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Applying the IUCN Global Standard for Nature-Based Solutions in Guandu Wetlands, Taiwan

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Abstract

Guandu Wetlands, an educational and research center in Taipei, provides conservation education for the public and university researchers. Mangroves within the wetlands deliver essential ecosystem services, socio-economic benefits, and play a critical role in mitigating rising CO_2 emissions. However, these ecosystems face threats from climate change and anthropogenic pressures. Nature-based Solutions (NbS) have emerged as an effective approach to address such societal and environmental challenges, and the International Union for Conservation of Nature (IUCN) has developed a Global Standard to ensure rigor and accountability in NbS projects. Implementing NbS in resource-limited contexts, however, poses challenges for long-term monitoring and management. This study aims to evaluate how the Guandu Wetlands align with the IUCN Global Standard for NbS, identifying stakeholder priorities, gaps, and trade-offs in wetland management. Interviews were conducted between April and June 2024 with key stakeholders—including Guandu Nature Park, the Forestry Bureau, the Taipei City Hall Hydrology Department, and the Wild Bird Society—using questions aligned with the IUCN Global Standard for NbS. The knowledgeable stakeholders independently scored each of the eight criteria, and the results were analyzed to identify priorities, gaps, and perceived trade-offs in wetland management. These findings highlight how each stakeholder perceives and prioritizes conservation and management strategies. Balanced trade-offs, adaptive management, and design at scale scored the highest, while sustainability & mainstreaming and economic feasibility scored low. This case study provides insights into NbS implementation and the role of universities, research, and education centers in monitoring wetland ecosystems. This research emphasizes opportunities to strengthen sustainable management, community engagement, and ecosystem stewardship. Overall, the study demonstrates how collaborative, science-based strategies can inform decision-making and generate tangible ecological and societal benefits of blue ecosystems.

Keywords
blue ecosystems; nature-based solutions; stakeholder engagement; wetlands

1. Introduction

Wetlands are increasingly under threat from global pressures, including biodiversity decline, land reclamation, pollution, and human-driven climate change (Barbier, 2011). Wetlands contribute a variety of ecosystem services, encompassing ecological, economic, and protective functions. They provide habitats for diverse terrestrial and aquatic wildlife populations, contribute to local economies, act as carbon sinks, trap sediments, regulate nutrient cycles, and serve as natural defenses against floods and storms. Additionally, wetlands play a crucial role in reinforcing coastal stability by reducing erosion and turbidity (Faunce & Serafy, 2006; Gu et al., 2022; Kathiresan, 2021; Malik et al., 2015; Taillardat et al., 2018). However, increasing anthropogenic pressures have led not only to widespread wetland degradation but also to changes in habitat composition and structure, particularly where mangrove expansion, restoration, or encroachment may occur at the expense of open mudflat habitats. Between the 1980s and 1990s, it was estimated that 35% of mangrove forest area was in decline while other regions suffered from 50–80% in loss (Romañach et al., 2018). To this end, wetlands must be recognized as natural assets that are essential to solving societal and environmental challenges (Barbier, 2011).

In response to the rising global concerns, Nature-based Solutions (NbS) have become an integral solution during the 2019 United Nations Climate Summit and the 2021 COP 26 (International Union for Conservation of Nature [IUCN], 2020). NbS aim to put nature at the forefront to address a spectrum of societal challenges, such as, but not limited to, climate change adaptation and mitigation, disaster risk reduction, ecosystem degradation and biodiversity loss, food security, human health, social and economic development, and water security (IUCN, 2020; Y. Liu et al., 2022). These solutions aim to maximize ecological benefits while ensuring resilience and cost-effectiveness (Chee et al., 2021; Guannel et al., 2016; C.-W. Liu et al., 2014; Taillardat et al., 2018). To ensure the quality and impact of NbS projects, the IUCN has established a Global Standard focused on accountability, outcome measurement, and continuous learning. However, this standard faces challenges that complicate achieving its goals, including issues with long-term monitoring, financial and logistical constraints, scalability, and a lack of systematic assessment and evaluation (Bautista et al., 2009; Meroni et al., 2017). For instance, restoring degraded mangrove areas can be costly, and scaling up NbS can be challenging due to their site-specific requirements and ecological sensitivities (Dahdouh-Guebas et al., 2021).

After nearly three decades under the Heritage Preservation Law, Taiwan advanced its environmental governance in 2015 by enacting the Wetland Conservation Act and the Coastal Management Act, positioning itself as a regional leader in wetland protection. These policies have supported the sustainable use of wetland ecosystem services and established frameworks for designating areas of "Wetland of Importance" (Y.-C. Chen & Shih, 2019; Su, 2014). Within this context, the Guandu Nature Reserve serves as a key case study for examining the dynamics of mangrove expansion and their encroachment into estuarine regions. The challenges outlined in this research closely mirror those faced in the Guandu Wetlands, where rapid urban development, agricultural demands, and climate pressures intersect with the need to conserve critical wetland ecosystems. Guandu Wetlands demonstrates the delicate balance between sustaining

biodiversity and meeting human needs, underscoring the importance of science-based, participatory approaches to resource management. In this context, universities play a vital role as collaborative platforms by conducting ecological monitoring and evaluating various research within Guandu Nature Park. By bridging research, community engagement, and policy discussions, universities help translate scientific insights into actionable frameworks for sustainable wetland management.

This study examines the extent to which the Guandu Wetlands align with the IUCN Global Standard for NbS. It contributes to the global NbS discourse by presenting a practical case of how stakeholder engagement and interdisciplinary research can inform conservation outcomes. Through interviews with representatives from Guandu Nature Park, the Forestry Bureau, the Taipei City Hall Hydrology Department, and the Wild Bird Society (Supplementary File, Table 1), this research assesses Guandu Wetlands' alignment with NbS. By understanding perspectives from various stakeholders, this research seeks to provide valuable insights for future conservation efforts, supporting the development of adaptive management strategies for the effective preservation of the Guandu Wetlands and similar ecosystems. The findings have broader implications for urban wetland governance, demonstrating how structured evaluation using global NbS standards can guide sustainable ecosystem management, strengthen collaboration among stakeholders, and support policy decisions aimed at maintaining ecological integrity while addressing societal needs. Ultimately, the study aims to enhance the understanding of wetland dynamics and contribute to the formulation of informed conservation strategies that can be applied more broadly.

1.1. Societal Issues & Interventions

For an intervention to be considered NbS, it must address one or more societal challenges. The Guandu Wetlands confront a multitude of pressing issues that necessitate the implementation of NbS to address key societal challenges. The three paramount societal challenges in Guandu Wetlands are climate change mitigation and adaptation, environmental degradation and biodiversity loss, and disaster risk reduction (IUCN, 2020; Table 1).

The Guandu Wetlands face pollution and low wastewater collection rates, leading to reduced food sources. The construction of embankments and alterations to riverbanks compress living spaces for various species. Coastal cementation and budgetary constraints further exacerbate habitat reduction. Human activities like sand and gravel collection, river dredging, and urban development contribute to habitat loss, disrupting the natural balance of ecosystems ("Rang women hai," 2018). Moreover, threats of human development have been an ongoing issue that the Taipei City Hydrology Department and the Guandu Nature Park Managers have to face publicly (Supplementary File, Tables 2 and 4). At a global scale, climate change and rising temperatures are driving changes in wetland ecosystems, influencing multiple habitat types, including bird habitats and wetland communities (Desta et al., 2012). While mangroves are inherently dynamic and respond to climatic variability, this broader context highlights the importance of NbS for enhancing ecosystem resilience in areas such as Guandu (Ayassamy, 2025). The Ramsar Convention emphasizes the importance of preserving wetlands, urging concerted efforts to address environmental challenges and promote sustainable practices ("Shi di zhongxin," 2014; "Xun hui tan tu," 2022). Additionally, harmful human activities such as illegal dumping of trash by unscrupulous companies and pesticide use threaten the wetland's biodiversity and result in water pollution ("Chongsheng de shi," 2013; Guandu Nature Park, 2013).

