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Short Communication

Biodiversity arks in the Anthropocene

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ABSTRACT

The Anthropocene proposal suggested that the Earth may have entered a new geological epoch, in which human activity and climate change are influencing the environment at global scale. Arrival of the Anthropocene is bringing an unprecedented challenge to the biodiversity that is essential to humans, and enhancing many benefits of nature to human being. However, biodiversity loss is aggravating in the rhythm of inevitable change in the Anthropocene, and the adaptation of biodiversity to the anthropogenic disturbance seems unable to keep pace with the human activity and climate change. Therefore, re-examination of the assumptions and practices upon the current conservation endeavor are needed. We suggested that biodiversity conservation should be paid more attention to the response from biodiversity to the human activity and climate change in the Anthropocene. Thus, the concept of biodiversity arks in the Anthropocene is proposed, that is, biodiversity arks in the Anthropocene are the areas where vulnerable biodiversity is sheltered to alleviate human activity and buffered from climate change under the anthropogenic disturbance. The concept should be implemented for biodiversity conservation to fill gaps between our knowledge and build on successful conservation and sustainability in the Anthropocene. It will be certainly important to conservation policy instruction and management under climate change, especially the implementation of climate buffering zones preserving biodiversity in the face of warming climate.

1. Introduction

Humans have dramatically altered the planet over the course of a century, from the increase in ocean acidity to landscape fragmentation and the climate change (Otto, 2018). The human imprint on the global environment has now become so pronounced that it was proposed that the Earth may have entered a new geological epoch, called the Anthropocene, in which human activity is influencing the environment at global scale (Maslin and Lewis, 2015; Zalasiewicz et al., 2017). Alongside and inextricably linked with human activity, rapid climate change is pervasively reshaping the environment and biodiversity. The interlinked influence of human activity and climate change is likely to have knock-on effects on biodiverse communities, human-dominated conservation prioritization and conservation planning in the fast-changing world. Moreover, current anthropogenic changes have outpaced past changes in the Earth

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system and human history (Ordonez et al., 2016).

Biodiversity is essential for human well-being and enhances many benefits of nature to people. The United Nations Convention on Biological Diversity (CBD) is intended to ensure conservation of biodiversity, its reasonable utilization, and sharing of benefits from utilization of genetic resources (Locke et al., 2019). However, biodiversity has been reducing throughout human history and is currently undergoing rapid decline, constituting the sixth mass extinction in the Earth's history (Isbel et al., 2017; Johnson et al., 2017). Accordingly, as biodiversity has been driven by the sense of a current or pending crisis in recent decades, innumerable international agreements, national policies, and research organizations have adopted biodiversity as their central focus. Nevertheless, biodiversity response to anthropogenic disturbance is often delayed, which may lead to the emergence of new assemblages and reshaping of protected areas. The Millennium Ecosystem Assessment highlighted the centrality of environmental management for poverty reduction and general well-being as well as the benefits of conserving ecosystems to people (Millennium Ecosystem Assessment, 2005). Moreover, biodiversity has aroused tremendous interests among scientists, policy makers, land managers, and the general public in term of understanding the spatial-temporal patterns and causes of biodiversity (Vellend et al., 2017). Thus, the conservation community, including authorities, institutes, and scholars, are called to rethink biodiversity conservation in the changing world of the Anthropocene.

In the human-dominated biosphere, a period of time often referred to as the Anthropocene, the combined effects of the fast-growing human population and global change on biodiversity do not encourage optimism. Globally, 95% of land has been modified to some degree by human activities (Kennedy et al., 2019), and 75% of terrestrial environments have been "significantly altered" by human actions. In the case of marine environments, this percentage reaches 66%, according to the recent report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (IPBES Report, 2019). Moreover, the likely range of global temperature increases with population, economic growth, and carbon use (Raftery et al., 2017). Recent assessment reported by the Intergovernmental Panel on Climate Change (IPCC) and IPBES highlighted the impacts from climate change and the risks from the unsustainable utilization of natural resources, that is, human influence on the climate system is clear (IPBES Report, 2019; IPCC, 2019). Further, climate change was projected to be a rapidly increasing additional driver for biodiversity loss (Arneth et al., 2020). Even future change in the position of the intertropical convergence zone indicated that zonally contrasting shifts of the tropical rain belt in response to climate change (Mamalakis et al., 2021). What is now known as the "Great Acceleration" reflects the sharply rising intensity of human activity observed since approximately 1950 (Steffen et al., 2015). The exponential trend or frequency of biodiversity-associated factors since the mid-20th century is extremely similar to other trends that signify the accelerating human impacts on the Earth system (Fig. 1). And now, there are either novel in the biological conservation sector or represent a substantial positive or negative step-change in impact at global or regional level that are related to human and ecosystem-level responses to climate change (Sutherland et al., 2021). Against this backdrop, it is critical to consider how the anthropogenic disturbance inevitably impacts global biodiversity and what the future of biodiversity is.

