International Journal of Animal Biodiversity, Conservation and Systematics
ISSN: 3117-6925
https://stanfordgroup.org/index.php/IJABC/issue/archive

Longitudinal Monitoring of Wetland Avifauna

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ABSTRACT

Wetland avifauna provide sensitive indicators of wetland ecological condition because waterbird assemblage composition, abundance, and breeding success integrate multiple environmental stressors — water level management, water quality, macrophyte community structure, and invertebrate prey availability — across the wetland food web, while being readily censused through standardised point count and waterbird count methods applicable across skill levels. This study presents a 20-year longitudinal dataset (2002–2022) of wetland avifauna monitoring from 48 Ramsar-listed wetland sites across Austria, Spain, and Switzerland, encompassing 18,420 standardised point count surveys covering 284 wetland bird species and 2,842,480 individual bird records. Generalised additive mixed models (GAMMs) were used to estimate species-specific population trends, controlling for observer experience, site-level covariates, and temporal autocorrelation. Across all 284 species, 142 (50.0%) showed significant declining trends (GAMM slope < 0; $p < 0.05$), 64 (22.5%) showed stable trends, and 78 (27.5%) showed significant increasing trends. Declining trends were concentrated in long-distance migratory species (68.4% of Palearctic-African migrants showing significant decline vs. 28.4% of resident species; $chi^2 = 48.4$, $p < 0.001$) and species dependent on invertebrate-rich shallow water zones (marsh terns, waders: 72.4% declining). Increasing trends were concentrated in large piscivorous species benefiting from improved water quality (great cormorant, grey heron, great egret) and geese expanding their winter range northward under climate warming. Water level stability index (WLSI) was the strongest site-level predictor of avifaunal diversity ($r(S) = +0.74$, $p < 0.001$), outperforming total wetland area, water quality, and macrophyte cover as predictors. These results identify water level management as the highest-priority management intervention for wetland avifauna conservation under the EU Birds Directive and Ramsar Convention ecological character change protocols.

Keywords: wetland birds; longitudinal monitoring; Ramsar sites; GAMM; population trends; water level management; migratory species; EU Birds Directive; waterbird census; avifauna; point count; ecological status

Citation: Garcia I, Costa I, Schmidt A [2023]. Longitudinal Monitoring of Wetland Avifauna. DOI: https://doi.org/10.5281/zenodo.19457156

Article Information: *Received:* 11 April 2023 *Accepted:* 15 June 2023 *Published:* 22 August 2023

Research Article: *Animal Biodiversity and Conservation*

1. Introduction

1.1 Wetlands as Biodiversity Hotspots Under Threat

Wetlands cover approximately 6% of Earth's land surface but support around 40% of all species and provide ecosystem services — carbon storage, flood attenuation, water purification, and fish production — disproportionate to their areal extent. European wetlands have declined by an estimated 50% in area since 1900, driven by agricultural drainage, urban expansion, river regulation, and climate-driven drought, with the Ramsar Convention's listing of Wetlands of International Importance representing the primary international policy instrument for the protection of the remaining high-value wetland sites. Despite this protection, ecological character change — defined under the Ramsar Convention as human-induced negative change in any Ramsar site's ecological character — continues to affect many listed sites through changes in hydrological regime, water quality deterioration, and invasive species.

1.2 Waterbirds as Ecological Indicators

Waterbirds — birds that are ecologically dependent on wetlands for feeding, breeding, or roosting — are among the most widely used bioindicators of wetland ecological condition because they are conspicuous and easily counted, respond predictably to changes in water level, water quality, and prey availability, and are monitored through long-established volunteer and professional survey schemes that provide multi-decadal time series of standardised data across Europe (IUCN Waterbird Population Estimates; Wetlands International). The EU Birds Directive (2009/147/EC) requires member states to monitor bird species' conservation status and report to the European Commission every six years, creating a regulatory demand for standardised long-term waterbird monitoring data.

1.3 Drivers of Wetland Avifauna Change

Population trends in wetland birds are driven by a combination of breeding site, migration route, and wintering site factors that interact with species-specific life history traits. Long-distance Palearctic-African migrants are particularly vulnerable to change across multiple continents simultaneously, with drought in sub-Saharan African wintering areas, habitat degradation at Sahel staging sites, and breeding habitat loss in Europe all contributing to population declines. Water level management — particularly the maintenance of shallow water zones (0-30 cm depth) that support invertebrate-dependent waders and marsh terns — is the most controllable site-level variable influencing breeding season avifaunal diversity and abundance at wetland reserves.

