

Wetland protection gaps in China: Insights from small and/or isolated wetlands (SIWs)

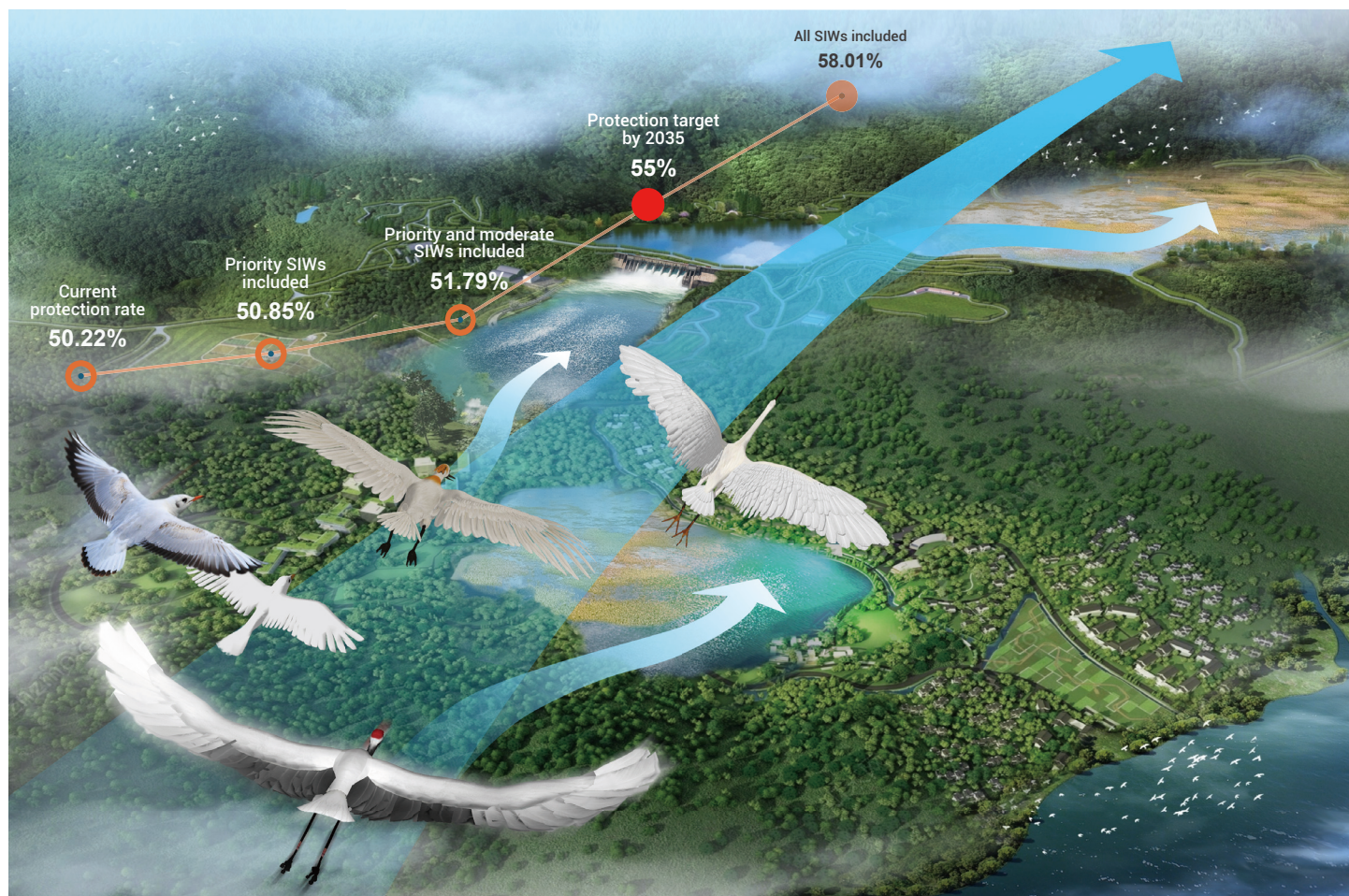
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GRAPHICAL ABSTRACT



PUBLIC SUMMARY

- Small and/or isolated wetlands (SIWs) are critical for biodiversity and ecological stability.
- We mapped SIWs across China and identified major conservation gaps at the national scale.
- Adding SIWs into reserves could raise wetland protection coverage by up to 8 percentage points.
- This study supports evidence-based strategies to achieve China's 2030 biodiversity targets.

Wetland protection gaps in China: Insights from small and/or isolated wetlands (SIWs)

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The establishment of protected areas remains a cornerstone strategy for conserving wetland ecosystems. However, many SIWs in China remain excluded from national conservation frameworks, despite their ecological importance. To address this gap, we developed a rapid assessment model integrating four key indicators — wetland area, waterfowl species richness, waterfowl abundance, and dominant wetland plant richness—to identify and evaluate unprotected SIWs at a national scale. The assessment was supplemented by expert-sourced online questionnaires to enhance data coverage, particularly for regions lacking systematic monitoring. A total of 1,473 unprotected SIWs were identified, encompassing approximately 3.39 million hectares. These wetlands represent critical conservation gaps in the current protected area network. Incorporating them into the national wetland protection system would raise China's protection level from 50.22% to 58.01%, surpassing the governmental target of 55% by 2035. Many of these SIWs are located along major migratory bird routes and in biodiversity-rich zones, underscoring their strategic ecological value. This study provides the first systematic evaluation of SIWs at the national level in China and proposes a scalable, data-driven framework for prioritizing wetland protection. The results offer actionable guidance for enhancing wetland conservation and contribute to the broader goals of the Global Biodiversity Framework and the Ramsar Convention.

INTRODUCTION

Wetlands encompass a diverse range of ecosystems, including marshes, swamps, bogs, and estuaries, each playing a distinct role in supporting biodiversity and maintaining ecological stability.¹ These ecosystems deliver essential services such as water purification, flood regulation, and carbon sequestration.² However, the global extent of wetlands has declined dramatically over the past century, driven by agricultural expansion, urban encroachment, pollution, and hydrological alterations.^{3,4} The ecological consequences are profound, threatening the survival of wetland-dependent species and undermining critical ecosystem services.⁵

Among these ecosystems, SIWs — typically less than 8 ha in area or lacking functional hydrological connectivity — have received comparatively little attention.⁶ Despite their limited spatial extent, SIWs frequently support distinct and locally adapted species assemblages,⁷ contribute to microclimate regulation, and maintain habitat heterogeneity and hydrological buffering at the landscape scale.^{8–10} Unlike larger, connected wetlands, SIWs provide disproportionately high ecological value relative to their size, serving as refuges for rare or specialized species, contributors to habitat diversity, stepping stones for migratory waterbirds, and localized regulators of hydrological and nutrient cycles. These supporting functions are therefore particularly critical for sustaining their distinct ecological roles and conservation significance, especially in fragmented or human-dominated environments.¹¹ Nevertheless, most SIWs in China remain outside the boundaries of formal protected areas,^{12,13} not due to a lack of ecological value, but because current conservation strategies and evaluation frameworks have not been designed to adequately detect or incorporate them.¹⁴ While national statistics specific to SIWs are lacking, wetlands larger than 8 ha have a protection rate of approximately 52%, suggesting that more fragmented and spatially dispersed

SIWs likely experience even lower levels of protection coverage.