In this study, we first examined the trends of biodiversity-associated factors during the global scale emergence of the Anthropocene, an era of ever intensifying human impact on the Earth systems and climate change. Accordingly, we highlighted the significance of biodiversity arks in the Anthropocene by emphasizing the necessary of biodiversity conservation, especially the response of biodiversity to human activity and climate change.

2. Biodiversity arks and anthropogenic disturbance

The concept of biodiversity arks in the Anthropocene is proposed to preserve the fragile biodiversity in a changing world. That is, biodiversity arks in the Anthropocene are the areas where vulnerable biodiversity is sheltered by buffering the anthropogenic

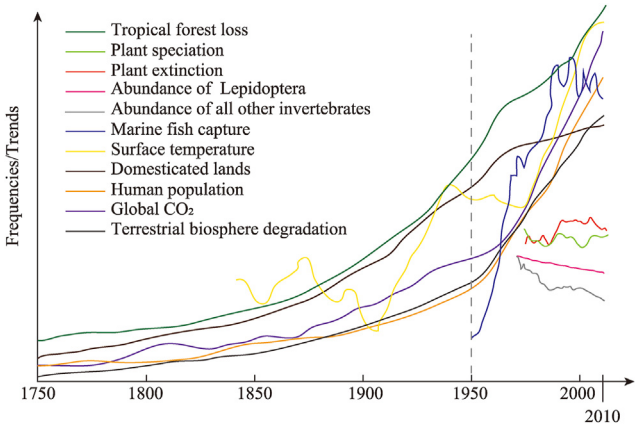

Fig. 1. Selected characteristics of biodiversity-associated factors trends from 1750 to the "Great Acceleration" period that human activity is accelerating. The figure used the following sources: the frequency of tropical forest loss, marine fish capture, surface temperature, domesticated lands, human population, global CO_2, and terrestrial biosphere degradation (adopted after Steffen et al., 2015); the frequency of global index of invertebrate abundance: Lepidoptera and all other invertebrates from 1970 (adopted after Dirzo et al., 2014); and the frequency of plant speciation and extinction from 1980 (adopted after Gao et al., 2020).

disturbance. This concept is important to fill the gaps between conservation policy and management under climate change at present and in the future.

Biodiversity has been invariably influenced by human activity (e.g., livelihood, economic growth, infrastructure, urbanization, and resource utilization) and climate change (Fig. 2) (Meng et al., 2019a, b). Further, the impact of human activity and climate change on the structure and function of biodiverse systems during this period is apparent in many key metrics, such as tropical forest loss, plant speciation/extinction, abundance of invertebrates, marine fish capture, surface temperature, domesticated lands, human population, global CO_2, and terrestrial biosphere degradation (Fig. 1). Therefore, we propose that biodiversity arks are key areas where fragile biodiversity can be sheltered from adverse effects in the Anthropocene; nevertheless, these areas have been neglected in conservation policy and management for years.

2.1. Human activity

Alongside the demographic growth of human population, the burgeoning demand on the resources of the planet has impacted global biodiversity dramatically. The far-reaching influence of human activity is contributing to the loss of biodiversity, including the habitats of biodiversity, landscape use, predatory fish, plant extinction, defaunation, and reduction of species abundance, etc. (Fig. 1). Obviously, human activity is accelerating the anthropogenic extinctions of species and loss of biodiversity (Braje and Erlandson, 2013). Fortunately, the influence of human activity on biodiversity has received considerable attention. Particularly, many nature reserves have been established, and relevant legislations have been proposed. These areas, where biodiversity is sheltered from human activity, can be considered as parts of biodiversity arks; e.g., national natural reserves and national parks have been set up to protect biodiversity in comprehensive ecological ranges. The existence of such “safe sites” is a basic requirement for biodiversity conservation.

