

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- ☐ ☒ The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement
- ☐ ☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
- ☐ ☒ The statistical test(s) used AND whether they are one- or two-sided
Only common tests should be described solely by name; describe more complex techniques in the Methods section.
- ☐ ☒ A description of all covariates tested
- ☐ ☒ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
- ☐ ☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
- ☐ ☒ For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
Give P values as exact values whenever suitable.
- ☒ ☐ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
- ☐ ☒ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
- ☐ ☒ Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection	All data used in this study were collected from freely-available open-source databases. A full list of data sources, including citations and active links, is provided in the section of Data availability and Supplementary Table 2.
Data analysis	All analyses were performed via R (v 4.1.2). The code used in the present study is available online. https://github.com/bobilong/birdsAIV/tree/master/WAE_bird

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

All raw datasets are available online, including the GBIF database of biodiversity occurrence data (<https://www.gbif.org/>), the BirdLife range maps (<https://datazone.birdlife.org/species/requestdis>), Wallace's realms (<https://macroecology.ku.dk/resources/wallace>), positive presence of AIV cases dataset (<https://empres-i.apps.fao.org/>), water proportion dataset (<https://land.copernicus.eu/en>), national gross domestic product and national human population datasets (<https://>

www.natureearthdata.com/), human density and poultry density datasets (<https://data.apps.fao.org/catalog/iso/15f8c56c-5499-45d5-bd89-59ef6c026704>), monthly gross primary productivity dataset (<https://doi.pangaea.de/10.1594/PANGAEA.879560>), net primary productivity (<https://modis.gsfc.nasa.gov/data/dataproduct/mod17.php>), normalized difference vegetation index (<https://modis.gsfc.nasa.gov/data/dataproduct/mod13.php>), the normalized difference water index (<https://modis.gsfc.nasa.gov/data/dataproduct/mod09.php>), leaf area index (<https://www.ncei.noaa.gov/products/climate-data-records>), the nighttime light density (<https://earthobservations.org/index.php>) and road density (<https://data.apps.fao.org/catalog/dataset/global-roads-inventory-project-grip-dataset>). The processed Waterbird Activity Entropy (WAE) layers and the minimum dataset required to interpret and verify the findings of this study have been deposited in Figshare at https://figshare.com/articles/dataset/_b_Enhancing_Global_Avian_Influenza_Exposure_Risk_Assessment_with_Waterbird_Activity_Entropy_b_/28504868. Source data for all main figures and supplementary tables are provided as a Source Data file with this paper.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender	Our study is not relevant with human characteristics such as sex and gender.
Reporting on race, ethnicity, or other socially relevant groupings	Our study is not relevant race, ethnicity, or other socially relevant groupings.
Population characteristics	Our study is not relevant with population characteristics.
Recruitment	We do not have human participants in this work.
Ethics oversight	Our study is not relevant with this issue

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Under the 'One Health' framework, and incorporating collaboration across different disciplines, we proposed a indicator waterbird activity entropy (WAE) to evaluate the richness, duration, and evenness of the dominant AIV natural host species. By integrating WAE with domestic animal and human densities, we infer contact possibility and estimate AIV exposure risk at cross-interfaces (i.e., among waterbirds, domestic animals, and humans). This approach successfully simulated monthly distribution data for 779 waterbird species, with the model demonstrating high accuracy for 9036 monthly distributions.
Research sample	We focused on waterbird species associated with wetlands and aquatic/marine habitats, as they are key carriers of diverse AIVs linked to spillover events in domestic animals and humans. Occurrence records for these species were obtained from the Global Biodiversity Information Facility (GBIF).
Sampling strategy	We aimed to include as many waterbird species as possible to ensure a robust and representative dataset.
Data collection	All data used in this study were collected from freely-available open-source databases, such as the GBIF and the WorldClim V2.1. A full list of data sources, including citations and links, is provided in the section of Data availability and Supplementary Table 2.
Timing and spatial scale	The study drew on global waterbird occurrence records from 1860–2022, covering 1,177 species in 15 orders to characterize present patterns. Ecological niche models and Waterbird Activity Entropy (WAE) were computed at a uniform global resolution of 0.5°×0.5° (≈55 km at the equator). All environmental and anthropogenic variables (climate variables, poultry density, and human population density) were standardized to this resolution to ensure consistent identification of global avian influenza exposure hotspots.
Data exclusions	We applied pre-established exclusion criteria to refine the dataset. First, to reduce the potential error in the exact location of a geographical point, we filtered out records with observation distances greater than 50 km (approximately 0.5° resolution) via the "coordinateUncertaintyInMeters" field. Second, considering the classification errors, taxonomic rearrangements and vagrant records, we excluded records that fell outside the established species distribution baselines. Third, in the analysis, we included only species with more than 9 unique records in each month to ensure sufficient data for monthly model construction. Ultimately, we retained 791 waterbird species for subsequent species distribution modeling and successfully simulated 779 of them.
Reproducibility	No experiments were conducted; however, the monthly species distribution models (SDMs) are reproducible using the provided code.
Randomization	This is not relevant as we aimed to include all available waterbird species.
Blinding	This is not relevant, as no experimental procedures were involved.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks

Not applicable for this study.

Novel plant genotypes

Not applicable for this study.

Authentication

Not applicable for this study.