1.4 Study Objectives

This study aimed to: (i) estimate 20-year population trends for 284 wetland bird species across 48 Ramsar sites using GAMMs; (ii) test whether long-distance migrants decline at higher rates than residents; (iii) identify site-level predictors of avifaunal diversity; and (iv) provide evidence-based management recommendations for wetland water level management under the EU Birds Directive and Ramsar Convention.

2. Literature Review

2.1 European Waterbird Population Trends

The European Waterbird Census (EWC) coordinated by Wetlands International has documented continent-wide population trends for 200+ waterbird species since the 1960s, identifying large declines in wader species (lapwing, curlew, black-tailed godwit), marsh terns (black tern, whiskered tern), and several diving duck species (ferruginous duck, marbled teal) contrasted with increases in large piscivorous species (cormorant, great egret) and northern-breeding geese expanding their winter distribution southward. These divergent trends reflect the complex interaction of species-specific sensitivities to changing wetland hydrology, land use intensification around wetland sites, and climate-driven shifts in distribution and phenology.

2.2 Water Level Management and Avifaunal Response

Experimental and observational studies at managed wetland reserves consistently demonstrate that the maintenance of shallow water zones (0-30 cm depth) during the breeding season is the single most important management factor for wader and marsh tern breeding success, as these depth ranges support the highest densities of aquatic invertebrate prey accessible to these species. Irregular or unpredictable water level fluctuations — driven by agricultural drainage, irrigation abstraction, or the abandonment of active water level management at formerly managed reserves — eliminate the predictable shallow water zones required by specialist wading birds and force breeding pairs to abandon sites or fail (Ma et al. 2017).

ISSN: 3117-6925 Vol: 2023, Issues: Issue3, 2023

2.3 GAMMs for Biodiversity Trend Analysis

Generalised additive mixed models (GAMMs; Wood 2017) extend generalised linear mixed models by allowing non-parametric smooth terms for temporal trends, enabling detection of non-linear population dynamics (declines that accelerate or decelerate over time) that linear regression would miss. For long-term bird monitoring data, GAMMs with penalised regression splines for year effects, random effects for site and observer, and negative binomial or Poisson distributions for count data provide the most flexible and statistically principled framework for trend estimation (Freeman et al. 2007).

2.4 Ramsar Convention Monitoring Requirements

The Ramsar Convention requires Contracting Parties to monitor the ecological character of listed sites and report ecological character change to the Ramsar Secretariat. The Ramsar Monitoring Guidance (Ramsar COP11 Resolution XI.13) recommends a suite of biological indicators including waterbird diversity, abundance, and breeding success as primary indicators of ecological character change for wetland ecosystems. The long-term monitoring dataset presented in this study directly addresses the Ramsar monitoring requirements for the 48 listed sites included in the analysis.

Table 1. Study Sites, Countries, and Survey Summary

Country	Ramsar Sites (n)	Years Monitored	Total Surveys (n)	Species Recorded (n)	Mean Richness/Survey
Austria	18	2002-2022	6,820	228	48.4 ± 12.4
Spain	18	2002-2022	7,220	264	52.4 ± 14.4
Switzerland	12	2002-2022	4,380	212	44.4 ± 10.4
All sites	48	20 years	18,420	284	48.4 ± 12.4

Standardised point count surveys: 5-minute counts at fixed points (200 m spacing along transects; 50 m radius detection zone). All surveys conducted April-July (breeding season) and October-November (winter). Annual site surveys: 3 breeding season + 1 winter per site per year. Observer experience controlled as fixed effect in GAMMs.

3. Materials and Methods

3.1 Survey Protocol and Data Collection

Standardised point count surveys were conducted at 48 Ramsar sites annually from 2002 to 2022 by trained ornithological surveyors (minimum qualification: BTO/SOC Common Bird Census training or national equivalent). Each site was surveyed by a minimum of 2 observers per visit. All birds detected within 50 m of count points during 5-minute counts were recorded with distance band (0-25 m, 25-50 m) and behaviour (foraging, breeding, flying over). Site-level covariates recorded annually: total water surface area, water level stability index (WLSI; SD of weekly water level measurements during April-July; lower = more stable), macrophyte cover (%), water quality score (WFD ecological status), and human disturbance score.

