highly endangered due to habitat destruction and other human activities. These areas are called biodiversity hotspots and include 36 regions. It is believed that effort and success in preserving the species of these areas can significantly impact maintaining the biodiversity of our planet. A domain must have two criteria to be considered a hotspot: 1. It should have at least 1,500 endemic vascular plant species that do not exist anywhere else on earth, 2. It must have 30% or less of its original natural vegetation. In simple terms, should be threatened.

Only 36 regions have hotspot conditions that cover 2.4 percent of the earth's surface (Fig. 2). However, more than 50 percent of the world's plant species, about 43 percent of birds, mammals, reptiles and amphibian species as endemics are present in these areas. Although biodiversity conservation is essential in all parts of the world, hotspots need to be given special attention because the most diverse regions of the earth face the most significant threats. These productive ecosystems are always the livelihoods of vulnerable and weak human societies. Although hotspots do not have a large area globally, ecosystems such as forests and other ecosystems in these hotspots provide a high percentage of the ecosystem services on which the vulnerable human population depends (Vamosi *et al.* 2006, Gos and Lavorel 2012, Bidegain *et al.* 2019).

Iran is one of the most important countries in the Middle East for biodiversity (Heydari *et al.* 2013a, Farashi and Shariati 2017). In a study of the terrestrial 18 mammal, 26 bird, and seven reptile species listed as threatened (i.e., near threatened, vulnerable, endangered, critically endangered) at the global and national levels considered. Results showed that about 24% of Iran could be considered as the biodiversity hotspots, out of which 10% are under protection. The results showed that large parts of Iran have the potential to be considered as biodiversity hotspots. These areas were mostly located in northern Iran, along with the Alborz and Zagros mountain ranges (Farashi and Shariati 2017).

Current and future challenges for biodiversity

Biodiversity is declining globally, and this decline has been more severe over the past 60 years (Domisch *et al.* 2011, Tittensor *et al.* 2014). One can see that biodiversity over the last decade due to extinction of plant and animal species, climate change, air pollution, land-use change, advances in technology and industry, development of agricultural and urban lands and changing human attitudes toward species, ecosystems, and landscapes, and generally to natural resources has become a more attractive topic for researchers (Jongman, 2002, Dirzo and Raven 2003, Henle *et al.* 2008, Pecl *et al.*, 2017, Heydari *et al.* 2020, Penuelas *et al.* 2020).

In different ecosystems, species loss rates are not the same. The World Wildlife Fund (WWF) has identified more than 200 ecological zones fully understood and remarkable examples of biodiversity in the world's ecosystems. Forest areas account for two-thirds of the ecological zones that are constantly changing around the globe (Fig. 3).

It is now widely believed that biodiversity is far beyond the number of species in one or more specific regions and that the conservation strategy cannot be based solely on the number of species in one or some ecosystems. Therefore, it is necessary to reconsider the protection measures and go toward an interdisciplinary approach by creating scientific-political partnerships (Marchese 2015). There is an increasing risk that shows food insecurity via agricultural expansion could lead to the loss of biodiversity through the destruction of critical habitats for conservation (Naylor 2011, Zabel *et al.* 2019). A hotspot analysis by Molotoks *et al.* (2017) determined areas of potential conflict between food security and biodiversity conservation. Overlap of Biodiversity Indicators with Risk of Agricultural Expansion Index indicates that most of the overlap can be found throughout Central America. Plant species richness also means high overlap in South East Asia, in particular China, Indonesia, and Papua New Guinea. South Africa also displays some overlap and areas in East Africa for mammal and bird species richness. Areas where high biodiversity confronts with high food insecurity or a high risk of agricultural expansion were examined and found to mainly occur in the tropics, with Madagascar standing out in particular. Some countries such as Ireland, Canada, and Sweden are usually in temperate regions and demonstrate the lowest risk of conflict between biodiversity and food security, as biodiversity tends to be lower while food security is higher. The areas identified are especially at risk of biodiversity loss, and so are global priorities for further research and for policy development to address food insecurity and biodiversity loss together (Molotoks *et al.* 2017; Fig. 4).