Recognizing the urgency of biodiversity loss, the Kunming-Montreal Global Biodiversity Framework (GBF), adopted at the 15th Conference of the Parties (COP-15), has established the ambitious “30×30” Target 3, which calls for the effective conservation and management of at least 30% of global terrestrial and inland water areas by 2030.^{15–17} This goal reflects an international commitment to expand and optimize protected area networks to ensure ecological representativeness and resilience.^{18,19} However, meeting this target requires inclusive planning that encompasses not only large, iconic wetlands but also small and ecologically significant sites such as SIWs.²⁰

In practice, most existing habitat assessment frameworks have been designed for large, spatially continuous wetland systems. These frameworks typically rely on data-intensive methods such as the Habitat Suitability Index (HSI), multi-criteria evaluation (MCE), biodiversity indices (e.g., Shannon–Wiener), and ecosystem service assessments.^{21–23} Each approach is dependent on specific data conditions: HSI models require quantitative species–habitat associations;²⁴ MCE methods depend on expert-based weighting schemes and consistent spatial inputs;²⁵ and ecosystem service assessments assume high-resolution, temporally stable remote sensing data.²⁶ These assumptions are rarely met in SIWs, where ecological data are limited, environmental conditions are highly variable, and spatial discontinuities are common.^{27–29}

To address these limitations, biodiversity-centered evaluation approaches offer a promising alternative.³⁰ SIWs often support unique plant communities and serve as critical habitats for migratory or localized bird species.^{31,32} Species richness and the presence of habitat-specialist taxa can function as robust indicators of ecological integrity in the absence of long-term datasets.³³ When combined with participatory tools — such as expert scoring or stakeholder surveys — these approaches can facilitate rapid, scalable assessments of habitat value under data-limited conditions.³⁴ Importantly, such methods are more attuned to the fine-scale ecological variation characteristic of SIWs and thus offer a practical pathway to identify conservation gaps that remain undetected by mainstream frameworks.^{35,36}

To this end, the present study developed a rapid evaluation model to identify and assess unprotected SIWs across China. By integrating national land survey data, spatial boundaries of existing reserves, dominant wetland plant richness, waterbird species and abundance, and data derived from a nationwide web-based questionnaire, we systematically mapped and characterized SIWs excluded from current protection systems. The findings provide new insights into the spatial distribution, ecological attributes, and conservation significance of SIWs and contribute to improving national-scale wetland protection planning under the GBF targets.

MATERIALS AND METHODS

Datasets and preprocessing

Unprotected wetlands. A geographic information system (GIS)-based overlay analysis was used to identify unprotected wetlands, integrating vector boundary data of national nature reserves and wetland data from China's Third National Land Survey (Figure 1). Wetlands exceeding region-specific area thresholds and lying outside protected boundaries were identified as SIWs representing protection gaps. These region-specific area thresholds

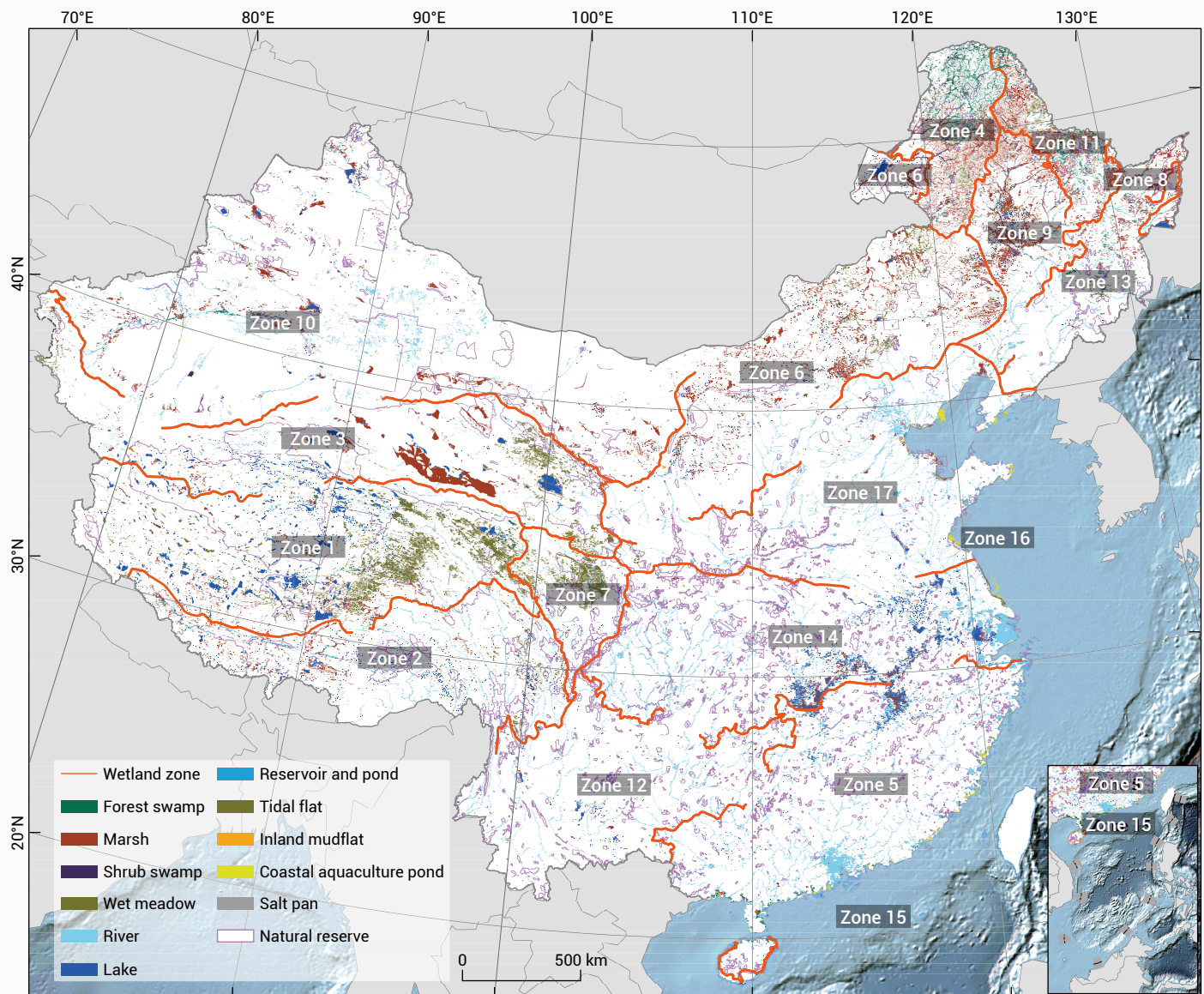


Figure 1. Geographic distribution of study wetlands, wetland zones, and existing nature reserves across mainland China Hong Kong SAR, Macao SAR, and Taiwan are not included. Data sources are provided in the Data and Code Availability section.

were determined based on the national standard for identifying small and micro wetlands and expert consultation. Considering differences in wetland distribution across China, we divided the country into coastal areas, wetland-rich provinces (Nei Mongol, Heilongjiang, Tibet, Qinghai, and Xinjiang), and other inland provinces, and applied corresponding area thresholds accordingly (see Table S1). The spatial boundaries of SIWs were directly extracted from the Third National Land Survey database as polygon vector data.

To supplement the identification process, a web-based questionnaire survey targeting unprotected SIWs was conducted from 25 September 2021 to 11 May 2022 (<https://www.wjx.cn/vj/tL3DZiG.aspx?v=56>; Table S2). A total of 223 valid responses were collected nationwide. The responses were spatially matched with the initially identified unprotected wetlands using a unified coding scheme, enhancing the completeness and reliability of the dataset. Respondents included personnel from wetland management agencies (61.0%), research institutions and universities (24.2%), and local conservation groups (14.8%).

Waterfowl species. Waterbird occurrence data were obtained from the eBird database,³⁷ BirdLife International, national and provincial bird surveys, and site-level monitoring reports from nature reserves (Table S3). All observations were standardized and consolidated into a unified dataset. Because most SIWs did not have direct bird survey records, existing bird observations

were used as a spatial supplement. We tested multiple buffer radii (1, 3, 5, and 10 km) and found that a 5-km buffer provided the best balance: Large enough to capture waterfowl mobility while avoiding overestimation for SIWs. Therefore, a 5-km buffer was applied to each survey point, and the buffered points were spatially overlaid with the unprotected SIWs. For overlapping areas, the maximum recorded values for species richness and abundance were extracted. A total of 360,000 survey records from 10,398 sites were compiled, with 2,660 points matched to 1,473 unprotected SIWs. Sites where waterfowl abundance exceeded 1% of total counts were flagged for further analysis.