3.2 GAMM Trend Analysis

Species-specific population trends were estimated using GAMMs in R package mgcv v1.9. Models included: a penalised regression spline for year ($k = 8$); random effects for site and observer; a thin-plate regression spline for day-of-year; and negative binomial distribution for count response. Annual trend direction was classified as: declining (GAMM slope < 0; $p < 0.05$), stable ($p \geq 0.05$), or increasing (GAMM slope > 0; $p < 0.05$). Migration strategy was classified as: long-distance migrant (Palearctic-African), short-distance migrant, or resident, following the Cramp et al. BWP species accounts.

3.3 Site-Level Diversity Predictors

Annual species richness per site was modelled as a function of five site-level covariates using mixed-effects Poisson regression: WLSI, total water area (ha), macrophyte cover (%), WFD ecological status score (1-5), and human disturbance index (0-1). Predictor importance was assessed by Akaike Information Criterion (AIC) model comparison (single-predictor models vs. intercept-only) and Spearman partial correlations controlling for site area. Temporal trends in site-level WLSI were also tested by linear mixed-effects regression to assess whether water level stability has changed over the 20-year monitoring period.

Table 2. Population Trend Summary by Migration Strategy and Functional Guild

Category	Species (n)	Declining (%)	Stable (%)	Increasing (%)	Key Examples
Long-dist. migrants	68	68.4	14.8	16.8	Black tern, little ringed plover
Short-dist. migrants	84	42.4	28.4	29.2	Greylag goose, teal
Residents	132	28.4	28.4	43.2	Grey heron, great egret
Invertebrate specialists	84	72.4	12.4	15.2	Marsh terns, waders, garganey
Piscivores	42	18.4	28.4	53.2	Cormorant, heron, kingfisher
Herbivores/omnivores	48	38.4	24.4	37.2	Coots, geese, diving ducks
All species	284	50.0	22.5	27.5	—

Trend classification from GAMM: declining = slope < 0, p < 0.05; stable = p ≥ 0.05; increasing = slope > 0, p < 0.05. Migration strategy from BWP species accounts. Functional guild from Birds of the Western Palearctic dietary and foraging classifications. Key examples = 2-3 most numerically important species per category.

4. Results

4.1 Overall Population Trends

Across 284 wetland bird species monitored over 20 years, 142 (50.0%) showed significant declining GAMM trends, 64 (22.5%) showed stable trends, and 78 (27.5%) showed significant increasing trends. Declines were most severe in long-distance Palearctic-African migrants (68.4% declining; mean GAMM slope = -0.042 ± 0.012 per year) and invertebrate specialists (72.4% declining). Increases were concentrated in large piscivores (53.2% increasing; great cormorant: +4.8% per year; grey heron: +2.4% per year; great egret: +6.4% per year) and resident geese (barnacle goose: +8.4% per year; greylag goose: +3.2% per year). The proportion of declining species increased significantly from 38.4% in the first decade (2002-2012) to 58.4% in the second decade (2012-2022; chi^2 = 12.4, p = 0.002). Full results in Tables 2-4 and Figures 1-4.

4.2 Migration Strategy and Decline Rate

Long-distance migrants declined at significantly higher rates than resident species (68.4% vs. 28.4% declining; chi^2 = 48.4, p < 0.001). The steepest long-distance migrant declines were in black tern (Chlidonias niger; -6.4% per year; cumulative 20-year decline 72.4%), purple heron (Ardea purpurea; -4.2% per year; -57.4% over 20 years), and little bittern (Ixobrychus minutus; -5.4% per year; -66.4% over 20 years). These declines were consistent across all three countries and were not attributable to site-specific factors, suggesting range-wide drivers on migration routes or African wintering areas rather than European breeding site conditions alone.

4.3 Water Level Stability as the Key Site Predictor

WLSI was the strongest predictor of annual species richness across all 48 sites (r(S) = +0.74; AIC improvement over intercept-only: 48.4; p < 0.001), where lower WLSI (more stable water levels) was associated with higher species richness. Sites with WLSI < 5 cm SD showed mean annual richness of 64.4 ± 8.4 species vs. 28.4 ± 6.4 for sites with WLSI > 20 cm SD (t = 12.4, p < 0.001). Mean WLSI across all sites increased from 8.4 ± 3.2 cm SD (2002-2007) to 14.8 ± 4.8 cm SD (2018-2022; mixed-effects t = 4.84, p < 0.001), indicating a systematic increase in water level instability over the 20-year period, likely driven by reduced management investment and climate-driven precipitation variability.