The Guandu Wetlands area was originally composed of marsh wetlands. After the severe dumping of waste soil, the primary focus shifted to habitat restoration. In late 2005, water from Shuomokeng Creek was redirected into the area to establish artificial wetlands, accompanied by the planting of various aquatic plant species. Years later, Guandu Wetlands managers still implement restoration projects for birds and plants to make better habitats for them to increase their biodiversity ("Chongsheng de shi," 2013). Another human intervention the managers implement is the exchange of saltwater to increase the biodiversity of the wetland. Increased food availability resulting from this process supports a larger bird population. Additionally, the presence of saltwater helps suppress the growth of invasive weeds. Guandu Nature Park managers have an array of conservation measures and environmental education projects that help in preserving the wetland's pristineness. Geographically located at the estuary, the Guandu Wetlands are strongly influenced by tidal conditions, resulting in frequent flooding. The area has also suffered substantial losses from multiple severe typhoon-induced floods (C.-W. Liu et al., 2014; Shih et al., 2022). The Guandu Wetlands' conservation efforts involve a bundle of NbS interventions implemented in collaboration with central competent authorities to enhance biodiversity and reduce flood risks (Supplementary File, Table 2). These continuous efforts include the restoration of salt marshes through controlled saltwater exchange, which maintains optimal salinity levels, increases food availability for waterbirds, supports the growth of native halophytic plants, and suppresses invasive weeds. Mangrove management and selective removal are also carried out to balance bird habitat availability while retaining the ecosystem services provided by mangroves, such as carbon storage and shoreline stabilization. In addition, continuous planting of native aquatic vegetation in restored wetlands provides nesting and foraging habitats and supports overall wetland biodiversity. Because the wetlands near Guandu are ecologically interconnected, managers coordinate interventions to minimize indirect impacts on neighboring wetlands, anticipating bird movement during restoration and other activities. All interventions are accompanied by ongoing monitoring of bird populations, vegetation, and water quality to guide adaptive management and enhance risk mitigation. While each NbS addresses specific ecological goals, they are implemented as an integrated bundle to collectively mitigate habitat degradation, reduce flood risks, and enhance waterbird habitats. For instance, although mangrove management may have localized unintended effects on bird populations, combining it with saltwater exchange and vegetation restoration maximizes overall biodiversity outcomes. Despite these continuous efforts, there remains a need for systematic planning, prioritization, and evaluation of interventions. To address this gap, our research employs the IUCN NbS framework to evaluate the effectiveness of the various interventions at Guandu Wetlands. Specifically, interviews were conducted with diverse stakeholders and scored each intervention, allowing us to assess their ecological and social outcomes, identify shortcomings in current management practices, and provide recommendations for improvement. This approach ensures that our study not only documents ongoing NbS efforts but also generates actionable, evidence-based insights to guide more effective, stakeholder-informed wetland management. A collaborative relationship exists between Guandu Nature Park managers and university researchers, which supports the conservation of these important NbS. For example, the park actively encourages students and scholars to carry out field studies within its boundaries (Supplementary File, Table 2). Professors and researchers are recognized as influential stakeholders valued for their informed perspectives, and they are generally positioned at the center of discussions and decision-making processes concerning Guandu Nature Park ("Shi di zhongxin," 2014; Supplementary File, Table 3). Until now, there have been 28 master's and doctoral dissertations studying Guandu Nature Park (2014); this body of research on Guandu Nature Park reflects the evolution of Taiwan's approaches to wetland conservation, environmental education, and community engagement over nearly three decades.

Table 1. Summary of societal challenges found in Guandu Wetlands and their description from previous literature.

Climate Change Mitigation and Adaptation	Environmental Degradation and Biodiversity Loss	Disaster Risk Reduction
Rising temperatures which lead to habitat loss.	Pollution and industrial water waste result in food reduction. The construction of embankments and alterations to riverbanks compress living spaces for various species. Coastal cementation and budgetary constraints further exacerbate habitat reduction. Human activities like sand and gravel collection, river dredging, and urban development contribute to habitat loss, disrupting the natural balance of ecosystems.	The Guandu Wetlands, situated at the estuary of the Tanshui and Keelung Rivers, are strongly influenced by tidal fluctuations and experience flooding twice daily. This area has suffered significant losses due to multiple severe typhoon-induced floods.

Sources: "Chongsheng de shi" (2013); Guandu Nature Park (2013); C.-W. Liu et al. (2014); "Shi di zhongxin" (2014); S.-S. Shih et al. (2022); "Xun hui tan tu" (2022).

2. Methods

2.1. Study Site

The study site is the Guandu Wetlands (Figure 1 and Supplementary File, Figure 1), located in the southwestern part of the Guandu Plain in Taipei, Taiwan, approximately 10 kilometers from the Tamsui River estuary (Hsu & Lee, 2018). The nature reserve covers an area of 57 ha and is primarily composed of Kandelia obovata mangroves and Phragmites patches, both of which are tolerant of cold conditions (Guandu Nature Park, n.d.; S.-C. Yang et al., 2013). The wetlands are influenced by multiple factors, including tidal fluctuations, arsenic-contaminated soils, and the uniform salinity of the estuary (C.-W. Liu et al., 2014; S.-C. Yang et al., 2013). Originally established as the Guandu Nature Reserve by the Taipei Municipal Government under the Cultural Heritage Preservation Law (Hsu & Lee, 2018), the site has been the focus of mangrove restoration efforts since the 1940s, driven by scientists, government officials, and conservation managers. Following its reclassification in 2021, entry into the wetlands no longer requires a permit. Over time, spatiotemporal changes have reshaped the wetlands, with mangrove coverage steadily expanding (Hsu & Lee, 2018). The wetlands support a diverse bird community, including members of the families Ardeidae, Shorebird sp.(Charadriidae, Glareolidae, Haematopodidae, Recurvirostridae, Rostratulidae, Scolopacidae), Laridae, Anatidae, Threskiornithidae, and Eastern cattle-egret (*Ardea coromanda*). Given its history of restoration and protection, combined with its rich biodiversity, cultural importance, and observable mangrove expansion, the Guandu Wetlands provide an ideal setting for this study (Figure 2).

Figure 1. Aerial map of the study site at Guandu Wetlands and Nature Park, Taipei, Taiwan. The red point indicates the official reference coordinates, and the yellow polygon delineates the official boundary of the Guandu Wetlands. Coordinates: 121.458718, 25.108917, 121.486183, 25.117767. Maps of park facilities are provided in the Supplementary File, Figure 1.