Wetland plant species. Dominant wetland plant species richness was estimated using species distribution models (SDMs) based on 203 representative species and 39,064 occurrence records.^{38,39} The data were obtained from the National Earth System Science Data Center (<http://www.geodata.cn>). Seventeen environmental variables relevant to climate, soil, and topography were selected to enter into the model simulation.⁴⁰ Five algorithms were applied via the biomod2 package in R: Generalized Linear Model (GLM), Generalized Additive Model (GAM), Generalized Boosted Regression Model (GBM), Random Forest (RF), and Maximum Entropy (MaxEnt). We performed model validation 10 times by randomly dividing the occurrence data into two sets, with 70% of the data used for modeling and 30% for vali-

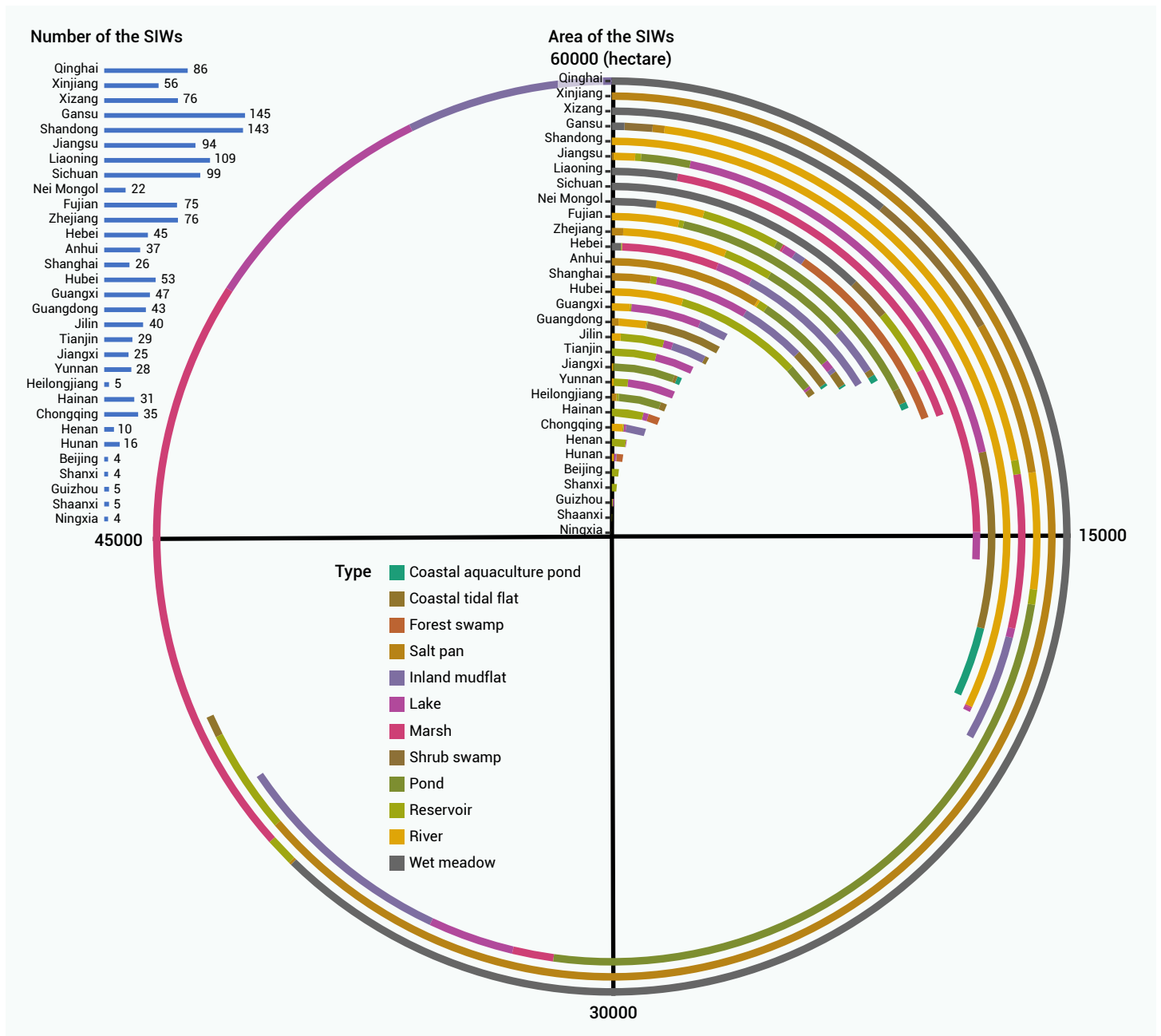


Figure 2. Wetland types and distribution of SIWs across provinces and regions Curved segments indicate total SIW area by type; blue segments represent the number of SIWs.

dation in each iteration. Model performance was evaluated using the area under the curve (AUC) and the true skill statistic (TSS). Only models with both AUC and TSS values greater than 0.8 were retained for ensemble model building. Performance was generally high, with RF, Maxent, and GBM showing the best accuracies (mean TSS ≥ 0.82 ; ROC > 0.90), while GAM performed substantially less well (mean TSS = 0.55; ROC = 0.78). Detailed validation statistics are provided in Table S1 & Figure S1. The result of the model ensemble was a probability surface ranging from 0 to 1. Predicted probabilities were converted into binary presence/absence using a conservative 0.7 threshold, selected after testing alternative cut-offs (0.5, 0.6, and 0.7) and found to best reduce overprediction in SIWs.⁴¹ Aggregated presence values across species were normalized to generate a spatial map of dominant wetland plant richness, from which values were extracted for each SIW.⁴²

Rapid assessment model

A rapid assessment model was developed based on four indicators: wetland area, waterfowl species richness, waterfowl abundance, and dominant wetland plant richness, which were selected through expert consulta-

tion to ensure representativeness and complementarity. To avoid multicollinearity, we tested independence among the four indicators using correlation analysis and PCA. Pairwise correlations were all below 0.4, and PCA confirmed distinct loadings, indicating complementary rather than redundant information (Table S4). To account for regional ecological variability, wetland zones were defined based on the Records of Mires in China (2nd Edition), dividing the terrestrial area into 17 distinct zones.⁴³ Zonal normalization was applied by using the maximum observed plant richness within existing reserves as a reference. Scoring criteria and thresholds for all indicators are detailed in Table S1. The total conservation priority score Q was calculated as:

$$Q = W \times \sum_{i=1}^4 X_i P_i \quad (1)$$

Where P_i is the score of each indicator, X_i is its weight determined through expert consultation with explicit consideration of bird conservation objectives to ensure that each indicator reflects its ecological importance in the assessment. Sensitivity analysis—including an equal-weights scenario and $\pm 20\%$