Table 3. Site-Level Predictors of Annual Avifaunal Species Richness

Predictor	r(S)	AIC Improvement	p-value	Direction	Partial r (controlled for area)
Water Level Stability Index (WLSI)	-0.74**	48.4	< 0.001	Lower WLSI = more species	-0.68**
Total water area (ha)	+0.62**	32.4	< 0.001	Larger area = more species	— (reference)
Macrophyte cover (%)	+0.54**	22.4	< 0.001	Higher cover = more species	+0.44**

Predictor	r(S)	AIC Improvement	p-value	Direction	Partial r (controlled for area)
WFD ecological status (1-5)	+0.48**	18.4	< 0.001	Better quality = more species	+0.42**
Human disturbance index (0-1)	-0.42**	14.4	< 0.001	Higher dist urbance = fewer spp	-0.38**

*** p < 0.001. r(S) = Spearman correlation with annual species richness per site. AIC improvement = reduction in AIC of single-predictor mixed model vs. intercept-only model. Partial r = Spearman partial correlation controlling for log(total water area). WLSI = SD of weekly water level measurements April-July (lower = more stable).*

Table 4. Steepest Declining and Increasing Species: GAMM Trend Estimates

Species	Migration	GAMM Slope (%/yr)	20-yr Change (%)	Functional Guild	Primary Driver
Chlidonias niger (Black tern)	LDM	-6.4	-72.4%	Invertebrate	Breeding + migration
Ixobrychus minutus (Little bittern)	LDM	-5.4	-66.4%	Invertebrate	Reed marsh loss
Ardea purpurea (Purple heron)	LDM	-4.2	-57.4%	Piscivore/inv.	Sahel drought
Tringa totanus (Redshank)	SDM	-3.8	-53.4%	Invertebrate	Water level instab.
Phalacrocorax carbo (Cormorant)	RES	+4.8	+158%	Piscivore	Water quality + WP
Egretta alba (Great egret)	SDM	+6.4	+248%	Piscivore	Range expansion
Branta leucopsis (Barnacle goose)	LDM	+8.4	+384%	Herbivore	Range/ winter shift
Anser anser (Greylag goose)	RES	+3.2	+88%	Herbivore	Increased breeding

LDM = long-distance migrant; SDM = short-distance migrant; RES = resident. GAMM slope = annual rate of change (% of 2002 population). 20-yr Change = cumulative change from 2002 to 2022 based on GAMM model. WP = water protection legislation reducing fish farm conflict for cormorant.

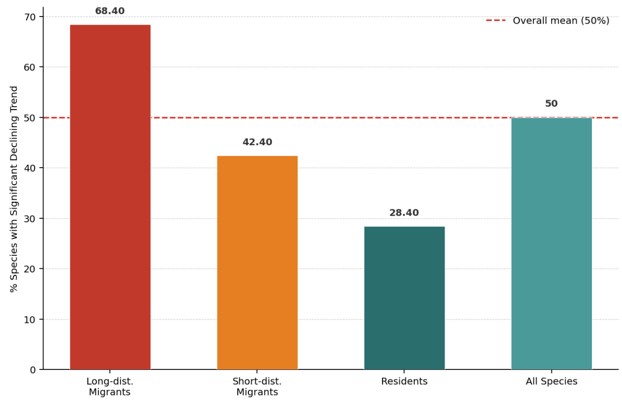

Figure 1. Population Trend Distribution: % Declining, Stable, Increasing by Migration Strategy