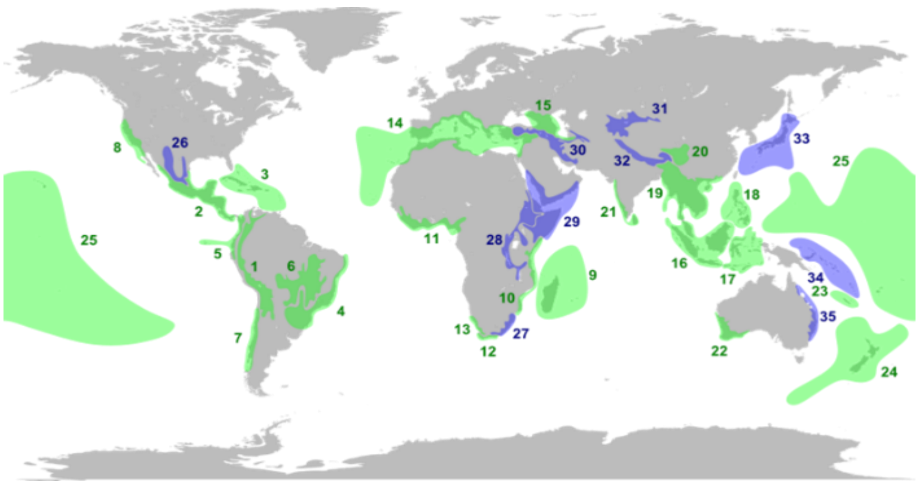

Figure 2. Biodiversity hotspots. The original proposal in green, and added regions in blue; 1. The Tropical Andes, 2. Mesoamerica, 3. The Caribbean Islands, 4. The Atlantic Forest, 5. Tumbes-Chocó-Magdalena, 6. The Cerrado, 7. Chilean Winter Rainfall-Valdivian Forests, 8. The California Floristic Province, 9. Madagascar and the Indian Ocean Islands, 10. The Coastal Forests of Eastern Africa, 11. The Guinean Forests of West Africa, 12. The Cape Floristic Region, 13. The Succulent Karoo, 14. The Mediterranean Basin, 15. The Caucasus, 16. Sundaland, 17. Wallacea, 18. The Philippines, 19. Indo-Burma, 20. The Mountains of Southwest China, 21. The Western Ghats and Sri Lanka, 22. Southwest Australia, 23. New Caledonia, 24. New Zealand, 25. Polynesia and Micronesia, An additional ten hotspots (blue) have since been added 26. The Madrean pine-oak Woodlands, 27. Maputaland-Pondoland-Albany, 28. The Eastern Afromontane, 29. The Horn of Africa, 30. The Irano-Anatolian, 31. The Mountains of Central Asia 32. Eastern Himalaya, 33. Japan, 34. East Melanesian Islands, 35. The Forests of East Australia, 36. North American Coastal Plain (Myers *et al*. 2000, Lamoreux *et al*. 2006, Pimm *et al.*, 2014; Noss *et al*. 2015).

Forests account for more than 80% of the world's terrestrial species, whose survival is threatened (Achard, 2009). The Convention on Biological Diversity (CBD) has estimated that an increase in deforestation over the last century has reduced the abundance of forest species by more than 30%. Species loss rates in forest areas are substantially faster than other ecosystems. By 2050, it is estimated that more than 38% of forest species will be lost (UNEP-GLOBIO 2008). In such a situation, conservation of biodiversity involves conservation of genetic resources and existing species, requiring a proper understanding and assessment of the status of the existing biodiversity and knowing the main succession pathway so as not to interfere with unintentional interference with the sequence pathway (Parminter 1992, Guo *et al.* 2019). It has worth mentioning that some unpredictable events such as COVID-19 may change the scenarios (Dinneen 2020).