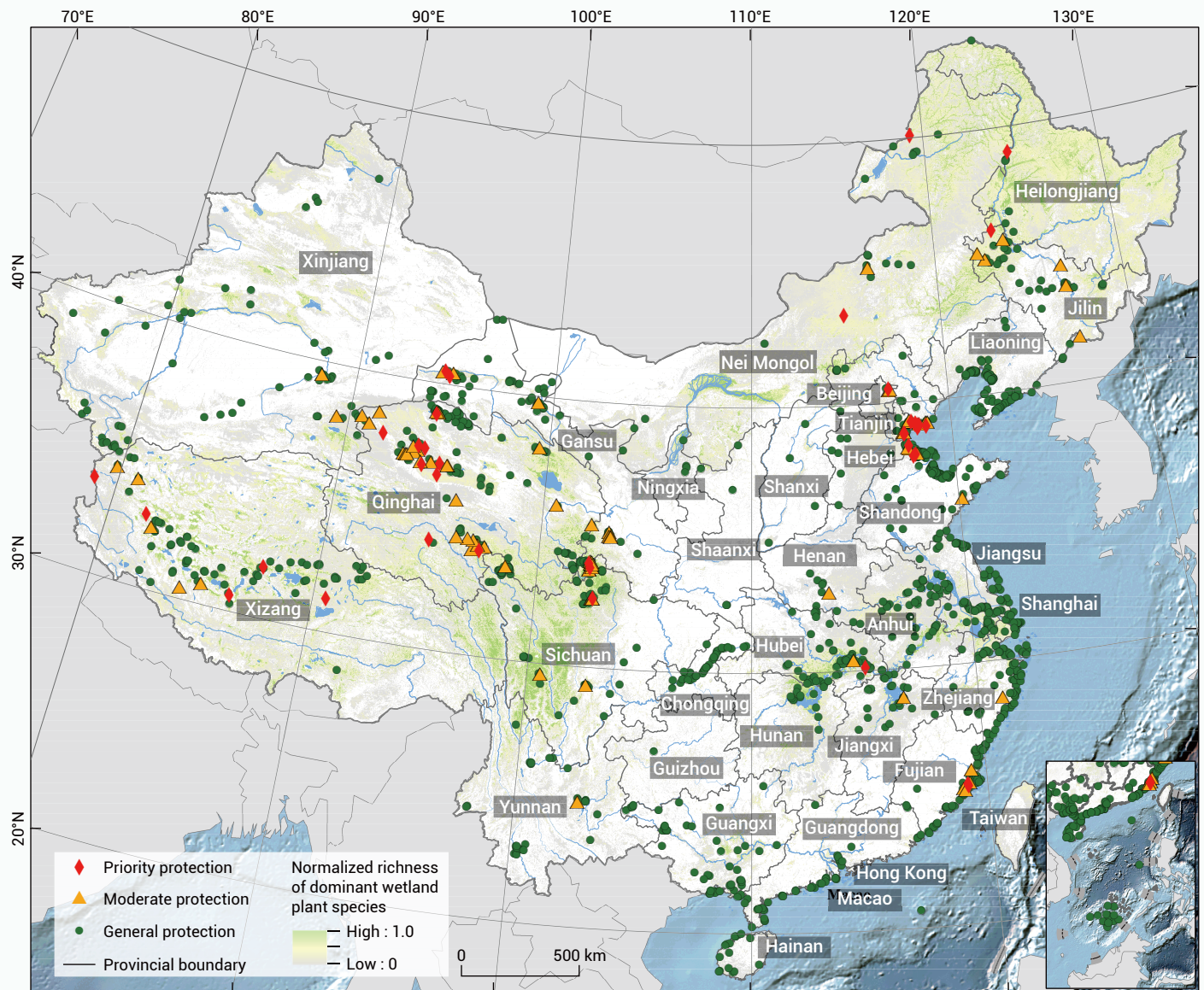


Figure 3. Spatial distribution of SIWs overlaid on the dominant wetland plant species richness map.

adjustments – confirmed robustness of the results ($p \geq 0.94$ for $\pm 20\%$ schemes; $p \approx 0.83$ for equal weights), with high overlap in top-priority sites (Table S5). W is a normalization constant (set to 25) to convert scores to a 0–100 scale. The final protection priority was categorized for each individual SIW polygon based on its Q value, using the following thresholds:

- (1) $Q \geq 70$: Priority Protection.
- (2) $50 \leq Q < 70$: Moderate Protection.
- (3) $Q < 50$: General Protection.

RESULTS

Overview of SIWs and wetland protection gaps

Using the GIS-based overlay method, 1,473 unprotected SIWs were identified across 31 provinces and regions (Table S6), with a total area of 3.39×10^6 ha. Of these, 522 were located in coastal provinces and 951 in inland provinces (Figure 2). To further illustrate the heterogeneity of SIWs across administrative and ecological gradients, we compiled a detailed summary of area ranges, medians, and interquartile values by province and wetland ecosystem type (Table S7), and visualized the provincial distributions by type (Figure S2).

Reservoirs accounted for the largest number of SIWs (20.5%), followed by coastal tidal flats (17.85%), wet meadows (14.87%), and lakes (12.56%). Together, these types represented 65.78% of all identified SIWs. Other notable

types included salt pans (9.50%), rivers (8.35%), and inland mudflats (5.57%). By area, lakes covered the most extensive gap area (0.87×10^6 ha, or 25.51%), followed by wet meadows (0.66×10^6 ha), reservoirs (0.41×10^6 ha), coastal tidal flats (0.37×10^6 ha), and salt pans (0.35×10^6 ha).

Designation of national wetland protection gaps

Based on the rapid assessment model, 39 SIWs were designated as priority protection gaps, primarily in Qinghai (8), Hebei (7), Xizang (5), Tianjin (3), Nei Mongol (3), Sichuan (3), Gansu (3), Fujian (2), Shandong (2), Beijing (1), Jilin (1), and Hubei (1). These sites included salt pans (10), wet meadows (9), lakes (8), tidal flats (6), rivers (5), reservoirs (2), marshes (2), one pond, and one inland mudflat, totaling 0.2731×10^6 ha or 8.05% of the total gap area (Figure 3). Geographically, priority SIWs were concentrated on the Qinghai–Tibet Plateau and along the Bohai coastal zone. This pattern reflects the large size and high modeled plant richness of inland plateau wetlands, as well as the elevated waterbird richness and abundance associated with coastal and estuarine systems.

An additional 83 SIWs were categorized as moderate protection gaps (0.4117×10^6 ha, 12.14%), mainly distributed across Qinghai, Sichuan, Gansu, Jilin, Tianjin, Hebei, Xizang, and Fujian, with small numbers in 9 other provinces (Figure 4). Wet meadow was the most frequent type (31), followed

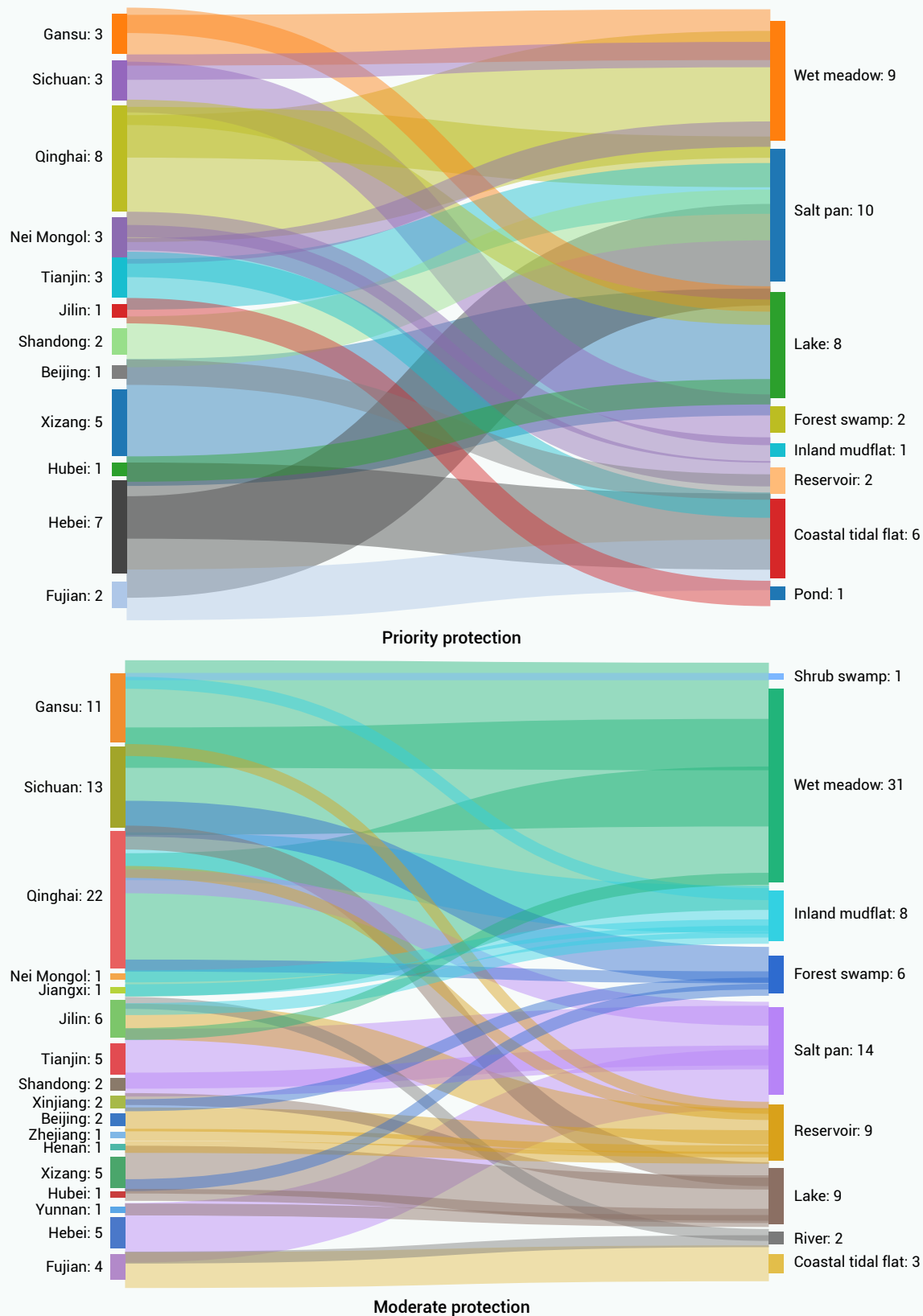


Figure 4. Locations and wetland types of priority and moderate protection SIWs Line thickness indicates the number of SIWs per type.

by salt pans (14), lakes (9), reservoirs (9), inland mudflats (8), marshes (6), tidal flats (3), rivers (2), and one shrub marsh. The remaining 1,351 SIWs (2.708×10^6 ha, 79.81%) were designated as general protection gaps.