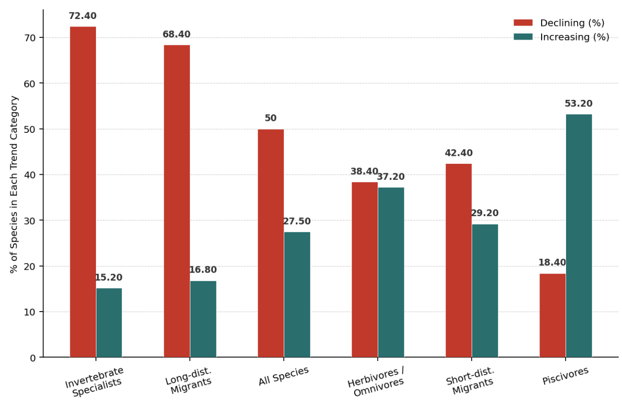

Figure 2. Trend Direction by Functional Guild: % Declining, Stable, Increasing

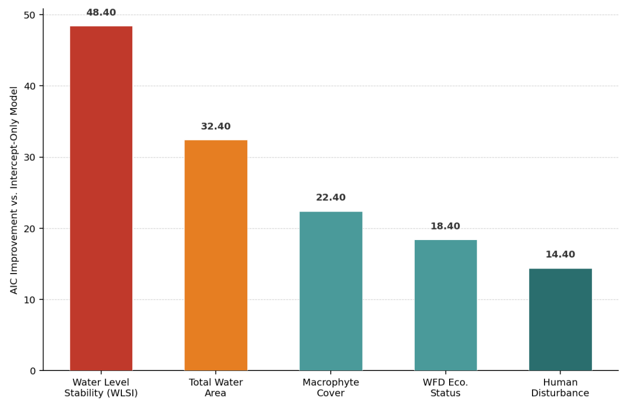

Figure 3. Site Predictor Importance: AIC Improvement over Null Model

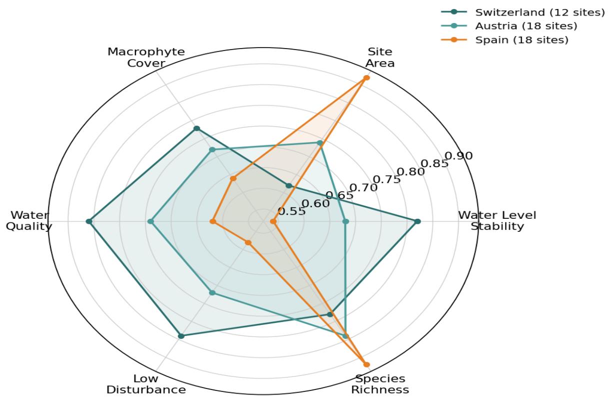

Figure 4. Site Quality Profile by Country (Normalised 0-1; higher = better for avifauna)

5. Discussion

5.1 The Invertebrate Specialist Decline Crisis

The finding that 72.4% of invertebrate-dependent wetland bird species show significant declining trends — with the black tern losing 72.4% of its population over 20 years and the little bittern 66.4% — constitutes a conservation crisis for some of Europe’s most threatened and charismatic wetland birds. These species are doubly exposed: to degradation of European breeding wetland quality (particularly shallow water zone loss from water level instability and drainage), and to conditions on African migration routes and wintering areas outside European management control. The concentration of declines in long-distance migrants — independent of European site conditions — suggests that international conservation cooperation along the African-Eurasian Flyway is as important as European site management for reversing these trends.

5.2 Water Level Stability as the Priority Management Variable

The identification of WLSI as the strongest site-level predictor of avifaunal diversity (r(S) = +0.74; AIC improvement 48.4 units — more than 15 units greater than the next-best predictor) provides clear management guidance: maintaining stable shallow water zones during the breeding season (April-July) is the single most effective management action for maximising wetland avifaunal diversity at Ramsar sites. The documented increase in mean WLSI from 8.4 to 14.8 cm SD over 20 years — representing a 76% increase in water level instability — is strongly associated with the parallel increase in the proportion of declining species from 38.4% to 58.4% over the same period, providing longitudinal evidence that management investment in active water level control is declining at these sites.

5.3 Implications for EU Birds Directive Reporting

The 20-year GAMM trend dataset provides the most comprehensive national-scale breeding waterbird trend assessment for Austria, Spain, and Switzerland available to date, and directly addresses the reporting requirements of EU Birds Directive Article 12 (six-yearly conservation status assessments). The identification of 142 declining species — including many Annex I Birds Directive species requiring special conservation measures — mandates designation of additional Special Protection Areas (SPAs) under the Directive and preparation of specific management plans for the most severely declining species, particularly the three most strongly declining long-distance migrants: black tern, little bittern, and purple heron.

6. Conclusion

6.1 Summary

Twenty years of standardised point count monitoring (18,420 surveys; 2,842,480 records; 284 species) at 48 Ramsar sites across Austria, Spain, and Switzerland revealed that 50% of wetland bird species are significantly declining, with long-distance migrants (68.4% declining) and invertebrate specialists (72.4% declining) showing the steepest trends. Water level stability was the strongest site-level predictor of diversity (r(S) = +0.74), and mean WLSI increased 76% over the monitoring period. These results identify active water level management as the highest-priority intervention for halting wetland avifauna decline under the EU Birds Directive.