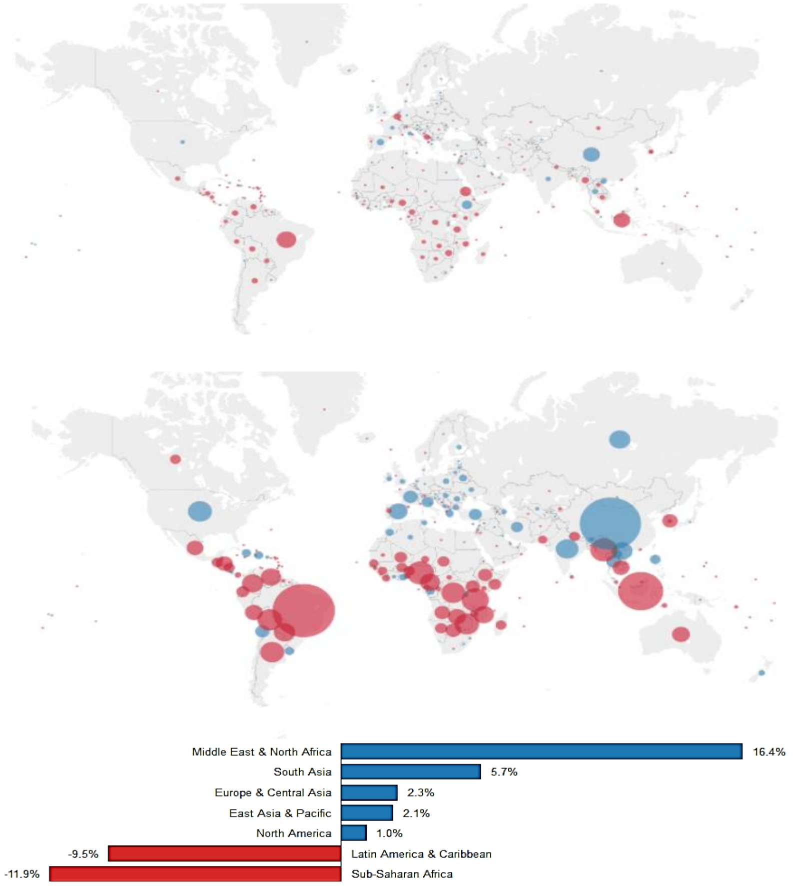

Figure 3. Changes (■: gained and ■: lost) in forest area (km²) 1990 (a) - 2015 (b) and regions which lost or gained forests (c) (Source: World Development Indicators)

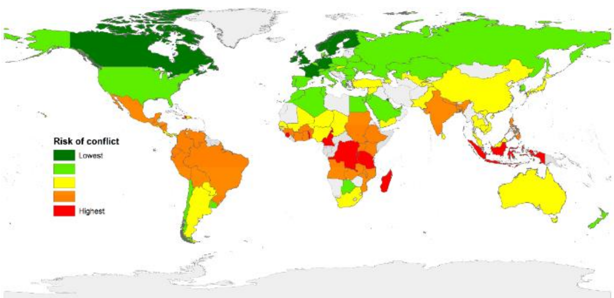

Figure 4. Index of conflict risk between food security and biodiversity (Molotoks *et al.* 2017)

Numerous studies have been conducted on the study of biodiversity in different regions of the world and in various natural and human-made ecosystems that have considered different concepts, hypotheses, goals, methods in different scales (Arita and Christen 2008, Jeffrey 2006, Matos *et al.* 2020, Yuan *et al.* 2020, Gonzalez *et al.* 2020, Newbold *et al.*

2020). One of the most critical issues in these studies is the examination of the impact of human disturbances on biodiversity, the challenges ahead, and different approaches to the restoration of degraded areas (Laurance and Williamson, 2001, Omidipoor *et al.* 2016, Wilson *et al.* 2016; Heydari *et al.* 2016, Pardini *et al.* 2017, Zwiener *et al.* 2017).

According to the IPBES World Report on Biodiversity and Ecosystem Services in 2019, 25% of plant and animal species are endangered because of human activities (Watts 2019, Plumer 2019). Researchers believe that reducing the biodiversity of plant and animal species has become one of the significant threats to natural ecosystems globally that require constant and targeted monitoring (Sala 2000, Heerink *et al.* 2001, Sodhi *et al.* 2004). Over the past three centuries, approximately 12 million km^2 of forests and woodlands have been cleared. Grasses and pastures have decreased by about 5.6 million km^2, and farms have increased by 12 million km^2 (Ramankutty and Foley 1999). Undoubtedly, such changes have had significant negative impacts on the world's faunal and floral biodiversity. The report shows that about 1 million plant and animal species are now threatened with extinction, many within decades, more than ever before in human history (United Nations 2019).