National protection level of wetlands

Incorporating the identified SIWs into the national conservation framework would markedly enhance overall wetland protection. Nationally, the protection level would increase from 50.22% to 58.01%, thereby exceeding the government's 2035 target of 55%. If only SIWs with a priority protection level are included, the level would rise modestly to 50.85%, while including both

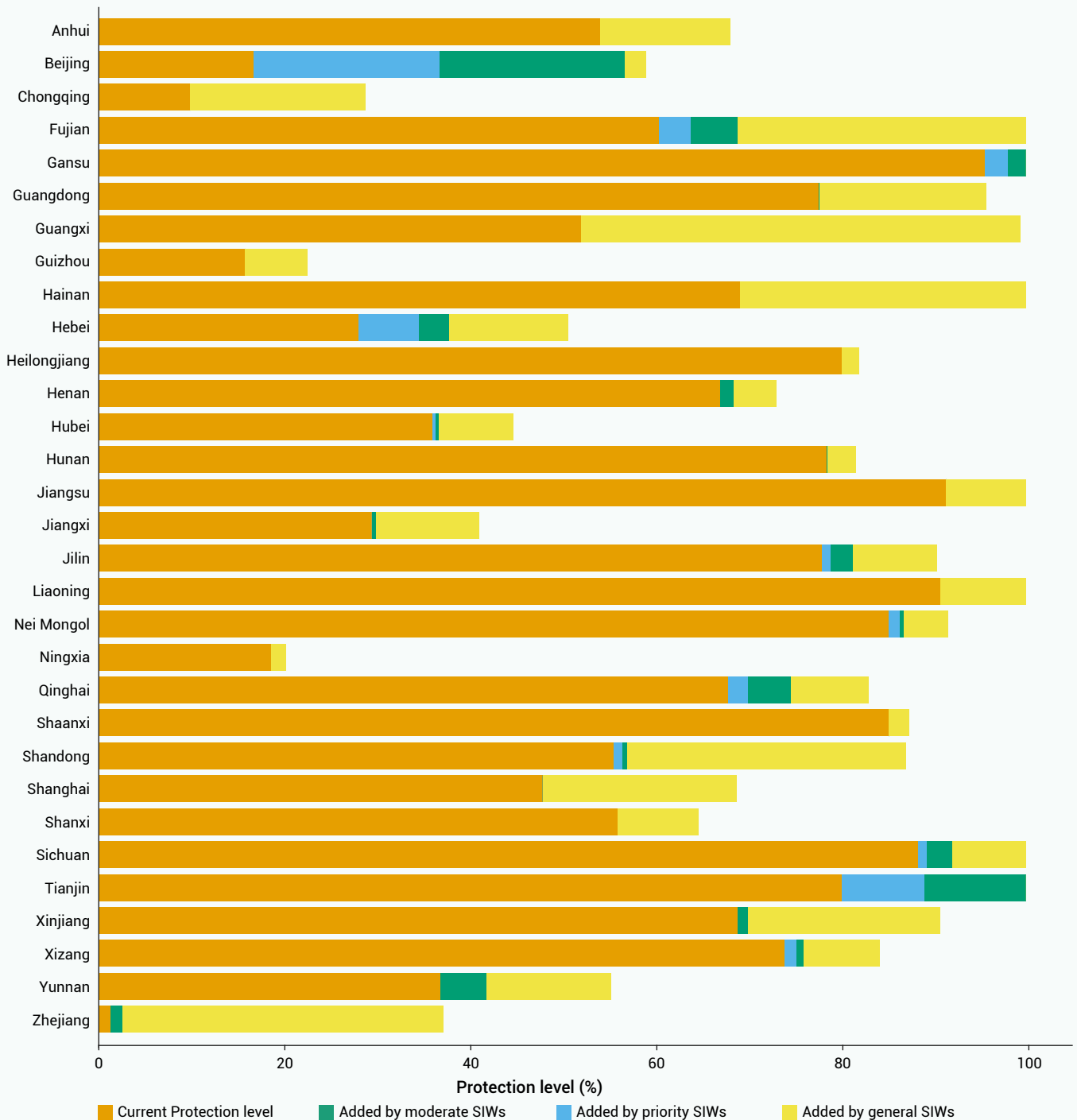


Figure 5. Provincial wetland protection levels before and after inclusion of SIWs, with stacked bars showing incremental gains from priority, moderate, and general categories.

priority and moderate SIWs would elevate it to 51.79%. These results demonstrate that partial inclusion would not suffice to reach the 55% target, underscoring the need for a stepwise approach that ultimately incorporates all SIWs into the protected area system. At the provincial level, the most substantial gains were observed in Fujian, Tianjin, and Guangxi. With SIWs nearly fully included, 24 out of 31 provinces would meet or surpass the 55% protection threshold (Figure 5).

Notably, over 900 of the identified SIWs intersect with major migratory bird routes, including more than 700 along the East Asian–Australasian Flyway. Inland gaps in Zones 3, 7, 9, 14, and 17 provide critical stopover habitats for threatened species such as *Leucogeranus leucogeranus* and *Ciconia*

boycciana (Figure 6).

DISCUSSION

Significance of SIWs in biodiversity protection

Although small in area, SIWs provide critical habitats and foraging grounds for migratory waterbirds (Figure 6), functioning as ecological stepping stones that facilitate refueling and resting during long-distance movements. In coastal regions, the inclusion of SIWs into the protected area system can substantially reduce the average distance between available stopover sites — from 20.9 km to 3.2 km — thereby improving habitat connectivity for migratory species. Many SIWs are also located in regions with high wetland plant