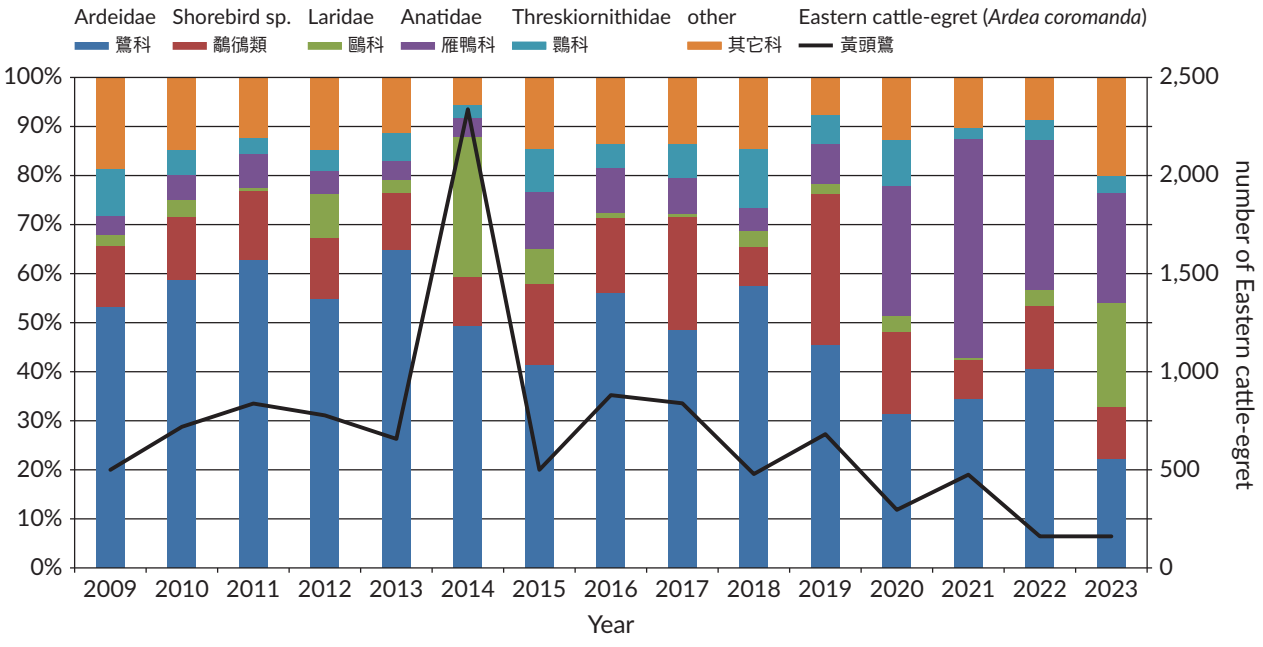

Figure 2. Bird biodiversity survey provided by Guandu Nature Park.

The organizational map in Figure 3 illustrates the division of labor and responsibilities among key stakeholders at Guandu Nature Park. At the top, the Taipei Wild Bird Society oversees the park through its Board of Directors, with a Director and Deputy Director managing operations. The Taipei City Government Animal Protection Office participates via the Camp Steering Committee, linking government oversight to park management. Park operations are divided into two main functional groups: Public Promotion and Field

Service. The Public Promotion Group includes the Public Affairs Department, which handles communications, marketing, and public relations, and the Ministry of Environmental Education, responsible for educational program development and resource management. The Field Service Group includes the Sales Service Department, which manages visitor services, ticketing, and on-site maintenance, and the Ministry of Environment Conservation, which oversees biodiversity research, wildlife habitat management, and infrastructure maintenance for ecological management. Supporting administrative tasks (e.g., finances, Figure 4) are coordinated through the administrative room, reporting to the Deputy Director. This structure ensures coordinated management of educational, operational, conservation, and administrative functions, with input from both governmental and non-governmental stakeholders.

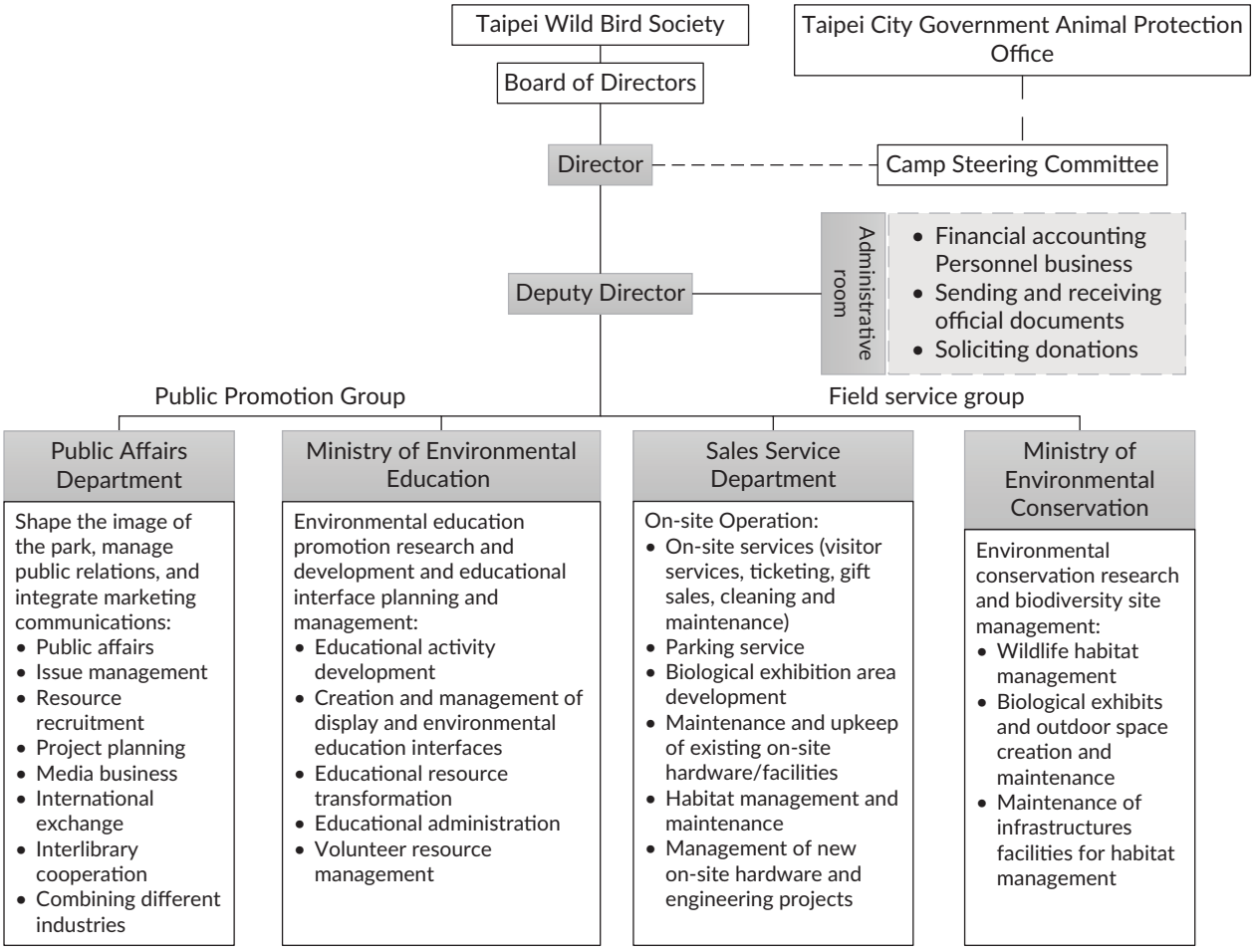

Figure 3. Stakeholder map of Guandu Nature Park managers with their respective responsibilities.

