PERSPECTIVE

Biodiversity co-benefits of World Heritage protection

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Preserving World Heritage sites (WHSs) safeguards unique habitats, maintaining varied ecosystems that are essential for the survival of numerous species. It fosters genetic diversity by conserving distinct gene pools within species. Protecting these sites upholds the equilibrium of the ecosystem, aiding in maintaining species richness and resilience. These protective efforts serve as living laboratories, offering insights into evolutionary processes and adaptation, enriching global biodiversity, and reinforcing the harmony between humans and nature. In this Perspective, we explore the threefold biodiversity co-benefits of World Heritage (WH) protection through the lenses of ecosystems, species, and genes. Finally, we outline future challenges in WH protection and their impacts on biodiversity conservation and sustainable development.

INTRODUCTION

As of the end of 2023, the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage List (WHL) comprised a total of 1,199 sites, with 933 exclusively designated as cultural sites, 227 solely recognized as natural sites, and 39 categorized as mixed sites encompassing both cultural and natural properties. Collectively, these designated sites cover over 380 million hectares (ha) of the Earth's surface, signifying their pivotal role in reflecting cultural and natural significance.[1,2]

Of particular significance, among the total 266 natural and mixed WHSs, 197 sites directly adhere to selection criteria associated with biodiversity outlined on the WHL (https://whc.unesco.org/en/list). Collectively, these sites represent a protected area that exceeds 340 million ha. Additionally, over 120 WHSs are cultural landscapes, embodying a profound and enduring interconnection between human societies, cultural practices, and the surrounding environments.[3] These sites often demonstrate land utilization methods that contribute significantly to the enrichment of biological diversity. Regions characterized by substantial cultural variety also tend to exhibit remarkable levels of biological diversity. Noteworthy is the presence of more than 160 cultural WHSs situated within Key Biodiversity Areas (KBAs).[3]

UNESCO has encouraged countries to prioritize WHSs in their national biodiversity strategies and action plans, in alignment with the Kunming-Montreal Global Biodiversity Framework. This framework aims to halt and reverse nature loss, including achieving the target of protecting 30% of the planet's lands, coastal areas, and inland waters by the decade's end. Biodiversity conservation is increasingly recognized as a vital co-benefit in UNESCO WH projects utilizing heritage-based conservation solutions. However, there remains an insufficient understanding of the specific value of WH protection and its co-benefits to biodiversity. In this context, we explore the threefold biodiversity co-benefits of WH protection through the lenses of ecosystems, species, and genes, as illustrated in Figure 1.

ECOSYSTEMS LENS

WHSs, particularly those designated as natural and mixed, cover a wide spectrum of ecosystems, ranging from mountains, forests, deserts, wetlands, and coasts, to reefs (refer to Figure 1). These unique and pristine ecosystems serve as natural and living laboratories, providing invaluable insights into ecological and biological processes while offering essential lessons for biodiversity conservation. Within WHSs, one can find unique ecological regions serving as habitats, such as the Sumatran Rainforest WHS in Indonesia or the Great Barrier Reef WHS in Australia. Protecting these sites ensures the preservation and health of globally significant ecosystems. Additionally, WHSs also often represent undisturbed or minimally disturbed environments where natural processes—like nutrient cycling, water purification, and pollination—unfold unhindered, thereby maintaining ecological integrity. Furthermore, WHSs, particularly forests and wetlands, serve as significant carbon sinks, playing a crucial role in mitigating climate change, as WH forests alone absorb an annual amount of CO_2 as high as 190 million tonnes,[4] according to UNESCO's latest global assessment.

The maintenance of intact and functional terrestrial, freshwater, marine, and coastal ecosystems within these WHSs helps preserve the ecological functions across diverse ecosystems and significantly increases biodiversity within the protected areas. Marine and coastal ecosystems within WHSs span over 200 million ha, while forest ecosystems cover approximately 70 million ha. Nearly 100 WH wetlands overlap wholly or partially with over 150 Ramsar sites, showcasing their unique and rare wetland ecosystems (Figure 1). One exemplary case is the Sundarbans WHS, which is the world's largest mangrove ecosystem situated in India and Bangladesh. Covering about 1 million ha, the Sundarbans plays a crucial role in conserving endangered tigers, acts as a vital buffer against coastal erosion and tidal surges, supports local communities through fisheries, and significantly contributes to carbon sequestration.[5] Protecting the Sundarbans WHS ensures the preservation of the diverse benefits these ecosystems offer, which benefit both for nature and for human communities.