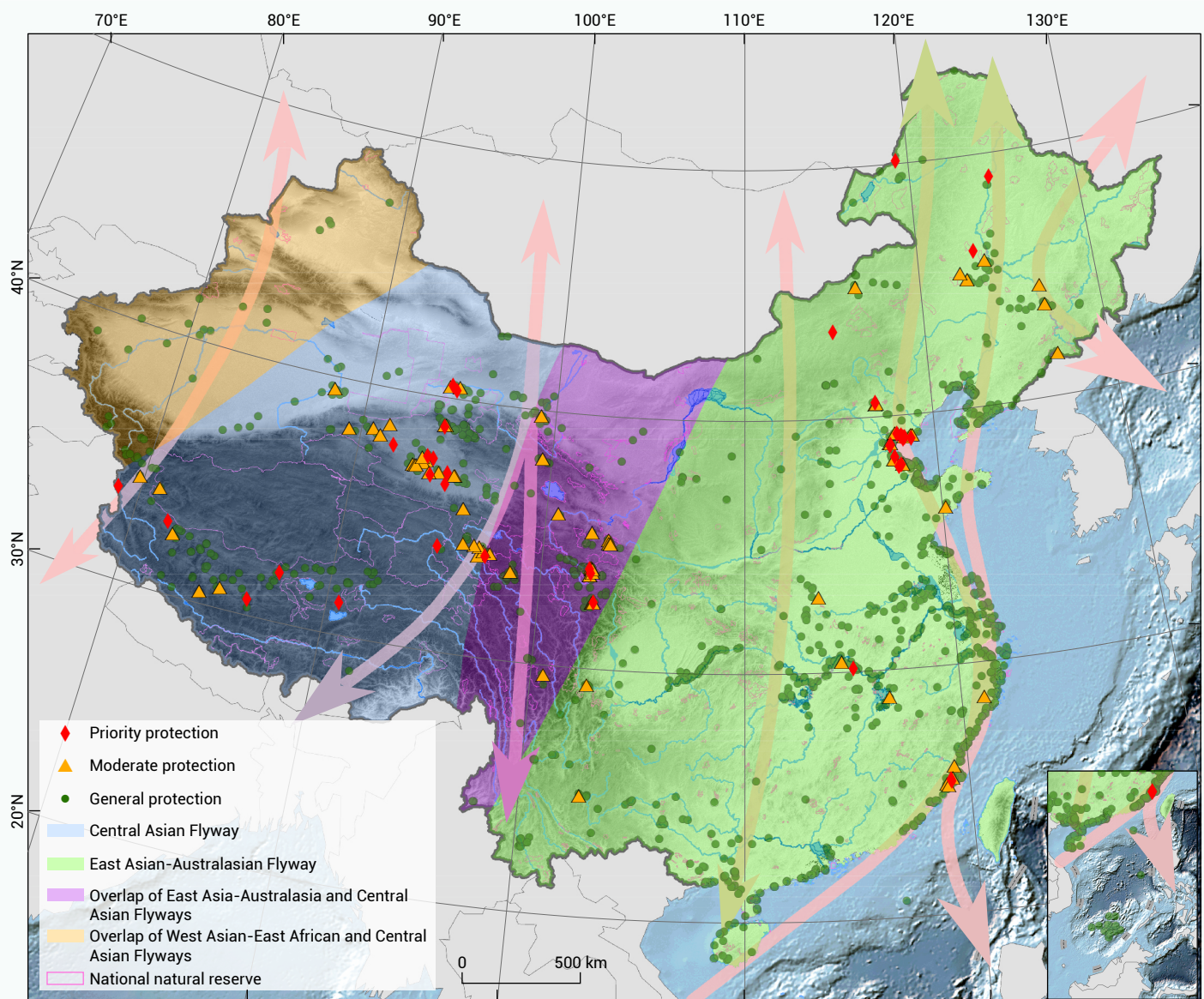


Figure 6. Migratory bird flyways and identified SIWs. Major national reserves and flyways are shown for spatial reference. Waterfowl migration routes were compiled from the WWF China database; protected area boundaries were derived from national and global datasets.

diversity, serving as refugia for a wide range of flora and fauna, including amphibians, fish, and invertebrates. Approximately 23% of all SIWs were identified as critical habitats for wetland plant species, particularly in Wetland Zones 2, 7, 9, and 14, which span the southern and eastern Tibetan Plateau, the middle and lower Yangtze Plain, the Songnen Plain, and the Zoige Plateau, respectively. These four zones collectively host 335 SIWs, accounting for 33.7% of all inland SIWs. Furthermore, over 17% of SIWs supported significant waterbird populations, with nearly 5 million individuals recorded. Notably, many of these wetlands are located along the East Asia–Australasian Flyway, one of the most important migration corridors globally.⁴⁴ Protection of SIWs is therefore essential for maintaining population viability of migratory birds and preserving ecological integrity at both national and international levels.

Feasibility of protection

Establishing and maintaining protected areas remains a fundamental strategy for biodiversity conservation.^{45,46} However, several existing reserves suffer from limited management capacity and inadequate site selection.⁴⁷ External pressures—such as land conversion, resource extraction, and climate change—further reduce their effectiveness.^{48,49} Conservation expansion, especially in human-dominated landscapes, must address trade-offs between ecological and socio-economic objectives.

China's current wetland protection level exceeds 50%,⁵⁰ with a national target of 55% by 2035. Our results indicate that incorporating the 1,473 identified SIWs would raise the protection level to 58%, exceeding the policy target. However, the dispersed distribution of SIWs makes it impractical to formally incorporate all of them. Instead, we unpack the optional ranges, showing protection levels of 50.85%, 51.79%, and 58.01% for priority-only, priority and moderate, and full SIWs inclusion, respectively. This highlights the importance of a stepwise approach, in which formal protected areas are complemented by stewardship measures to provide a more feasible pathway for enhancing national protection coverage. Priority SIWs should be considered for designation as independent protected areas. Moderately ranked SIWs can be integrated into adjacent reserves where feasible, while general-level SIWs may benefit from targeted measures such as enhanced patrolling and activity regulation. Long-term monitoring is essential across all categories to inform adaptive management. Nonetheless, spatial constraints pose challenges: only 87 SIWs (5.9%) are located within 5 km of existing protected areas, limiting opportunities for direct inclusion. Establishing new reserves or wetland parks for isolated SIWs may therefore be necessary.

Wetland type diversity is also an important consideration. Salt pans and wet meadows were frequently identified as high-priority sites. Artificial wetlands—such as salt pans and paddy fields—provide key foraging habi-

tats for waterbirds.^{51–53} Coastal salt pans in particular function as important wintering and stopover sites for migratory waterbirds, while wet meadows contribute disproportionately to habitat heterogeneity and provide transitional habitats in plateau and inland regions. These distinct ecological roles explain their prominence compared with larger systems such as lakes and reservoirs. However, balancing conservation with economic functions such as salt production requires context-specific strategies. For instance, implementing seasonal management protocols during migration periods can mitigate conflicts. Similarly, wet meadows, though floristically simple, offer essential stopover habitat and require sustained restoration to retain ecological function. Strategic conservation planning must therefore consider wetland type, species use patterns, and adjacent land-use pressures to maximize conservation outcomes for SIWs. Many SIWs belong to underrepresented wetland subtypes — such as inland mudflats, saline meadows, and ephemeral wetlands — which are often overlooked in conventional protection planning. Including these sites can enhance ecological representativeness and help countries align with the spirit of Target 3 by ensuring broad protection coverage across diverse wetland subtypes.

Challenges and strategies in protection

Despite their ecological significance, SIWs face several practical challenges. First, their small size increases vulnerability to external disturbances such as agriculture and urban expansion.^{54,55} Among the identified SIWs, 59.3% were within 5 km of farmland and 7.8% near urban areas. Second, their dispersed distribution complicates coordinated monitoring and management. Third, their ecological contributions are often underestimated in formal decision-making processes. Most priority SIWs identified in this study lack long-term monitoring records.

To address these challenges, a multi-faceted approach is required. Establishing a standardized, high-resolution monitoring system based on remote sensing, GIS, and species distribution models (SDMs) is a critical first step.^{56–58} Citizen science initiatives can supplement technical monitoring by expanding spatial coverage and enhancing stakeholder engagement.^{59,60} Policy frameworks should integrate rapid assessment tools that evaluate both ecological value and human pressures.⁶¹ However, these must be aligned with regional land-use planning and governance structures. In trans-boundary or ecotonal areas, cross-jurisdictional coordination is essential. Functional evaluation tools such as W-PAWF (Wetland Protection Area and Functionality Weighting Framework) offer practical support for prioritizing restoration.⁶² Future assessments may also benefit from incorporating the distribution of rare and endangered species and adopting ecosystem risk frameworks, such as the IUCN Red List of Ecosystems, to identify SIWs with exceptional conservation importance.^{63,64} In addition, the integration of amphibians and other key taxonomic groups, once consistent national datasets become available, would further improve the comprehensiveness of biodiversity representation. Quantifying the ecological and economic trade-offs of seasonal management protocols, such as regulating salt production during migration periods, will also be an important direction for enhancing the feasibility of management recommendations. In sum, closing the protection gap for SIWs requires the convergence of advanced monitoring technologies, inclusive community engagement, and adaptive policy frameworks.

CONCLUSION

This study presents the first national-scale assessment of SIWs in China, revealing substantial conservation gaps that, if addressed, would raise the protection level above the national 2035 target. By integrating spatial, biodiversity, and expert-sourced data into a replicable rapid assessment model, we provide a pragmatic framework to guide the inclusion of SIWs into future conservation planning. These findings directly inform the implementation of Target 3 of the Global Biodiversity Framework and advance the Ramsar Convention's call to recognize underrepresented wetland types.