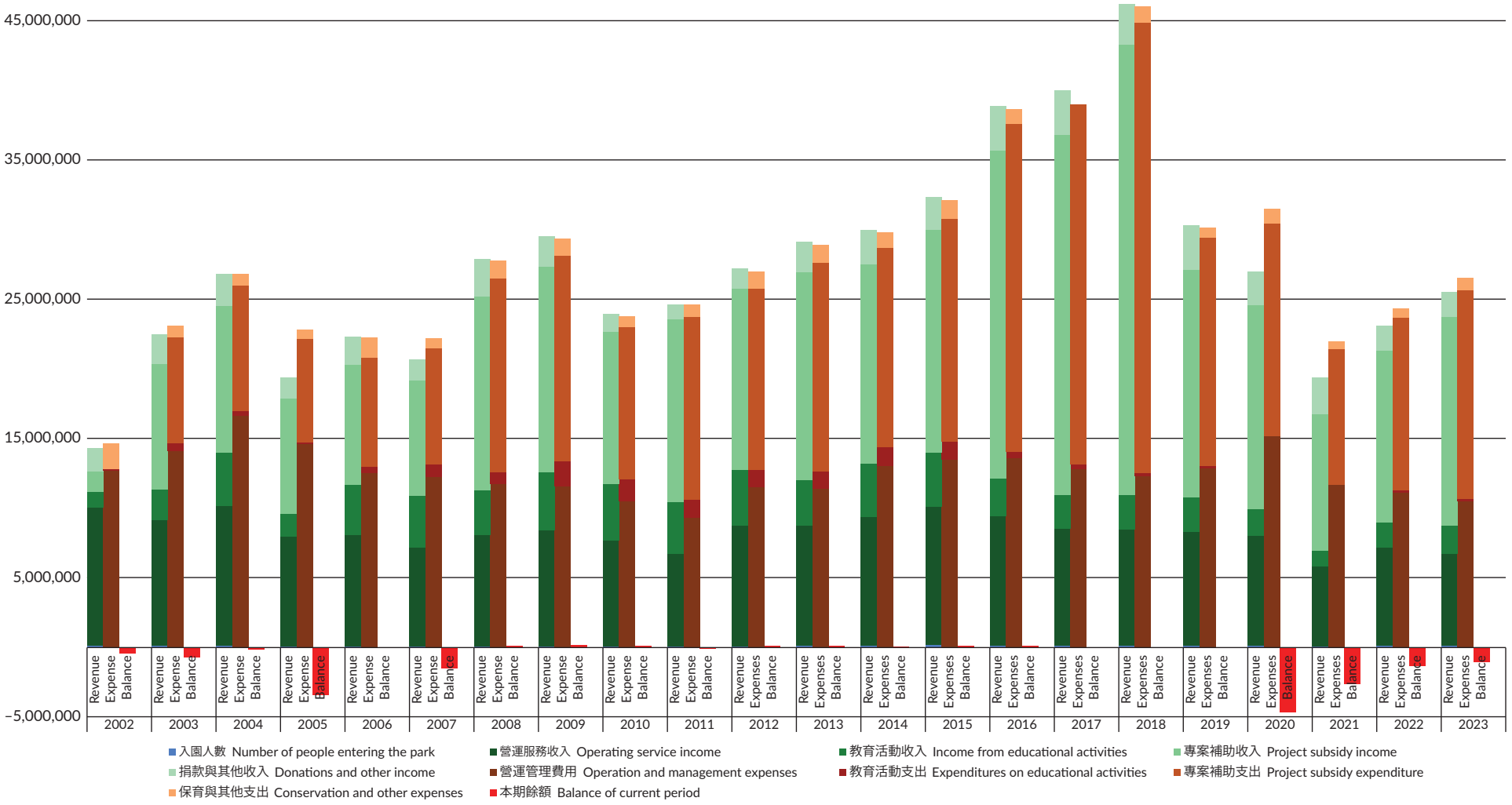

Figure 4. Guandu Nature Park economic feasibility with expenditures and revenues in TWD.

2.2. Data Collection & Framework

The IUCN Global Standard for NbS offers a comprehensive framework that guides stakeholders about the design, implementation, and verification of NbS (IUCN, 2020). Applying the IUCN criteria to the Guandu Wetlands allows us to systematically evaluate the effectiveness of past and ongoing restoration and management actions, highlight areas for improvement, and demonstrate how interdisciplinary stakeholder engagement and adaptive management contribute to the realization of NbS outcomes. This tool has been applied in various contexts, such as guiding sustainable aquaculture practices in Zanzibar (Le Gouvello et al., 2023). Its eight criteria (societal challenges, design at scale, biodiversity net-gain, economic feasibility, inclusive governance, balance trade-offs, adaptive management, and sustainability and mainstreaming) have each of them 3–5 indicators, totaling 28 indicators (Le Gouvello et al., 2023). In this research, the English version of the standard was translated into Chinese, with additional guiding questions introduced to deepen the understanding of each criterion and indicator (Supplementary File, Questionnaire 1). Key interviewees were selected based on their extensive knowledge and active involvement in Guandu Wetlands management, including representatives from Guandu Nature Park, the Forestry Bureau, the Taipei City Hall Hydrology Department, and the Wild Bird Society (Supplementary File, Table 1). These interviews were conducted from April to June 2024. Since there are two representatives from Guandu Nature Park with different specialties, they provided independent scores for the criteria they have extensive knowledge about. As some discrepancies were observed between their assessments, the scores were averaged to obtain a balanced measure, reflecting both operational and conservation perspectives.

All interviewees assigned individual scores to each indicator using a scoring scheme adapted from Le Gouvello et al. (2023; 0 = insufficient, 1 = partial, 2 = adequate, 3 = strong). Detailed descriptions of each scoring level were provided with the questionnaire (Supplementary File, Questionnaire 1). Criterion-level scores were calculated by summing indicator scores, dividing by the maximum possible score for each criterion, and normalizing the result to a percentage scale (×100).

3. Results

3.1. Score of Indicators

Among the individual indicators, the highest scoring was 5.3 Stakeholders Identification and Involvement, which achieved an average of 91.7% among four stakeholders, reflecting strong performance in recognizing and including relevant actors. This was closely followed by 6.2 Rights, Usage of, and Access to Land and Resources at 87.5%, and both 6.1 Costs and Benefits of Associated Trade-offs and 5.4 Stakeholders Involvement in Decision Making, each with 83.3%. Another indicator showing strong performance was 5.1 Grievance Resolution Mechanism with 79.2%. Indicators with adequate performance, including 8.2 Policy, Regulations, and Laws, 8.1 Information Sharing for Transformative Change, 7.2 Monitoring and Evaluation Plan, 3.2 Biodiversity Conservation Outcomes, 2.1 Interactions Between Economy, Society, and Ecosystems, and 1.2 Documented Societal Challenges, all scored 75.0%. Slightly lower were indicators 7.3 Framework for Adaptive Management, 6.3 Periodic Review of Safeguards, and 5.5 Decision-making Beyond Jurisdictional Borders, each at 70.8%. Indicators at the lower tier of the adequate category included 4.2 Cost-effectiveness Study, 3.3 Unintended Adverse Consequences, 2.2 Complementarity and Synergies, and 1.1 Identification and Prioritization of Societal Challenges, each at 66.7%. Even lower were 7.1 NbS

Strategy, 4.1 Direct and Indirect Benefits and Costs, 3.4 Enhancement of Ecosystem Integrity and Connectivity in NbS Strategy, 3.1 Ecosystem State and Drivers of Degradation and Loss, and 2.3 Risk Identification and Management, each scoring 58.3%, along with 4.4 Resourcing Options and 4.3 Alternative Solutions to Test Effectiveness, both at 50.0%. The lowest results were observed in 1.3 Identified Human Well-Being Outcomes at 41.7%, while two indicators, 8.3 National and Global Targets and 5.2 Indigenous People Involvement, scored 0%, indicating a complete lack of evidence or action in these areas (Table 2 and Figure 5).

Table 2. Summary of the total 28 indicator scores in percentage.