However, some localities are missed and should be included in the protected areas. For example, the Fengshui forests in China have a high cultural value and are often considered sacred by the locals, who are unwilling to trespass them. The biodiversity there has frequently escaped disturbance from human activity (Tang et al., 2013). Such sites play an important role in preserving biodiversity, but are merely considered as enclaves in previous conservation strategies and are excluded from the protected areas. Therefore, the definition of biodiversity arks can fill the gaps between the existed conservation strategies and future frame of biodiversity conservation.

Moreover, it is worth pointing out that *ex situ* conservation areas (such as arboreta, botanical, and zoological gardens) whilst useful and practical as “safe sites” for rare and/or endangered species or individuals, cannot protect multiple species within whole ecosystems. In contrast, *in situ* biodiversity arks primarily aim to conserve communities and populations of species in the whole ecosystems.

Currently, the identified global biodiversity hotspots (Myers et al., 2000) are regions with high-biodiversity conservation priority. However, the designated biodiversity hotspots are inevitably subjected to the human imprint. For instance, the economic growth and improving standards of living inadvertently impact biodiversity conservation globally, particularly in developing countries (Meng et al., 2019a), e.g., regions of the Indochina Peninsula are considered as global biodiversity hotspots (Fig. 2a). This implied that biodiversity in hotspots is destroying as natural resources are exploited to alleviate poverty. As biodiversity hotspots change, biodiversity strategies ought to change accordingly—but how do we find and appropriately execute the most suitable changes?

Beyond the myriad effects that human activity has had on trends of biodiversity-associated factors, the world’s biological diversity is changing via evolutionary and/or ecological change at a global biodiversity level from intra-species to inter-species and the community. We should pay more attention to defining biodiversity arks to diminish the impact of human activity and shelter biodiversity in the Anthropocene, although many protected areas have already been established.

2.2. Climate change

Human-induced loss of biodiversity has long been a paradigm in conservation ecology. However, climate change was the principal driver of diversity change in only a handful of studies examined, and it exhibited the same mix of positive, negative, and neutral effects

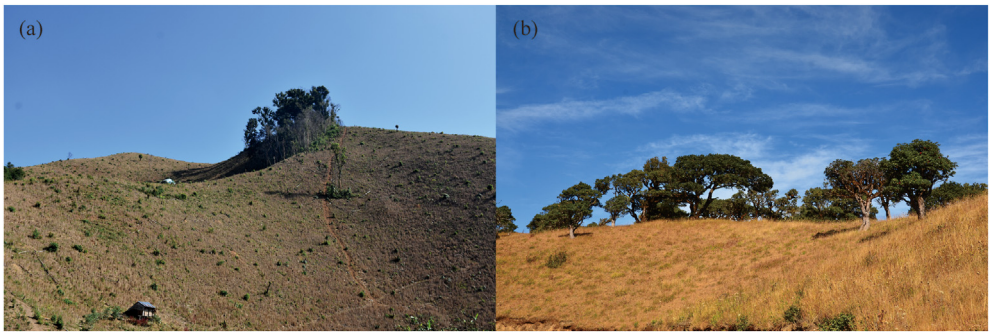

Fig. 2. Biodiversity arks should be the key areas where the vulnerable biodiversity is sheltered to alleviate human activity and buffered the climate change under the anthropogenic disturbance. For example, human activity and climate warming are impacting on the biodiversity, even in regions of the Indochina Peninsula, which are considered as the global biodiversity hotspot, e.g., the slash-and-burn cultivation in Laos (a) and the cold-adapted plants at high elevation (mountaintop) of Victoria Hills, Arakan Yoma, Myanmar (b).

as other drivers (Vellend et al., 2013). Most importantly, post-2020 biodiversity targets must unavoidably embrace climate change (Arneth et al., 2020), i.e., warming climate, extreme temperature, or extreme rainfall events. Thus, understanding the relation between climate change and biodiversity in the human-dominated biosphere is critical for assessing and mitigating the impact of environmental changes on biodiversity.