REFERENCES

- Mitsch W.J. and Gosselink J.G. (2000). The value of wetlands: Importance of scale and landscape setting. *Ecol. Econ.* **35**:25–33. DOI:10.1016/S0921-8009(00)00165-8
- Davidson N.C. (2014). How much wetland has the world lost. *Long-term and recent*

- trends in global wetland area. *Mar. Freshw. Res.* **65**:934–941. DOI:10.1071/MF14173
- Zedler J.B. and Kercher S. (2005). Wetland resources: Status, trends, ecosystem services, and restorability. *Annu. Rev. Environ. Resour.* **30**:39–74. DOI:10.1146/annurev.energy.30.050504.144248
- Fan B. and Li Y. (2024). China's conservation and restoration of coastal wetlands offset much of the reclamation - induced blue carbon losses. *Glob. Change Biol.* **30**:e17039. DOI:10.1111/gcb.17039
- Fluet-Chouinard E., Stocker B. D., Zhang Z., et al. (2023). Extensive global wetland loss over the past three centuries. *Nature* **614**:281–286. DOI:10.1038/s41586-022-05572-6
- Semlitsch R.D. and Bodie J.R. (1998). Are small, isolated wetlands expendable. *Conserv. Biol.* **12**:1129–1133. DOI:10.1046/j.1523-1739.1998.98166.x
- Leibowitz S.G. (2003). Isolated wetlands and their functions: An ecological perspective. *Wetlands* **23**:517–531. DOI:10.1672/0277-5212(2003)023[0517:IWATFA]2.0.CO;2
- Cohen M.J., Creed I.F., Alexander L., et al. (2016). Do geographically isolated wetlands influence landscape functions. *Proc. Natl. Acad. Sci. USA* **113**:1978–1986. DOI:10.1073/pnas.1512650113
- Mushet D.M., Calhoun A.J., Alexander L.C., et al. (2015). Geographically isolated wetlands: Rethinking a misnomer. *Wetlands* **35**:423–431. DOI:10.1007/s13157-015-0631-9
- Yang B., Yuan X., Tang F., et al. (2024). Small wetlands: Critical to flood management. *Science* **386**:859–859. DOI:10.1126/science.ads2055
- Xiong Y., Mo S., Wu H., et al. (2023). Influence of human activities and climate change on wetland landscape pattern—A review. *Sci. Total Environ.* **879**:163112. DOI:10.1016/j.scitotenv.2023.163112
- Zhang J., An S. and Leng X. (2020). Status of wetland research in China. *Mar. Freshw. Res.* **71**:1572–1591. DOI:10.1071/MF20103
- Wang Y., Sun J., Wu Y., et al. (2024). Spatiotemporal variation of small and micro wetlands and their multiple responses to driving factors in the high-latitude region. *Wetlands* **44**:1–15. DOI:10.1007/s13157-024-01882-9
- Xu W., Fan X., Ma J., et al. (2019). Hidden loss of wetlands in China. *Curr. Biol.* **29**:3065–3071. e3062. DOI:10.1016/j.cub.2019.07.053
- Secretariat C B D. (2022). Briefing note on scientific and technical issues related to the global monitoring of biodiversity. <https://www.cbd.int/doc/c/0aef/09cb/0f9654d627222534df6c7a98/id-om-2022-01-inf-02-en.pdf>
- Secretariat C B D. (2022). Decision adopted by the conference of the parties to the convention on biological diversity: 15/4 Kunming–Montreal global biodiversity framework. <https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf>
- Secretariat C B D. (2022). Proposed monitoring framework for the post-2020 global biodiversity framework. Secretariat of the Convention on Biological Diversity. <https://www.cbd.int/doc/c/f191/8db7/17c0a45b42a5a4fcd0bbb8c/sbstta-24-l-10-en.pdf>
- Ekardt F., Günther P., Hagemann K., et al. (2023). Legally binding and ambitious biodiversity protection under the CBD, the global biodiversity framework, and human rights law. *Environ. Sci. Eur.* **35**:80. DOI:10.1186/s12302-023-00786-5
- Diaz S., Zafra-Calvo N., Purvis A., et al. (2020). Set ambitious goals for biodiversity and sustainability. *Science* **370**:411–413. DOI:10.1126/science.abe1530
- Flitcroft R.L., Abell R., Harrison I., et al. (2023). Making global targets local for freshwater protection. *Nat. Sustain.* **6**:1499–1502. DOI:10.1038/s41893-023-01193-7
- Koma Z., Seijmonsbergen A.C., Grootes M.W., et al. (2022). Better together? Assessing different remote sensing products for predicting habitat suitability of wetland birds. *Divers. Distrib.* **28**:685–699. DOI:10.1111/ddi.13468
- Masoud A.M., Belotti M., Alfara A., et al. (2022). Multi-criteria analysis for evaluating constructed wetland as a sustainable sanitation technology, Jordan case study. *Sustainability* **14**:14867. DOI:10.3390/su142214867
- Yang W., Zhong J., Xia Y., et al. (2023). A comprehensive multi-metric index for health assessment of the Poyang Lake wetland. *Remote Sens.* **15**:4061. DOI:10.3390/rs15164061
- Xu Z., Dong B., Wei Z., et al. (2023). Study on habitat suitability change and habitat network of rare wintering cranes in important international wetlands. *Ecol. Indic.* **154**:110692. DOI:10.1016/j.ecolind.2023.110692
- Odgaard M.V., Turner K.G., Bøcher P.K., et al. (2017). A multi-criteria, ecosystem-service value method used to assess catchment suitability for potential wetland reconstruction in Denmark. *Ecol. Indic.* **77**:151–165. DOI:10.1016/j.ecolind.2016.12.001
- Zhou L., Guan D., Huang X., et al. (2020). Evaluation of the cultural ecosystem services of wetland park. *Ecol. Indic.* **114**:106286. DOI:10.1016/j.ecolind.2020.106286
- Saenz - Agudelo P., Delrieu - Trottin E., DiBattista J.D., et al. (2022). Monitoring vertebrate biodiversity of a protected coastal wetland using eDNA metabarcoding. *Environ. DNA* **4**:77–92. DOI:10.1002/edn3.200
- Sahour H., Kemink K.M. and O'Connell J. (2021). Integrating SAR and optical remote sensing for conservation-targeted wetlands mapping. *Remote Sens.* **14**:159. DOI:10.3390/rs14010159
- Gxokwe S., Dube T. and Mazvimavi D. (2022). Leveraging google earth engine platform to characterize and map small seasonal wetlands in the semi-arid environments of South Africa. *Sci. Total Environ.* **803**:150139. DOI:10.1016/j.scitotenv.2021.150139
- Jetz W., McGowan J., Rinnan D.S., et al. (2022). Include biodiversity representation indicators in area-based conservation targets. *Nat. Ecol. Evol.* **6**:123–126. DOI:10.