Indicator	Average Score (%)	Qualitative Scores
1.1 Identification and Prioritization of Societal Challenges	66.7	Adequate
1.2 Documented Societal Challenges	75.0	Strong
1.3 Identified Human Well-Being Outcomes	41.7	Partial
2.1 Interactions Between Economy, Society, and Ecosystems	75.0	Strong
2.2 Complementarity and Synergies	66.7	Adequate
2.3 Risk Identification and Management	58.3	Adequate
3.1 Ecosystem State and Drivers of Degradation and Loss	58.3	Adequate
3.2 Biodiversity Conservation Outcomes	75.0	Strong
3.3 Unintended Adverse Consequences	66.7	Adequate
3.4 Enhancement of Ecosystem Integrity and Connectivity in NbS Strategy	58.3	Adequate
4.1 Direct and Indirect Benefits and Costs	58.3	Adequate
4.2 Cost-Effectiveness Study	66.7	Adequate
4.3 Alternative Solutions to Test Effectiveness	50.0	Adequate
4.4 Resourcing Options	50.0	Adequate
5.1 Grievance Resolution Mechanism	79.2	Strong
5.2 Indigenous People Involvement	0.0	Insufficient
5.3 Stakeholders Identification and Involvement	91.7	Strong
5.4 Stakeholders Involvement in Decision Making	83.3	Strong
5.5 Decision-making Beyond Jurisdictional Borders	70.8	Adequate
6.1 Costs and Benefits of Associated Trade-Offs	83.3	Strong
6.2 Rights, Usage of, and Access to Land and Resources	87.5	Strong
6.3 Periodic Review of Safeguards	70.8	Adequate
7.1 NbS Strategy	58.3	Adequate
7.2 Monitoring and Evaluation Plan	75.0	Strong
7.3 Framework for Adaptive Management	70.8	Adequate
8.1 Information Sharing for Transformative Change	75.0	Strong
8.2 Policy, Regulations, and Laws	75.0	Strong
8.3 National and Global Targets	0.0	Insufficient

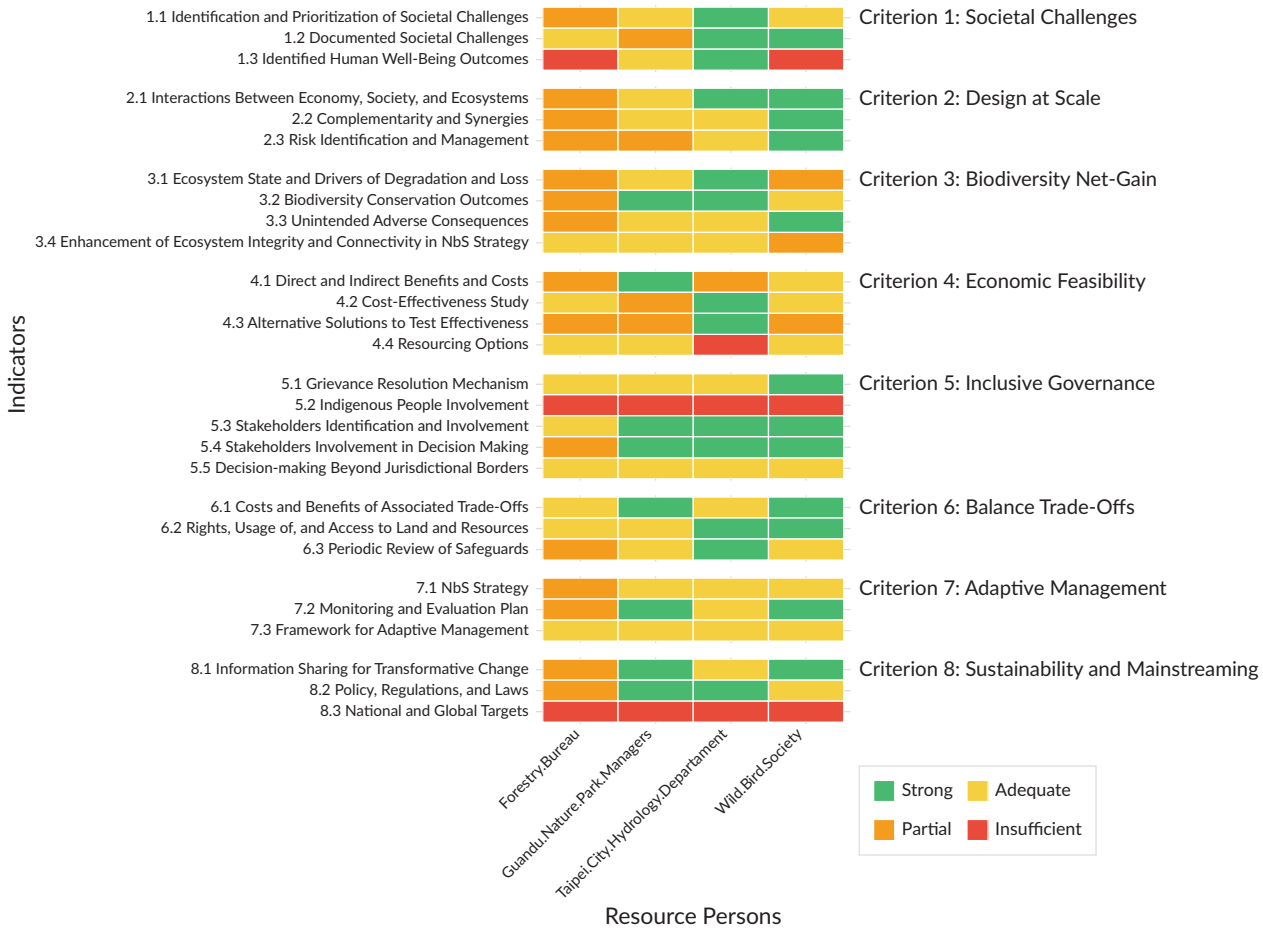

Figure 5. Results of the IUCN NbS self-assessment tools across all 28 indicators for each interviewee.

3.2. Results by Criterion

From the four stakeholders, Criterion 6: Balance Trade-Offs achieved the highest score with an average of 2.42 (80.6%), indicating strong performance in addressing costs, benefits, rights, and safeguards. This was followed by Criterion 7: Adaptive Management with an average score of 2.04 (68.1%), and Criterion 2: Design at Scale with 2.00 (66.7%), both showing adequate performance. In the middle range, Criterion 5: Inclusive Governance scored 1.95 (65.0%), and Criterion 3: Biodiversity Net-Gain scored 1.94 (64.6%), suggesting partial to adequate progress. Criterion 1: Societal Challenges followed closely with 1.83 (61.1%). The lowest scoring criteria were Criterion 4: Economic Feasibility with 1.69 (56.2%) and Criterion 8: Sustainability and Mainstreaming with 1.50 (50.0%), highlighting areas where improvements are most needed to strengthen the overall NbS assessment (Table 3 and Figure 6).

Table 3. Summary of the total eight criterion scores in percentage.

Criterion	Average Score (%)	Qualitative Score	Qualitative Summary
1: Societal Challenges	61.1	Adequate	Societal issues are identified and documented but further improvements in focusing on human well-being must be addressed.
2: Design at Scale	66.7	Adequate	Guandu Nature Park has many partnerships (e.g., NGOs, donors, schools) but their framework for conservation is not transferable or applicable to others.
3: Biodiversity Net-Gain	64.6	Adequate	Bird biodiversity is continuously monitored, including during periods affected by typhoons; however, the ecological effects of management interventions require time to manifest as measurable changes in biodiversity.
4: Economic Feasibility	56.2	Adequate	Costs are transparently documented, and corporate sponsorship supports conservation efforts; however, funding constraints indicate the need for cost–benefit analysis.
5: Inclusive Governance	65.0	Adequate	Multiple government departments actively engage the public through surveys, public consultations, and designated public engagement offices. Guandu Nature Park employs a feedback system that enables residents and visitors to report concerns via direct communication, government channels, or on-site staff.
6: Balance Trade-Offs	80.6	Strong	Stakeholders understand the ecological and economic trade-offs, but a cost–benefit analysis is required.
7: Adaptive Management	68.1	Adequate	Guandu Nature Park managers oversee external reviews related to environmental education and safety, maintain certification standards, and conduct real-time biodiversity monitoring with high-quality bird data. Management activities are scheduled based on long-term ecological observations, with construction halted during breeding seasons and maintenance timed to minimize disturbance to resident and migratory wildlife.
8: Sustainability and Mainstreaming	50.0	Partial	Guandu Nature Park actively engages in national and international collaborations through exchanges, training programs, and partnerships with organizations. Guandu Nature Park abides by governmental policy and regulations.