It is widely believed that the increasing concentration of greenhouse gases, i.e., CO_2 (Fig. 1), is the main cause of global warming. These gases trap the atmosphere heat, increasing global temperatures via the greenhouse effect. Accordingly, the increasing global temperatures inevitably impact biodiversity. Despite increasing concern about the elevated species extinction risk as global temperatures rise, it is difficult to confirm the causal link between climate change and species extinction (Panetta et al., 2018). Although climate-driven decline or extinction seems difficult to detect, climate change intensifies the diversity losses of terrestrial plant and animal communities across multiple spatial scales, and organizational levels are already widespread (Thomas et al., 2006; Dirzo et al., 2014; Panetta et al., 2018; Harrison, 2020).

Biodiversity arks focus on the formation of buffering zones to protect biodiversity from climate change in the Anthropocene. Climate change, particularly warming climate, negatively affects the geographic distribution of alpine, boreal, and cold-temperature plants (Meng et al., 2019b). Actually, the effects of climate change on biodiversity have been modelled. Species turnover in future communities may fall behind simplistic expectations based on species' range shifts with unlimited dispersal following warming climate (Alexander et al., 2018). Thus, the effects of buffering zones around biodiversity on global change should also be considered. In the past decades, ecological niche modelling has shed light on the biodiversity response to the environmental changes of the Quaternary and has identified the existing refugia that have preserved current species' lineages. Habitat contraction-expansion and latitudinal-altitudinal shifts have enabled species to survive in the adverse climate oscillations of the Quaternary. According to the proposed concept, zones that are buffered from warming climate in the Anthropocene can contribute to biodiversity conservation.

In the Anthropocene, climate change may not have adverse effects on thermophilic species; contrarily, it may, even enhance biodiversity in some tropical and subtropical regions. However, the potential impacts of climate change on cold-adapted species in the polar, boreal, and alpine regions are severe; this is also true for high elevation climate refugia in tropical habitats (Fig. 2b) (Meng et al., 2019b). Therefore, biodiversity arks focus on species-specific habitats, and more attention should be paid to organisms whose physiological response to environmental changes from global warming is slower than the shifts of climate change. High-elevation and high-latitude regions that shelter vulnerable cold-adapted organisms should be parts of biodiversity arks and should be valued in conservation policies. In these regions, the keystone taxa of cold-adapted species will show different degrees of sensitivity to climate change in different regions, leading to widespread community deconstruction and reconstruction.

Undoubtedly, the responses of species to climate change are overwhelmingly negative. Previous researches illuminated that plant and animal community diversity decline more than increase, and plant extinction excels plant speciation under climatic warming (e.g., Dirzo et al., 2014; Gao et al., 2020; Harrison, 2020). Moreover, the population-level and species-level extinctions of animals showed decline in the abundance of butterflies, frogs, and over 300 species of terrestrial vertebrates (Thomas et al., 2006; Dirzo et al., 2014). In some regions, the topographic variation in microrefugia provides empirical evidence that microclimatic heterogeneity can substantially reduce the extinction risk due to climate change through microclimatic buffering (Suggitt et al., 2018). Therefore, working to identify potential biodiversity arks for modern populations at risk from the ongoing warming climate, particularly for polar, boreal, alpine, and/or cold-adapted organisms, is of critical importance. At present, coalescent simulations based on discrete population genetics/genomics offer a promising approach of producing fine-scale global or regional climate models. Such models facilitate the direct testing of alternative biogeographic hypotheses, which are derived from species distribution models, to identify biodiversity arks. Namely, the species distribution models that map ecological niches on the Earth's climate surfaces can help identify biodiversity arks, assess the determinants of species ranges, and predict the spatial and/or temporal occurrence of species in the Anthropocene. The identified biodiversity arks could reverse the biodiversity crisis caused by climate change, especially by warming climate.

3. Significance of biodiversity arks

In the Anthropocene, human activity and climate change are playing growing roles in accelerating the modern extinction of biodiversity after the spread of domestication, agriculture, urbanization, and globalization, etc. The systematic program of coordinated interdisciplinary research would contribute significantly to the definition of the Anthropocene and the understanding of anthropogenic-induced biodiversity extinction processes on a global level. Thus, recognizing biodiversity arks in the Anthropocene is crucial to maintaining existing populations via conservation management and restoration. Biodiversity arks in the Anthropocene will promote the understanding of the present and future biodiversity response to anthropogenic disturbance, particularly in key areas that can greatly benefit from biodiversity conservation, restoration, and potential re-expansion.