- 1038/s41559-021-01620-y
31. Howe R.W., Niemi G.J., Bracey A.M., et al. (2023). An index of biotic condition (IBC) using birds as indicators of coastal wetland quality in North America's Laurentian Great Lakes. *Ecol. Indic.* **156**:111174. DOI:10.1016/j.ecolind.2023.111174
 32. Blackwell M.S.A. and Pilgrim E.S. (2011). Ecosystem services delivered by small-scale wetlands. *Hydrol. Sci. J.* **56**:1467–1484. DOI:10.1080/02626667.2011.630317
 33. Stapanian M.A., Waite T.A., Krzys G., et al. (2004). Rapid assessment indicator of wetland integrity as an unintended predictor of avian diversity. *Hydrobiologia* **520**:119–126. DOI:10.1023/B:HYDR.0000027731.16535.53
 34. Walters D., Kotze D., Rebelo A., et al. (2021). Validation of a rapid wetland ecosystem services assessment technique using the Delphi method. *Ecol. Indic.* **125**:107511. DOI:10.1016/j.ecolind.2021.107511
 35. Cahyaningsih R., Brehm J.M. and Maxted N. (2021). Gap analysis of Indonesian priority medicinal plant species as part of their conservation planning. *Glob. Ecol. Conserv.* **26**:e01459. DOI:10.1016/j.gecco.2021.e01459
 36. De Alban J.D.T., Leong B.P.I., Venegas-Li R., et al. (2021). Conservation beyond the existing protected area network is required to improve species and habitat representation in a global biodiversity hotspot. *Biol. Conserv.* **257**:109105. DOI:10.1016/j.biocon.2021.109105
 37. Sullivan B.L., Wood C.L., Iliff M.J., et al. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biol. Conserv.* **142**:2282–2292. DOI:10.1016/j.biocon.2009.05.006
 38. Li P., Lou Y., Tang H., et al. (2022). Current status and protection and utilization countermeasures of plant resources in wetlands of China. *Wetl. Sci.* **20**:517–528. DOI:10.13248/j.cnki.wetlandsci.2022.04.008
 39. Zhang Y., Xu H., Chen H., et al. (2014). Diversity of wetland plants used traditionally in China: A literature review. *J. Ethnobiol. Ethnomed.* **10**:1–19. DOI:10.1186/1746-4269-10-72
 40. Xue Z.S., Zou Y.C., Zhang Z.S., et al. (2018). Reconstruction and future prediction of the distribution of wetlands in China. *Earths Future* **6**:1508–1517. DOI:10.1029/2017ef000807
 41. Thuiller W., Gueguen M., Renaud J., et al. (2019). Uncertainty in ensembles of global biodiversity scenarios. *Nat. Commun.* **10**:1446. DOI:10.1038/s41467-019-09519-w
 42. Titeux N., Maes D., Van Daele T., et al. (2017). The need for large-scale distribution data to estimate regional changes in species richness under future climate change. *Divers. Distrib.* **23**:1393–1407. DOI:10.1111/ddi.12634
 43. Ming J. and Kuiyi Z. (2023). Records of Mires in China (2nd Edition) (Science Press). https://www.hceis.com/home/book_view.aspx?id=6711
 44. Studds C.E., Kendall B.E., Murray N.J., et al. (2017). Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nat. Commun.* **8**:14895. DOI:10.1038/ncomms14895
 45. Allan J.R., Possingham H.P., Atkinson S.C., et al. (2022). The minimum land area requiring conservation attention to safeguard biodiversity. *Science* **376**:1094–1101. DOI:10.1126/science.abl9127
 46. Pimm S.L., Jenkins C.N. and Li B.V. (2018). How to protect half of Earth to ensure it protects sufficient biodiversity. *Sci. Adv.* **4**:eaat2616. DOI:10.1126/sciadv.aat2616
 47. Xia S.X., Yu X.B., Millington S., et al. (2017). Identifying priority sites and gaps for the conservation of migratory waterbirds in China's coastal wetlands. *Biol. Conserv.* **210**:72–82. DOI:10.1016/j.biocon.2016.07.025
 48. Durán A.P., Rauch J. and Gaston K.J. (2013). Global spatial coincidence between protected areas and metal mining activities. *Biol. Conserv.* **160**:272–278. DOI:10.1016/j.biocon.2013.02.003
 49. Watson J.E., Dudley N., Segon D.B., et al. (2014). The performance and potential of protected areas. *Nature* **515**:67–73. DOI:10.1038/nature13947
 50. Yi Q., Huixin G., Yaomin Z., et al. (2024). Global conservation priorities for wetlands and setting post-2025 targets. *Commun. Earth Environ.* **5**:4. DOI:10.1038/s43247-023-01195-5
 51. Qiu J., Zhang Y. and Ma J. (2024). Wetland habitats supporting waterbird diversity: Conservation perspective on biodiversity-ecosystem functioning relationship. *J. Environ. Manage.* **357**:120663. DOI:10.1016/j.jenvman.2024.120663
 52. Kasahara S., Morimoto G., Kitamura W., et al. (2020). Rice fields along the East Asian-Australasian flyway are important habitats for an inland wader's migration. *Sci. Rep.* **10**:41118. DOI:10.1038/s41598-020-60141-z
 53. Sripanomyom S., Round P.D., Savini T., et al. (2011). Traditional salt-pans hold major concentrations of overwintering shorebirds in Southeast Asia. *Biol. Conserv.* **144**:526–537. DOI:10.1016/j.biocon.2010.10.008
 54. Birch W.S., Drescher M., Pittman J., et al. (2022). Trends and predictors of wetland conversion in urbanizing environments. *J. Environ. Manage.* **310**:114723. DOI:10.1016/j.jenvman.2022.114723
 55. Zhang J., Ma K. and Fu B. (2010). Wetland loss under the impact of agricultural development in the Sanjiang Plain, NE China. *Environ. Monit. Assess.* **166**:139–148. DOI:10.1007/s10661-009-0990-x
 56. Hansen M.C., Potapov P.V., Moore R., et al. (2013). High-resolution global maps of 21st-century forest cover change. *Science* **342**:850–853. DOI:10.1126/science.1244693
 57. Merchant D., Lathrop R.G., Santos C.D., et al. (2023). Distribution modeling and gap analysis of shorebird conservation in northern Brazil. *Remote Sens.* **15**:452. DOI:10.3390/rs15020452
 58. Penjor U., Kaszta Z., Macdonald D.W., et al. (2021). Prioritizing areas for conservation outside the existing protected area network in Bhutan: The use of multi-species, multi-scale habitat suitability models. *Landsc. Ecol.* **36**:1281–1309. DOI:10.1007/s10980-021-01225-7
 59. Pocock M.J., Tweddle J.C., Savage J., et al. (2017). The diversity and evolution of ecological and environmental citizen science. *PLoS One* **12**:e0172579. DOI:10.1371/journal.pone.0172579
 60. Terer T., Muasya A.M., Dahdouh-Guebas F., et al. (2012). Integrating local ecological knowledge and management practices of an isolated semi-arid papyrus swamp (Loboi, Kenya) into a wider conservation framework. *J. Environ. Manage.* **93**:71–84. DOI:10.1016/j.jenvman.2011.08.005
 61. Rooney R.C., Royall O., Robinson D.T., et al. (2022). Evaluating the development and use of a rapid wetland assessment tool (ABWRET-A) in policy implementation in Alberta, Canada. *Environ. Sci. Policy* **136**:575–587. DOI:10.1016/j.envsci.2022.07.020
 62. Backhaus P.J., Wardrop D.H., McCarty G.W., et al. (2024). Developmental framework for a desktop hydrogeomorphic wetland functional assessment derived from field-based data. *Environ. Monit. Assess.* **196**:217. DOI:10.1007/s10661-024-12373-z
 63. Bland L.M., Keith D.D.A., Miller R.M., et al. (2017). Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria. *International Union for the Conservation of Nature (IUCN), Gland, Switzerland*. DOI:10.2305/IUCN.CH.2016.RLE.3.en
 64. IUCN (2024). Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria, Version 2.0. *IUCN Red List of Ecosystems Programme*. <https://portals.iucn.org/library/node/51533>

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AUTHOR CONTRIBUTIONS

H. W. and Z. X. conceived the study. Z. X., S. X. and H. W. developed the modeling framework and assessment method. Z. X. and S. D. performed modeling and analysis. Z. X. wrote the original draft, and H. W., M. J., X. L., X. Y., Y. W., L. L. and B. P. D. contributed to the text and provided comments. Z. X. and S. X. contributed to web-based questionnaire survey. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

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.

DATA AND CODE AVAILABILITY

The datasets used in this study are publicly available from the following sources: Wetland distribution: National Marsh Wetland Status Vector Dataset (<https://doi.org/10.12041/geodata.272068600499185.ver1.db>). Wetland zones: Records of Mires in China (Second Edition, Science Press, 2023). Protected areas: National Nature Reserve boundaries from the Resource and Environmental Science Data Center (<https://www.resdc.cn/data.aspx?DATAID=272>); additional information from the Ministry of Ecology and Environment of China (<https://www.mee.gov.cn>), the World Database on Protected Areas (<https://www.protectedplanet.net>), the National Geospatial Information Resource Catalog Service System (<https://www.webmap.cn>), and the China Nature Reserve Specimen Resource Sharing Platform (<http://www.papc.cn>). Waterfowl migration routes: WWF China (<https://wwf.panda.org/>). Wetland plant distribution records: National Earth System Science Data Center (<http://www.geodata.cn>). Waterbird occurrence data: eBird (<https://ebird.org>), BirdLife International, national and provincial bird surveys, and site-level monitoring reports from nature reserves (Table S3). Additional processed datasets and model outputs supporting the findings of this study are available from the corresponding author upon reasonable request.

SUPPLEMENTAL INFORMATION

It can be found online at <https://doi.org/10.59717/j.xinn-geo.2026.100179>

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