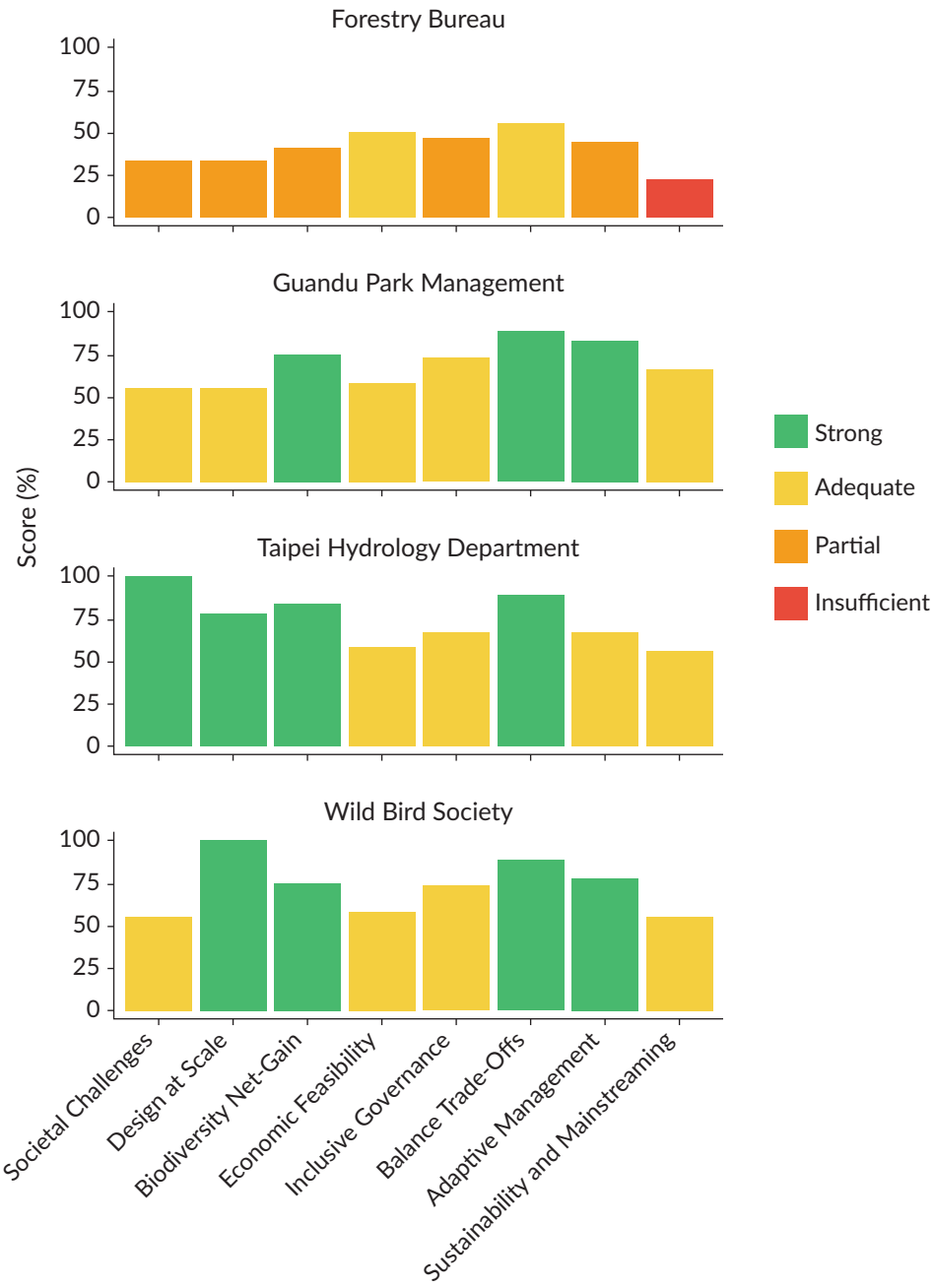

Figure 6. Results of the IUCN NbS self-assessment tools across the eight criteria for each interviewee.

4. Discussion

This study applied the IUCN Global Standard for NbS to assess the Guandu Wetlands, offering insights into the site's performance across key criteria and highlighting stakeholder-specific strengths and areas for improvement. Overall, Guandu Wetlands demonstrated a satisfactory level of alignment with the Global Standard, especially in the areas of stakeholder participation, adaptive management, and trade-off recognition. In addition, selected student dissertations were incorporated as supplementary evidence to illustrate how ongoing academic research aligns with and supports specific criteria of the IUCN Global Standard for NbS. The following sections discuss the site's performance across all eight criteria in detail.

4.1. Criterion 1: Addressing Societal Challenges

Guandu Wetlands has established mechanisms to engage stakeholders and document societal challenges, including flood prevention, public health, and ecosystem services. While conservation efforts are supported by government regulation and documented stakeholder involvement, public understanding of wetland benefits, such as flood mitigation and connections to human well-being, remains limited, and development pressures from private landowners persist. Integrating social and economic factors, monitoring human well-being, and clearly communicating environmental benefits are needed to strengthen public support and justify NbS investments (Aguilera-Rodríguez et al., 2025).

4.2. Criterion 2: Design at Scale

Design at scale emphasizes that NbS should extend beyond site-specific interventions to consider broader ecological connectivity, cross-sectoral coordination, and long-term scalability (IUCN, 2020). In the context of Guandu Wetlands, scaling NbS requires continuous monitoring and the alignment of actions across landscapes and institutions to ensure that local interventions contribute to wider ecosystem outcomes.

The conservation department in Guandu Nature Park is central to guiding the present and future of the wetlands. While the department possesses substantial expertise and operational capacity, its management framework is not always directly transferable to other sites due to differences in ecological conditions, legal contexts, and governance arrangements. Nevertheless, Guandu Nature Park contributes to knowledge exchange through networks such as Wetland Link International, facilitating information sharing and learning among wetland sites (Supplementary File, Tables 2, 6, and 7).

At the local level, partnerships with schools and educational programs support long-term environmental monitoring while enhancing conservation education. These collaborations not only enrich student learning but also generate valuable ecological data. Expanding data sharing across wetlands in Taiwan could further strengthen understanding of environmental change and migratory bird dynamics, reinforcing regional cooperation in wetland conservation (Supplementary File, Table 3).

Despite these opportunities, scaling NbS beyond Guandu remains challenging. Park managers and Forestry Bureau representatives highlighted constraints related to limited resources, legal boundaries, competing land-use interests, and nearby polluting industries. While invasive species and habitat management can be effectively addressed within the park, extending such measures beyond its boundaries is difficult, leaving broader ecological pressures such as invasive species spread largely unmanaged (Supplementary File, Table 2).

Connectivity among wetlands also introduces ecological risks that must be carefully managed (Kininmonth et al., 2015). Construction or habitat modification within Guandu may displace birds to nearby wetlands, while mangrove removal in surrounding areas can similarly alter species distribution. To mitigate these risks, the Taipei City Hydrology Department has recommended smaller-scale construction approaches to minimize disturbance. Ongoing monitoring, cross-agency coordination, and adaptive management are essential to addressing these interconnected impacts (Supplementary File, Table 4).

Stakeholder coordination was repeatedly emphasized as critical for effective scaling. Interviewees recommended establishing issue-specific working groups with clearly defined responsibilities, improving data accessibility, and strengthening mechanisms for communication and accountability. Such measures can enhance participation from government agencies, NGOs, corporations, and the public, while fostering broader awareness of NbS principles (Supplementary File, Tables 3 and 5).