3.1. Differences from previous conservation strategies

As previous and existing conservation strategies cope with the decline in biodiversity, worldwide conservation efforts are increasing. Conservation paradigms, practices, and policies have shifted over time and have been variably successful (Rands et al., 2010). For example, many nature reserves have been established, and legislation has been proposed to protect global biodiversity in recent decades. Accordingly, the creation of national park, as a traditional approach to biodiversity conservation, has evolved to encompass awareness of the diverse benefits provided by protected areas. In such areas, the importance of local conservation initiatives and interest in protected area management has been addressed well and aroused broad attentions. Beyond this, the concept of biodiversity arks emphasizes that key areas outside the protected zones should also be considered in the Anthropocene. That is, the concept mainly concerns

two aspects: forming protected areas and climate buffering zones in response to human activity and climate change, respectively (Fig. 3). Biodiversity arks expand existing protected areas to shelter non-protected areas with potential conservation priority. As the last intact landscapes, biodiversity arks shelter biodiversity from the disturbance of human activity and climate buffering zones. These areas are critical at a time of changing climate because they act as refugia for biodiversity and constitute the most resilient parts of the ecosystem to human activity and climate change. However, these areas do not receive much attention, and should be considered explicitly in future conservation frames of target-setting efforts.

As is known, biodiversity includes three elements, i.e., genetic diversity, species diversity, and ecosystem diversity, which provide numerous essential services to the human-dominated society. Genetic diversity is recognized as one of three basic elements of biodiversity under the CBD (www.cbd.int), and is the focus of many researches on conservation genetics. Moreover, species is the evolutionary unit, and species diversity is the basic elements for evolutionary change when biodiversity is inferred. Here, we suggest that specific areas overlooked by previous conservation strategies should be considered. In other words, the ecosystem diversity of these specific areas preserves much species and subsequent genetic diversity that is critical for adapting to changing climate. Habitats and biotic interactions are more frequent than species individual and genetic diversity. Thus, genetic and/or species diversity targets and indicators in biodiversity conservation should be improved, and *in situ* biodiversity arks can greatly assist entire ecosystems to maintain their functions, stability, and services.

3.2. Implementation in biodiversity conservation in the future

The continued expansion of human population, consumption, economic growth, and resources over-exploration has resulted in the unsustainable loss of biological diversity, which has been exacerbated the conflict between the anthropogenic disturbance (e.g., human activity and climate change) and biodiversity conservation (Meng et al., 2019a, b). The perspective we propose herein is based on understanding of the underlying biodiversity values, broadening of traditional conservation regions (i.e., existing or previously protected areas), and emphasizing the benefits of nature to human. Modern conservationists are proponents of protected and conserved areas if they provide benefits to human beings and modern conservation perspective advocates for collaboration with resource users and economic growth.

The concept should be implemented in biodiversity conservation to fill the gaps between our knowledge and successful conservation in the Anthropocene. Conservation interventions should aim at ensuring that biodiversity arks remain sustainable in the long-term and at promoting self-managing biodiverse ecosystems. Most importantly, this concept constitutes a new conservation framework to assess and manage the impact of human activity and climate change on current and future patterns of biodiversity distributions. This will help disentangle the effects of multiple drivers of anthropogenic disturbance, allowing for a better understanding of ecosystem dynamics and illuminating the avenues of conservation policies and management in a changing world. Thus, future researches on biodiversity conservation and biogeography should elucidate the fine-scale processes and distribution patterns that buffer biodiversity against the vagaries in the Anthropocene.

3.3. Suggestions

Although conservation efforts have produced much encouraging results in the past decades, they have achieved little in forestalling biodiversity losses as they have failed to address the unsustainable utilization of environments and the shrinkage of biodiversity in the Anthropocene. In what follows, we provide region-specific suggestions for biodiversity conservation.