SPECIES LENS

Conserving species is integral to protecting biodiversity, and WHSs play a pivotal role in achieving this endeavor. Despite covering less than 1% of the Earth's surface, WHSs harbor over 20% of the globally documented species (Figure 1).[3] This includes an impressive array of over 75,000 plant species and more than 30,000 species of mammals, birds, fishes, reptiles, and amphibians.[1,3] Many WHSs are located within biodiversity hotspots, regions renowned for their exceptional abundance of endemic species found nowhere else. Protecting these sites ensures the preservation of numerous species that are unique to Earth. For example, the Galápagos Islands WHS in Ecuador showcases the remarkable biodiversity typical of hotspots, hosting iconic species like the Galápagos giant tortoise (*Chelonoidis niger*). Furthermore, WHSs serve as sanctuaries for some of the planet's most endangered species, sheltering over 20,000 at-risk species, including populations of wild tigers, giant pandas, and elephants, with up to one-third of their remaining global numbers residing within these areas.[3] The conservation efforts within WHSs could significantly aid in the recovery of these endangered flagship species. The Socotra Archipelago WHS in Yemen is home to the Dragon's Blood Tree (*Dracaena cinnabari*), a protected iconic plant species that is shielded from threats like habitat loss, overgrazing, and climate change.

Beyond hosting endemic and iconic species, WHSs harbor numerous keystone species, exerting a disproportionate influence on their ecosystems. Safeguarding these species is critical for maintaining the equilibrium of the ecosystem. For instance, the protection of Sumatra's tropical rainforests underscores the significance of conserving diverse plant species that provide habitat and sustenance for an array of terrestrial life, including for over 300 bird species and more than 200 mammal species.[6] Moreover, some species have deep cultural significance for indigenous communities. Protecting these

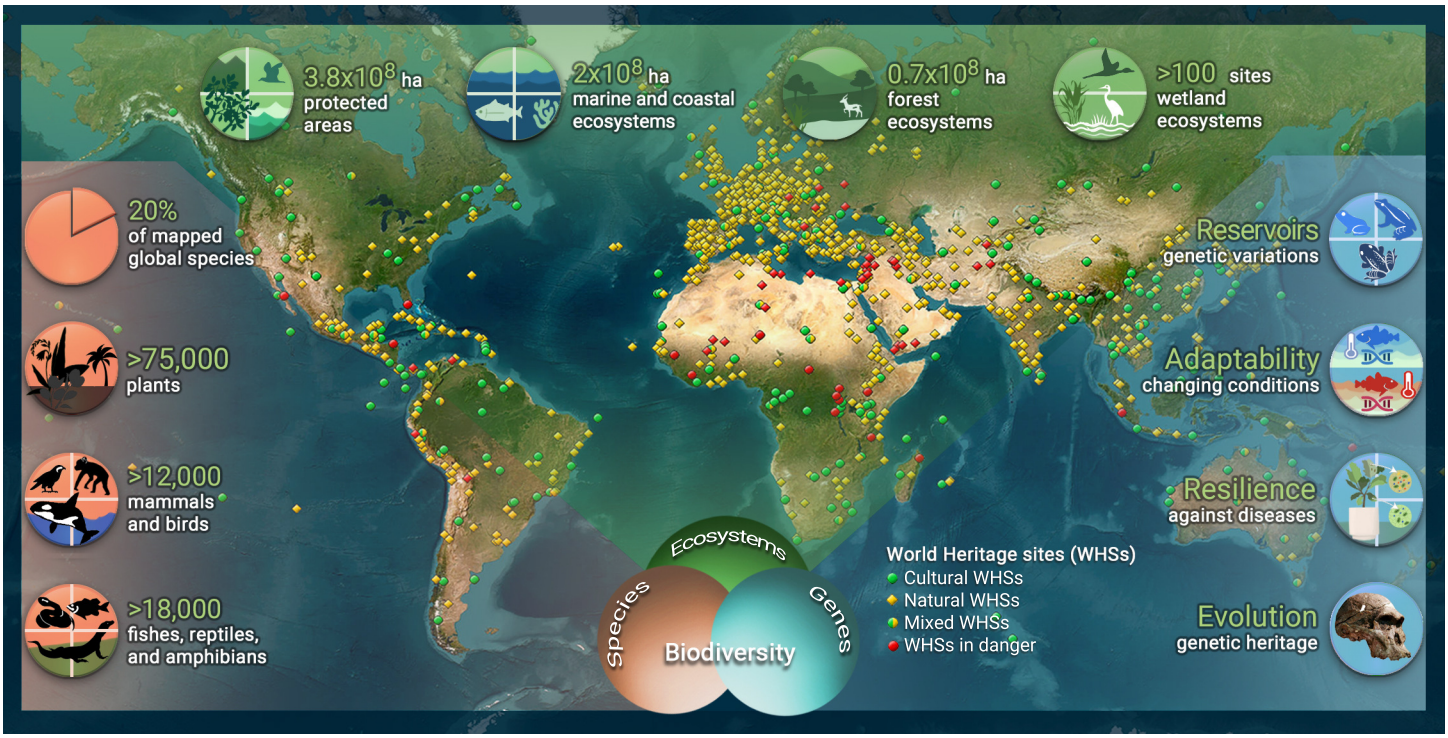

Figure 1. An illustration of the three lenses of biodiversity co-benefits of World Heritage protection The list of World Heritage sites can be downloaded from https://whc.unesco.org/en/list/.

areas ensures the continuity of the relationship between these species and local communities.[2]