Overall, while Guandu Wetlands provides a valuable reference for multi-stakeholder NbS implementation, interviewees consistently noted that upscaling remains difficult due to limited public awareness and contextual differences among sites. As echoed by Megyesi et al. (2024), effective scaling of NbS requires not replication, but adaptation grounded in local ecological conditions, governance structures, and stakeholder capacities.

4.3. Criterion 3: Biodiversity Net-Gain

Early studies conducted by university students (e.g., Chiang, 2001; Lin, 1995) focused on the ecological impacts of landscape change and the dynamics of bird communities, complementing the Guandu Nature Park managers surveys and together providing a strong foundation for understanding biodiversity conservation within the park. This ecological baseline enabled subsequent research to explore the human dimensions of conservation, particularly visitor attitudes, environmental behaviors, and ecotourism (Feng, 2006; Lee, 2001; C.-W. Liu et al., 2014; Tsai, 2005). Biodiversity monitoring in Guandu Nature Park remains complex, particularly due to the influence of migratory and invasive species on long-term records. Water birds are the primary indicator species, providing quantifiable measures of ecosystem health, though counts can fluctuate even when environmental improvements occur, likely reflecting broader ecological or migratory changes. Despite challenging weather conditions and occasional construction activities that may obscure observations, the Guandu Nature Park managers continue regular surveys. Historical baseline data spanning the past 20 years highlight trends in bird populations and underscore the importance of long-term monitoring. While the Forestry Bureau believes that management efforts are maintaining habitat quality, it remains unclear whether biodiversity outcomes are consistently measurable or improving as expected. Evidently, utilizing the baseline data is important. Overall, ongoing monitoring at Guandu provides critical insight into the park's biodiversity dynamics, emphasizing the value of long-term datasets and the need to consider both natural and anthropogenic factors in conservation assessments.

4.4. Criterion 4: Economic Feasibility

Criterion 4 was the second-lowest indicator, as economic barriers have made upscaling, implementing, and monitoring NbS difficult (Martin et al., 2025). Guandu Nature Park is no exception. All costs are documented and communicated to the public, as transparency is a key aspect of the wetlands' governance. Revenue comes from entrance fees, parking, souvenir shops, restaurants, donations, and grants from corporations (e.g., HSBC; Supplementary File, Tables 6 and 7), as well as government funding. While government agencies provide project-based funding, Guandu Nature Park does not receive direct subsidies, making self-generated income crucial. Corporate sponsorships vary annually, adding to financial uncertainty. Despite these challenges, Guandu Nature Park managers effectively track income sources, ensuring compliance with regulations, though additional funding is needed to sustain operations and expand conservation efforts. The score reflects that all costs and revenues are considered, rather than financial gains (Figure 4).

There are always pressures to develop the wetlands for potential revenue. However, the site is already protected, and its management relies on a combination of city government support, corporate funding, and self-generated income through shops and restaurants. Government agencies depend on Guandu Nature Park managers to implement ecological work and environmental education, while corporations contribute to enhance their environmental, social, and governance (ESG) image. Compared to corporations, government funding is less flexible and varies with policies and leadership. Given this uncertainty, additional resourcing options are desirable. Potential approaches include leveraging community contributions, such as labor from students or company employees, and generating income through rentals for photoshoots, events, or advertisements. Detailed site data could also support proposals to organizations like the IUCN to enable international collaborations. All initiatives should be carefully designed to maintain environmental quality and align with public welfare objectives (Supplementary File, Table 3).

According to the Forestry Bureau, local residents benefit from the flood control, education, and tourism provided by Guandu Wetlands, although no cost-effectiveness studies were reported. Although quantifying both tangible and intangible benefits is challenging, natural solutions may surpass artificial ones (Supplementary File, Table 3). This is because natural systems often provide multiple co-benefits simultaneously, whereas artificial designs are typically developed to address a single function (Raymond et al. 2017). Therefore, preserving the natural environment often proves more effective than human-made designs. It is essential to identify benefits that support both people and ecosystems, particularly in disaster prevention, green spaces, and areas that promote stress relief. Ideally, protection costs should remain low and focus on minimizing disturbances; however, expenses typically increase once human interventions are introduced (Supplementary File, Table 5). Comparing these results with a prior study on sustainable aquaculture in Zanzibar (Le Gouvello et al., 2023), it is noteworthy that both Taiwan and Zanzibar, despite differing socio-economic contexts, face similar challenges related to the economic viability of NbS projects.

4.5. Criterion 5: Inclusive Governance and Stakeholder Engagement

Over time, university-based research has increasingly examined institutional frameworks and collaborative governance in Guandu Nature Park. For example, Z.-S. Chen (2014) and Ho (2011) underscored the role of civil society groups, government agencies, and local communities in shaping the park's governance structures. Similarly, Huang (2014) highlighted how partnerships between the park and private organizations, such as HSBC, contributed to advancing environmental education and outreach. These studies reflect a growing recognition that successful conservation requires strong partnerships and inclusive decision-making processes. Another significant research trajectory centers on environmental education and capacity building. Numerous dissertations (e.g., S. H. Chen, 2005; K. M. Liu, 2004; W.-R. Yang, 2012) have evaluated the effectiveness of curricula, interpretive programs, and volunteer engagement. Collectively, these works illustrate how Guandu Nature Park has served as a living laboratory for developing and testing innovative education strategies, particularly those designed for school groups, teachers, and community volunteers. Such initiatives not only enhance ecological literacy but also foster long-term stewardship. In addition, Guandu Nature Park has been studied as a site of socio-ecological interactions. Research on ecotourism, leisure activities, and residents' perceptions (e.g., Hung, 2009; Y.-W. Liu, 2011; Tsai, 2005) reveals both opportunities and tensions. While ecotourism provides economic and educational benefits, it also raises questions about managing visitor impacts and balancing conservation goals with community needs. Political ecology perspectives (Hung, 2009) have further illuminated how governance decisions

intersect with issues of equity, access, and power. Taken together, these studies demonstrate that Guandu Nature Park is more than a protected area; it is a nexus of ecological, social, and institutional dynamics. The park has become a testing ground for integrating biodiversity conservation with education, recreation, and community development. However, the literature also points to persistent challenges, including the need for more effective policy integration, stronger long-term monitoring of ecological change, and sustained collaboration among diverse stakeholders. Future research may benefit from explicitly connecting ecological outcomes with social impacts, thereby advancing understanding of how urban wetland parks can simultaneously support conservation, education, and community well-being.

4.6. Criterion 6: Balancing Trade-Offs

Balanced trade-offs require that stakeholders recognize the existence of such compromises (IUCN, 2020). Moreover, trade-offs must be both quantitatively and qualitatively determined (IUCN, 2020). When trade-offs arise, clear boundaries between stakeholders and the use of resources must be maintained and respected to prevent destabilization of NbS (IUCN, 2020). Trade-offs are an inevitable aspect of environmental management, particularly in multifunctional ecosystems like wetlands (Gibson, 2013). In Guandu, conservation is prioritized over potentially conflicting uses such as land development and tourism-related disturbances (e.g., photographers entering core conservation zones; Supplementary File, Table 2). In an ecological context, balancing ecological benefits such as allowing seawater into the wetland represents a trade-off between ecological gains and agricultural concerns. The controlled inflow enhances biodiversity by supporting benthic organisms and bird populations, while also lowering maintenance costs by reducing weed growth. At the same time, too much seawater could increase soil salinity, threatening nearby farmland. To balance these outcomes, managers regulate the process by limiting gate openings to once or twice a month, ensuring both ecological integrity and agricultural sustainability (Supplementary File, Table 2). The protection of monetary trade-offs is safeguarded by the accountants in Guandu Nature Park to ensure transparency. Additionally, frameworks such as climate resilience, net-zero initiatives, Sustainable Development Goals (SDGs), and third-party certification and verification mechanisms (e.g., Société Générale de Surveillance) are ensured by the Guandu Nature Park managers. Both regular evaluations internally and internal frameworks ensure respect and limits between various trade-offs (Supplementary File, Tables 2 and 4). In regard to respecting trade-offs, interestingly, the idea of a Guandu Wetlands NbS working team was raised, emphasizing the need for open communication among stakeholders and the importance of addressing their concerns. Such discussions may lead to one of two possible outcomes: a mutual agreement, or a decision where some stakeholders remain partially dissatisfied but are willing to compromise (Supplementary File, Table 3).