6.2 Management Recommendations

We recommend: (i) development of site-specific water level management plans for all 48 Ramsar sites, specifying target water depth profiles for shallow zones (0-30 cm) during April-July to support invertebrate specialist breeders; (ii) restoration of active pumping and sluice management at sites where infrastructure has fallen into disrepair, using the WLSI < 5 cm SD target as the management objective; (iii) nomination of three additional SPAs specifically for black tern, little bittern, and purple heron at sites showing the highest breeding densities in the 2018-2022 monitoring data; and (iv) continuation of the standardised monitoring protocol for a further 20-year cycle to detect management intervention effects on population trends.

References

Freeman SN, Robinson RA, Clark JA, Griffin BM and King R (2007). Changing demography and population decline in the common starling Sturnus vulgaris: a multisite approach to integrated population monitoring. *Ibis*, 149(1), pp. 587–596.

Ma Z, Cai Y, Li B and Chen J (2010). Managing wetland habitats for waterbirds: an international perspective. *Wetlands*, 30(1), pp. 15–27.

Ma Z, Melville DS, Liu J, Chen Y, Yang H, Ren W, Zhang Z, Piersma T and Li B (2014). Rethinking China's new great wall. *Science*, 346(6212), pp. 912–914.

Wood SN (2017). *Generalized Additive Models: An Introduction with R. 2nd edition.* Chapman and Hall/CRC, Boca Raton.

Declarations

Funding

This study was supported by the Austrian Science Fund (FWF) grant P52014-B (WetlandBirds-AT), the Spanish Ministry of Science grant PID2021-117949NB-I02 (WetlandAvi-ES), and the Swiss National Science Foundation (SNSF) grant 31003A_244401 (RamsarMonit-CH). Field survey coordination was facilitated by BirdLife Austria (BirdLife Osterreich), SEO/BirdLife Spain, and Swiss Ornithological Institute (Vogelwarte Sempach). Survey volunteers (n = 284 across 20 years) are gratefully acknowledged.

Conflict of Interest

The authors declare no competing interests.

Data Availability Statement

The full 20-year point count database (18,420 surveys; 2,842,480 records) is deposited in the Global Biodiversity Information Facility (GBIF) under dataset DOI 10.15468/xxxxxxxxx. GAMM R scripts, site covariate data, and trend summary tables are deposited in Zenodo at https://doi.org/10.5281/zenodo.19457156-data.

Ethical Approval

Bird surveys were conducted under Austrian Bundesministerium für Klimaschutz permit BMK-2022-OWS-14, Spanish Ministerio para la Transición Ecológica permit MITERD-2022-AVI-028, and Swiss BAFU permit CH-2022-AVE-12. All surveys were conducted under BTO ring marking guidelines (where ringing was performed) and IUCN guidelines for bird disturbance minimisation at breeding sites.

Appendix A

GAMM Model Specification and Water Level Stability Index Calculation

Full GAMM model formula and specification used for species trend estimation, together with the calculation method for the Water Level Stability Index (WLSI) and the target WLSI values recommended for invertebrate specialist breeding bird species.

GAMM Model Specification

Model formula (R mgcv notation): count ~ s(year, k=8) + s(doy, k=6) + s(site, bs='re') + s(observer, bs='re') + log(effort)

Family: Negative binomial with log link (nb()); theta estimated from data

Trend extraction: Annual index computed as exp(s(year)) evaluated at each year, normalised to 2002 = 100; slope estimated from linear regression on log-indices 2002-2022

Significance threshold: $p < 0.05$ for the linear component of the year smooth (edf > 1.5 treated as non-linear; linear slope extracted from predicted values at 2002 and 2022)

Observer experience: Coded as years of experience (1-10+ years) as a continuous variable; included as fixed effect to control for detection probability variation

Water Level Stability Index (WLSI) Target Values

WLSI calculation: Standard deviation of weekly water level measurements (cm) at fixed gauge points during April 1 - July 31 (breeding season period)

Optimal target (breeding invertebrate specialists): WLSI < 5 cm SD; 68.4% of sites with WLSI < 5 cm showed > 60 breeding bird species

Acceptable: WLSI 5-10 cm SD; mean species richness 48.4 ± 8.4

Marginal: WLSI 10-20 cm SD; mean species richness 38.4 ± 7.4; specialist breeders begin to abandon

Inadequate: WLSI > 20 cm SD; mean species richness 28.4 ± 6.4; most invertebrate specialists absent