GENES LENS

Genetic diversity is fundamental for adaptability, resilience, and evolution (Figure 1). WHSs, owing to their distinct ecosystems and diverse species, often house vast genetic reservoirs.[7] The diverse and heterogeneous habitats within WHSs provide ideal conditions for genetic mutations to emerge, while larger population sizes in these areas help avert genetic drift, significantly contributing to the preservation of genetic diversity. Consequently, by safeguarding and maintaining habitats, WHSs actively foster natural evolutionary processes, facilitating the emergence of new genetic variations and potential new species over time. The genetic materials present in these areas, rich in biodiversity, hold promising applications in various fields such as medicine, agriculture, and beyond. An exemplary case is found in the Andean potatoes. While the global selection of consumed potatoes typically consists of a few dozen to a hundred varieties, the high Andes region boasts over 4,000 varieties, each with its unique genotype.[8] These potatoes not only represent cultural heritage but also serve as an extensive genetic repository. This diversity signifies a reservoir of potential crop varieties to explore should current staples become less viable due to changing environmental conditions.

A more diverse genetic pool equips species to better adapt to changing conditions. As habitats undergo shifts due to the interplay of habitat degradation, environmental pollution, and global warming, species possessing a broader genetic toolkit can adapt more effectively. Genetic diversity often translates into a wider range of defense mechanisms against diseases. This not only benefits the species themselves but also hold implications for humans, particularly concerning crops. Moreover, exploring genetic diversity within WHSs offers invaluable insights into the evolutionary history of species. For instance, the analysis of ancient DNA from fossils found in the Cradle of Humankind WHS in South Africa has provided critical data about human evolution and our shared genetic heritage.[9]

CHALLENGES AND FUTURE PERSPECTIVES

WHSs account for approximately 8% of the total area covered by over 280,000 terrestrial and marine protected areas globally.[1] However, these sites confront multiple stressors from both global warming and human activities, including agricultural expansion, infrastructure growth, poaching, overtourism, and the proliferation of non-native species.[10] These threats can lead to reduced ecosystem stability, habitat deterioration, and loss. Even a small rise in temperature, such as 1°C increase, could drastically expose many species to climate-related threats.[3] It's crucial for the global community, supported by mechanisms like the WH Convention, to prioritize and finance the protection of these sites. This involves integrating local communities into conservation efforts and promoting sustainable practices, such as leveraging sustainable development insurance.[3] Amidst the convergence of mounting natural and human-induced challenges, it is imperative to leverage science, technology, engineering, policy, and finance to recognize and uphold the co-benefits of biodiversity associated with WH protection. Additionally, the conservation community should further disseminate information about the biodiversity co-benefits associated with WH protection. This effort aims to garner increased public and political support, drawing attention to the multifaceted advantages of preserving these unique and invaluable sites.

Recognizing the evident bias toward terrestrial sites within WHSs is crucial, particularly considering the urgent need to safeguard marine biodiversity. Addressing this imbalance is crucial for the comprehensive preservation of global biodiversity. The example of the Great Barrier Reef WHS in Australia illustrates this urgency. As an ecosystem, it encompasses a vast marine expanse teeming with life, hosting over 4,000 mollusks, 1,500 fish, 400 types of coral, 240 birds, and numerous other marine organisms (source: https://whc.unesco.org/en/list/154/). The genetic diversity within this reef is remarkable, with its diverse coral assemblage exhibiting wide genetic variations. Some species demonstrate better tolerance to warmer waters, offering potential benefits in a warming world. Despite the substantial co-benefits, challenges persist. Therefore, targeted measures emphasizing the significance of marine conservation efforts within the WH framework are imperative. Implementing potential strategies, such as increasing nominations for marine sites, employing specialized management methodologies, and fostering collaborative conservation initiatives involving local communities and stakeholders, represents a viable path forward.

While WHSs are often seen as the final defense against species extinction,[3] it's concerning that 56 of these sites are currently endangered, and numerous areas remain outside the protective scope of WH designation. Therefore,

conducting a comprehensive assessment of the challenges faced by WHSs, including both endangered sites and regions lacking UNESCO designation, is crucial. Proposed solutions involve strengthening the management frameworks of existing WHSs and expanding conservation initiatives to include vulnerable sites, as well as establishing criteria for the identification and nomination of new WHSs. These steps aim to bridge the existing conservation gaps and reinforce the protection and expansion of the WH network, ensuring more robust global WHSs preservation.

CONCLUDING REMARKS

Through the lenses of ecosystems, species, and genetic diversity, we have demonstrated the multifaceted co-benefits of WH protection for conserving biodiversity. Preserving WHSs not only safeguards unique ecosystems but also ensures the survival of numerous species. Furthermore, maintaining genetic diversity with these sites would preserve species' adaptive capacity for environmental changes. We have also highlighted the urgency of understanding the processes that affect WHSs, such as climate and anthropogenic threats. To maximize the co-benefits of conservation, concerted and multidisciplinary efforts are needed to address these challenges and to strengthen the protection of WHSs. This practice is expected to facilitate the sustainable management of the rich biodiversity in WHSs, contributing to the global initiative of conserving the planet's biological diversity for future generations.

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DECLARATION OF INTERESTS

The authors declare no competing interests.