Firstly, minimizing the impacts of human activity in biodiversity hotspots within the developing countries is a conservation priority. However, human activity inadvertently impacts biodiversity conservation globally, particularly in developing countries where local people need to raise the living standard using the biodiversity resources. Biodiversity loss and poverty are interlinked problems,

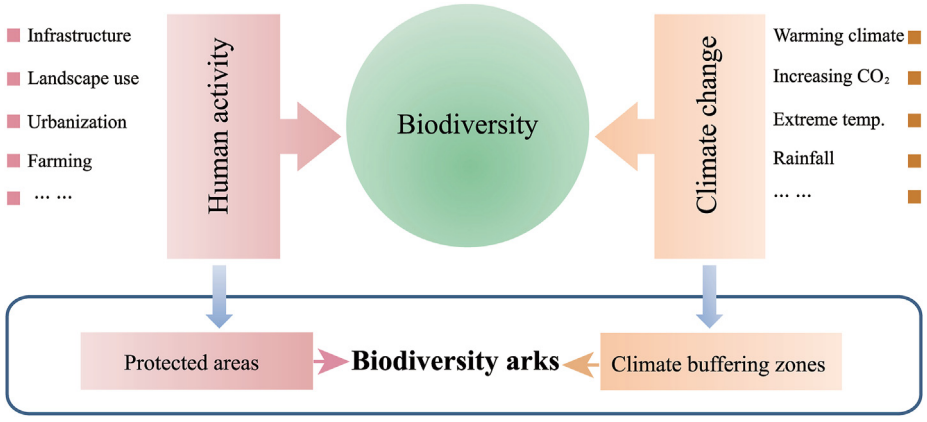

Fig. 3. Biodiversity arks in the Anthropocene are the areas where vulnerable biodiversity is sheltered to alleviate human activity and buffered climate change under the anthropogenic disturbance. The abbreviation temp. represents temperature.

conservation and poverty reduction need be tackled together in a collaborative framework, although the success of such integrated strategies is typically elusive (Adams et al., 2004).

Secondly, high-biodiversity habitats of rare and endangered species, which can potentially offer to massive benefits on entire ecosystems, should be converted to protected areas. For example, the sacred places with whole ecosystem (e.g., the Fengshui forests that local residents are unwilled to set foot in), in which much biodiversity is conserved *in situ*. As well, some places with the endangered and rare species but the habitats have been demolished by human need to be paid close attention.

Finally, identifying potential climate buffering zones is critical for mitigating the impact of climate change on biodiversity which is negatively colossal. However, the buffering zones to climate change, particularly the warming climate, are to be embraced for the contribution to preserve the biodiversity in the face of future climate change.

4. Going forward

Biodiversity is essential to human well-being, however, people have reduced biodiversity throughout human history. The loss of biodiversity and degradation of ecosystems are likely to further accelerate at present and in future. The challenges to address the impact of anthropogenic disturbance on biodiversity conservation are daunting. In particular, in the Anthropocene, people mainly focus on wealth creation and the internationally recognized estimates of GDP but are far from recognizing the significance of biodiversity in the conventional measures of well-being. Therefore, understanding the biodiversity crisis is urgent, and the related authorities should pledge to avert it with the help of conservationists and biologists.

In 2021, Parties to the CBD (Fifteenth session of the Conference of the Parties, COP15) are expected to meet in Kunming of China to build a shared future for all life on the Earth. A new global biodiversity framework aimed at halting and reversing biodiversity loss, encouraging biodiversity sustainability, and ensuring the equitable sharing of its benefits will be agreed. Simultaneously, we expect the concept to be exposed to a range of perspectives on the conservation and sustainability of biodiversity in the Anthropocene that can contribute to developing and implementing in the post-2020 global biodiversity framework.

Herein, we emphasize that attempting to turn the tide on biodiversity loss will require more attention to human activity and climate change. In the Anthropocene, biodiversity arks are key areas where vulnerable biodiversity can be sheltered from human activity and buffered from climate change (Fig. 3). Protected areas are safeguarded from human activity to a certain extent, but the other regions besides with high conservation significance should also be shielded from anthropogenic disturbance. Most importantly, little is known about the identification of climate buffering zones, although the warming climate increases the vulnerability of biodiversity. Efforts, policies, and effective management of biodiversity conservation should be guided by the proposed biodiversity arks in the Anthropocene. In the face of climate change, climate buffer zones are an important conservation priority over management and policy instruction.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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