4.7. Criterion 7: Adaptive Management

Wetland ecosystems undergo dynamic changes; thus, stakeholders are in charge of adjusting NbS management strategies. In the past, legal restrictions limited effective management; however, following the reclassification of Guandu Nature Park, operations were able to address emerging issues as they arose. Regular monitoring now ensures stability, prevents deterioration, and serves as the foundation of various conservation projects (Supplementary File, Tables 2 and 5). In terms of adaptive management, Guandu Nature Park has obtained various government standards and licenses to be able to manage and operate the park. For instance, local knowledge and real-time monitoring data were used to determine the best time

when construction, grass trimming, and conservation efforts are optimal for minimal disruption of natural habitats, especially for migratory birds. From March to May, the managers stop construction to avoid disturbing the breeding season of birds, insects, and small mammals. August to September is considered a suitable time for tasks like weeding, as most young animals have matured and can move independently. However, all work must be completed before November, when migratory birds arrive for the winter, as any disturbances could drive them away permanently. Their 20 years of experience allow them to predict seasonal patterns and plan management activities accordingly to minimize ecological disruption (Supplementary File, Table 2). The previous example mentioned is grounded in adaptive management and iterative learning, where challenges are continuously identified, solutions are applied, and strategies are refined based on results. The Guandu Nature Park managers utilize farming processes, emphasizing the need to work in harmony with seasonal cycles. By observing nature's rhythms, managers can make informed decisions that balance conservation goals with necessary interventions. When managing NbS, flexibility is key as unforeseen ecological shifts may demand adaptive responses (Smith & Chausson, 2021). Long-term monitoring and collaboration with local communities also strengthen the effectiveness of interventions. Practical insights, often gained through trial and error, play a vital role in improving conservation practices. At the same time, recognizing human impacts on ecosystems and integrating scientific research can enhance management outcomes. Ultimately, effective environmental management relies on a blend of experience, evidence, and adaptability (Supplementary File, Table 2). The Wild Bird Society mentions that monitoring of these changes is adequate, but planning for the future is more substantial (Supplementary File, Table 5).

4.8. Criterion 8: Sustainability and Mainstreaming

Although Criterion 8 received the lowest score in Guandu Wetlands, this was primarily because there are no predominant aboriginal communities in this part of Taipei, Taiwan. Guandu Nature Park actively engages in national and international collaborations, staff training, and knowledge exchange, while conducting environmental education and SDG-related programs to enhance public awareness and learning. Park managers participate in wetland construction and decision-making, collaborating with NGOs and professionals to analyze monitoring data and develop iterative improvement plans. While government regulations and policy promotion support NbS implementation, inconsistent stances between local and central authorities remain a key challenge to mainstreaming NbS.

4.9. Recommendations

Based on the interviews, it is recommended that stakeholders reach consensus on the adoption of NbS, beginning with clear definitions of what qualifies as NbS and the standards that must be met. This endeavor requires a lot of coordination that may potentially lead to misunderstandings (Directorate General for Research and Innovation, 2023). Its success depends on whether the stakeholders are engaged with the establishment and expansion of NbS despite its challenges (Teo et al., 2023). A major challenge in the upscaling of NbS is financial funding. Scholars argue that NbS funding can co-exist with broader climate financing mechanisms (Molloy et al., 2024). However, existing NbS such as Guandu Wetlands still rely on financial support from the private sector, government sources, and non-governmental organizations, rather than high-level or dedicated climate-related funding mechanisms. Based on this study on Guandu Wetlands, there is a lack of attention to economic feasibility in Guandu Wetlands and even other sites (e.g., Zanzibar; Chairat & Gheewala, 2024; Le Gouvello et al., 2023).

In this case study, where ecological monitoring and financial data are available, a database of NbS would be valuable for stakeholders and university researchers to facilitate the scaling up of NbS (Supplementary File, Table 2; Almassy et al., 2018; Chee et al., 2021; Molloy et al., 2024). Overall, when it comes to management and boundaries and limits to trade-offs, all stakeholders are responsible and knowledgeable of tasks and well-defined laws (Supplementary File, Table 5). For example, the Forestry Bureau leaves the democratic decision-making to the Guandu Nature Park managers but still participates in steering committees, contributing to the high score in inclusive governance. This finding aligns with previous studies that claim participation has a positive impact on environmental governance outcomes (Newig et al., 2023). Despite the use of progressive ecological management approaches, it remains essential to translate ecological benefits into quantifiable costs and benefits in order to convince a broader range of stakeholders to adopt NbS. More often than not, negative impacts of gray solutions are not accounted for; this is vital to highlight the benefits of NbS (Anderson et al., 2021). Assessment of NbS is critical to confirm that they effectively address climate-related challenges and to evaluate their impacts on ecosystem structure, functioning, and biodiversity outcomes. For instance, the Taipei Hydrology Department has implemented selective mangrove management, including controlled thinning, to maintain water flow capacity and open mudflat habitats, with the dual aim of mitigating localized flooding risk and supporting waterbird populations (Supplementary File, Table 4). Other recommendations include aligning with the Taskforce on Nature-related Financial Disclosures, as suggested by interviewees, which could help attract corporate partnerships and emphasize biodiversity outcomes (Supplementary File, Table 3).

4.10. Limitations

While the NbS criteria were translated into Chinese, some indicators proved challenging to interpret without additional context provided by guided questions. Notably, Criterion 2 (Design at Scale) did not score as highly for representatives from the Forestry Bureau and Guandu Nature Park managers as it did for the Taipei Hydrology Department and the Wild Bird Society. Furthermore, since the questionnaire was mostly for NbS managers, the perspectives of the private donors and residents in Taipei City were not taken into account, as NbS does not have a high public awareness yet in Taipei City. Future works must include the perspectives of residents in NbS implementation and planning.

5. Conclusion

The application of the IUCN Global Standard for NbS to the Guandu Wetlands highlights the importance of balancing trade-offs, practicing adaptive management, and designing interventions at scale. These principles are particularly relevant in ecologically sensitive and urban-adjacent environments such as Guandu Wetlands. While stakeholders including the Forestry Bureau, local authorities, and academic institutions are represented in governance structures and planning forums, the translation of shared objectives into on-the-ground interventions varies in scope and intensity. In this context, researchers and the academe play a critical role by generating ecological evidence and providing studies on the management of Guandu Wetlands—they give an independent basis for evaluating NbS performance. By integrating scientific evidence into management decisions, policymakers can prioritize interventions that maximize ecological and social benefits, while also justifying resource allocation for restoration and conservation initiatives. Strengthening the interface between scientific research and management practice, alongside continuous monitoring of ecological transitions, will be essential for adaptive management and for informing future NbS

initiatives in Guandu and comparable urban wetlands. Furthermore, lessons learned from Guandu's multi-stakeholder approach can guide other urban wetland projects, support biodiversity conservation, enhance ecosystem services, and inform regional and national policies on sustainable wetland management.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Data are available upon request.

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Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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