A report by hundreds of international experts has highlighted the worrying decline of biodiversity around the world and its dangers to human civilization. According to this report, during the past century, in the most critical habitats from the savanna of Africa to the rainforests of South America, the biodiversity of native plants and animals has decreased by more than 20 percent (Plumer 2019). Such a threat indicates the necessity of a careful and scientific assessment and monitoring of diversity with more efficient approaches and methods.

It is essential to pay more attention to the determination of the protected areas within biodiversity hotspots to increase a functional network of the protected areas within the hotspots. Conservation management must be developed around the world to address the threats to biodiversity caused by habitat degradation, habitat disruption, and overexploitation (Farashi and Shariati 2017, De Santo *et al.* 2019).

Discussion

Biodiversity is an essential element of life on earth. However small they may seem, the enormous diversity and complexity of interactions between species keep our ecosystems functioning and our economies productive. Humans are changing the landscape so dramatically that a million species of plants and animals are now at risk of extinction. This is a severe threat to the ecosystems that people worldwide depend on for their survival (Upreti and Upreti 2002, Sodhi *et al.* 2004, Meng *et al.* 2019). Ecological niches of many plant and animal species are degraded, and opportunistic and invasive species have invaded to empty ecological niches due to their high tolerance to stress conditions (Boutin and Jobin 1998, Peterson and Vieglais 2001, Peterson 2003, Lemos *et al.* 2019).

With the current trend, especially global warming and climate change, what is the future that can be imagined for biodiversity? Based IPCC prediction on Climate Change for 2100, temperature increases up to 1.5 – 4.5 °C in the worst-case scenario, likely to results in significant experiencing of aridification in the next 30 years (Jowkar *et al.* 2016). Similarly, for example, Ashrafzadeh *et al.* (2019) evaluate climate change effects on endemic salamander in Iran for the year 2050 and reported a decline of 56–98% of the suitable habitat. Besides, do biodiversity indices reflect these changes? How to prevent this disaster? The fact is that biodiversity in many ways is lost without the human understanding of the depth of this disaster. One clear example is the priority society places on maximizing economic profits without considering the environmental consequences for future generations. The essential task of researchers has always been a tangible reflection of these threats. However, do their scientific tools work well in this regard?

As noted, a large number of diversity indices can be used to quantify biodiversity. Still, in some cases, these choices confuse researchers and fail to adequately assess the status of biodiversity.

On the other hand, continuous assessments of biodiversity at different scales and prediction of its status under different scenarios in the future do provide the basis for various management measures such as conservation of natural areas (Heydari *et al.* 2013 b, Ashrafzadeh *et al.* 2019, Tahmasebi *et al.* 2020). Considering that the purpose of presenting different indices is to cover the weak points or correct the older diversity indices, so with proper classification of indices and awareness of their strengths and weaknesses, to a large extent, we can be successful in selecting, using, and analyzing the results of these indices. However, their use can justify the reduction of factors, such as land-use change and climate change (Thuiller *et al.* 2006, Roberts *et al.* 2020). These measures certainly require strong regional, national, and international laws and regulations.

Conclusion

As a concept, biodiversity safeguards the functioning and sustainability of ecosystems and ecosystems services against natural/anthropogenic changes and degradation. Biodiversity loss can permanently reduce future life options. While the state of biodiversity in the world is worse than previously thought, many biodiversity assessments have not been able to express the long-lasting impact of abrupt land changes (Jung *et al.* 2019). Most protected areas and biodiversity hotspots in the world do not have a specific management plan. In other words, there is no regular national planning for protected areas, which this wrong procedure must be changed. Scientists hope to help governments to gain a balance between economic development and biodiversity conservation by outlining the services that nature can provide for people and trying to quantify biodiversity with appropriate and efficient indices, as well as identifying what is missing with reduced biodiversity. It is essential to pay more attention to the determination of the protected areas within biodiversity hotspots to increase a functional network of the protected areas within the hotspots. Conservation management must be developed around the world to address the threats to biodiversity caused by habitat degradation, habitat disruption, and overexploitation.

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